4th International Workshop on Microwave Research and Applications

BOOK OF ABSTRACTS

June 28th – July 3rd, 2026
Coma-ruga, Tarragona (Spain)

4^{th} International Workshop on Microwave Research and Applications

June 28^{th} – July 3^{rd}, 2026
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Hotel Estival Maramar

<u>Organizing Committee</u>
Javier Tejada
Eugene Chudnovsky
Jose Maria Lopez Villegas
Joan Manel Hernàndez
Jaume Calvo de la Rosa

COMA-RUGA 2026

INTERNATIONAL WORKSHOP ON MICROWAVE RESEARCH AND APPLICATIONS

June 28 – July 3, 2026 | Hotel Estival Maramar, Coma-ruga, Tarragona (Spain)

TIME	Sunday June 28th	Monday June 29th	Tuesday June 30th	Wednesday July 1st	Thursday July 2nd	Friday July 3rd
09:30 – 10:10		**José María de Teresa** *Applications of Focused Electron and Ion Beams for Nanofabrication*	**Eugene Chudnovsky** *Macroscopic Quantum Tunneling in Magnets and Superconductors (The Legacy of Tony Leggett)*	**Ping Sheng** *Using Electrical Dipole Resonance to Generate Broad-Band Microwave Absorption*	**David Citrin** *Terahertz Imaging of Art and Archaeology*	**Enrique del Barco** *Adiabatic Spintronics with Topological Magnetic Insulators*
10:10 – 10:40		**Xavier Obradors** *Forty years of HTS: the long and winding road to high current conductors*	**Gloria Platero** *Quantum information transfer through atomic arrays*	**Pablo Cerrato Serrano** *Enhanced Magnon Damping via Acoustic Fabry-PÃ©rot Resonances in YIG/GGG Bilayers*	**Hiro Nakamura** *THz photostriction in van der Waals multilayers*	**Chao Chen Ye** *Double quantum spin Hall phase in bilayer $ZrTe_5$*
10:40 – 11:00		COFFEE BREAK	COFFEE BREAK	COFFEE BREAK	COFFEE BREAK	COFFEE BREAK
11:00 – 11:30		**Quim Badosa Felip** *Surface Acoustic Waves assisted manipulation of spin and orbital currents in ferromagnetic/light-metal bilayers*	**Nicolas Zapata** *Quantum Information Processing with Superconducting Microwave Electronics*	**POSTER SESSION** (Extended coffee break)	**Salvador Barraza Lopez** *Tunable terahertz opto-mechanics of MoS_2 bilayers with homogeneous in-plane strain*	**Irfan Siddiqi** *Simulating New Phases of Quantum Matter with Superconducting Qudits*
11:30 – 12:00		**Oleksandr Malyuskin** *Subwavelength Microwave and MM-Wave Resonators as a Platform for Next-Generation Multifunctional Sensors*	**Eran Ginossar** *Symmetry-protected states of interacting qubits in superconducting quantum circuits*	**Iran Bahena** *An Equivalent Circuit Approach for Characterizing Magnetodielectric Composites with Microwave Resonant Sensors*	**Viktor Rindert** *High Frequency Magnetic Resonance using Terahertz Generalized Spectroscopic Ellipsometry*	**Anna Castellví i Picanyol** *Non-Resonant Magnetoacoustic Waves Imaged by Stroboscopic MOKE*
12:00 – 12:30		**Kai-Da Xu** *A Waveguide Bandpass Filter Using Periodic Cylindrical Cavities and Double Ridges in D-Band*	**Darío González** *Towards single spin magnetic spectroscopy with superconducting quantum circuits*	**Jaume Calvo de la Rosa** *Investigating novel heterogeneous bilayer structures for broadband radar absorption*	**Yan Sun** *Temperature-Dependent Terahertz Electrodynamics and Coupled Excitonic-Lattice Modes in Ta_2NiSe_5*	**Pol Forn-Díaz** *Tony Leggett's influence on superconducting qubits: Coherent Quantum Dynamics and Macroscopic Realism*
12:30 – 16:00		LUNCH	LUNCH	LUNCH	LUNCH	CLOSING REMARKS
16:00 – 16:40		**Fernando Sols** *Remembering Tony Leggett*	**Alberto Amo** *Lattice quantum electrodynamics with molecular emitters in microcavities*	**Dmitry Garanin** *Skyrmion Cyclotron Resonance in Ferrimagnets*	**Vincent Harris** *Impedance-Engineered Magnetodielectrics: A New Paradigm in RF Materials Impedance Matching to Free Space*	
16:40 – 17:10		**Joan Manel Hernàndez** *Macroscopic Quantum Phenomena in Magnetism: Experimental Developments Inspired by Leggett and Chudnovsky*	**Álvaro Gómez León** *Topological properties of discrete step quantum walks*	**Fernando Luis** *Circuit quantum electrodynamics near spin clock transitions*	**Marc Vazquez-Aige** *Free-space EM characterization measurements with temperature control and machine learning implementation*	
17:10 – 17:30		COFFEE BREAK	COFFEE BREAK	COFFEE BREAK	**Pilar Marin** *Wireless Multi-Parametric Sensing of Hydrogel Scaffolds via Giant Magnetoimpedance in Amorphous Magnetic Microwires*	
17:30 – 18:00		**Milena Grifoni** *Spin-boson models under strong ac-driving*	**Alexandre Buzdin** *Circularly Polarized Terahertz Radiation as a Mechanism for the Control and Manipulation of Quantum States in Superconducting Ring*	**David Citrin** *Terahertz Nondestructive Evaluation of Advanced Microelectronics Packaging*	COFFEE BREAK	
18:00 – 18:30		**Stefano Bosco** *Quantum computing with magnetic systems*	**Fernando Sols** *Hawking time crystals*	**Dario Arena** *Spin Dynamics in Ferrimagnetic Insulators Across Time & Length Scales*		
18:30 – 19:00		**Kirill Fedorov** *Sharing secrets in superconducting quantum networks* *18:30 – 19:10				
	19:30 **Welcome Party** **at Hotel Estival Maramar**			**20:30** **Conference Dinner** **at Cara el Mar restaurant**		

COMA-RUGA 2026

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MONDAY, JUNE 29th

09:30 – 10:10	**José María de Teresa** *Applications of Focused Electron and Ion Beams for Nanofabrication*
10:10 – 10:40	**Xavier Obradors** *Forty years of HTS: the long and winding road to high current conductors*
10:40 – 11:00	COFFEE BREAK
11:00 – 11:30	**Quim Badosa Felip** *Surface Acoustic Waves assisted manipulation of spin and orbital currents in ferromagnetic/light-metal bilayers*
11:30 – 12:00	**Oleksandr Malyuskin** *Subwavelength Microwave and MM-Wave Resonators as a Platform for Next-Generation Multifunctional Sensors*
12:00 – 12:30	**Kai-Da Xu** *A Waveguide Bandpass Filter Using Periodic Cylindrical Cavities and Double Ridges in D-Band*
12:30 – 16:00	LUNCH
16:00 – 16:40	**Fernando Sols** *Remembering Tony Leggett*
16:40 – 17:10	**Joan Manel Hernàndez** *Macroscopic Quantum Phenomena in Magnetism: Experimental Developments Inspired by Leggett and Chudnovsky*
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09:30 – 10:10	**Eugene Chudnovsky** *Macroscopic Quantum Tunneling in Magnets and Superconductors (The Legacy of Tony Leggett)*
10:10 – 10:40	**Gloria Platero** *Quantum information transfer through atomic arrays*
10:40 – 11:00	COFFEE BREAK
11:00 – 11:30	**Nicolas Zapata** *Quantum Information Processing with Superconducting Microwave Electronics*
11:30 – 12:00	**Eran Ginossar** *Symmetry-protected states of interacting qubits in superconducting quantum circuits*
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WEDNESDAY, JULY 1st

09:30 – 10:10	**Ping Sheng** *Using Electrical Dipole Resonance to Generate Broad-Band Microwave Absorption*
10:10 – 10:40	**Pablo Cerrato Serrano** *Enhanced Magnon Damping via Acoustic Fabry-Parot Resonances in YIG/GGG Bilayers*
10:40 – 11:00	COFFEE BREAK
11:00 – 11:30	**POSTER SESSION** **(extended coffee break)**
11:30 – 12:00	**Iran Bahena** *An Equivalent Circuit Approach for Characterizing Magnetodielectric Composites with Microwave Resonant Sensors*
12:00 – 12:30	**Jaume Calvo de la Rosa** *Investigating novel heterogeneous bilayer structures for broadband radar absorption*
12:30 – 16:00	LUNCH
16:00 – 16:40	**Dmitry Garanin** *Skyrmion Cyclotron Resonance in Ferrimagnets*
16:40 – 17:10	**Fernando Luis** *Circuit quantum electrodynamics near spin clock transitions*
17:10 – 17:30	COFFEE BREAK
17:30 – 18:00	**David Citrin** *Terahertz Nondestructive Evaluation of Advanced Microelectronics Packaging*
18:00 – 18:30	**Dario Arena** *Spin Dynamics in Ferrimagnetic Insulators Across Time & Length Scales*

20:30
CONFERENCE DINNER
at Cara el Mar restaurant

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THURSDAY, JULY 2nd

09:30 – 10:10	**David Citrin** *Terahertz Imaging of Art and Archaeology*
10:10 – 10:40	**Hiro Nakamura** *THz photostriction in van der Waals multilayers*
10:40 – 11:00	COFFEE BREAK
11:00 – 11:30	**Salvador Barraza Lopez** *Tunable terahertz opto-mechanics of MoS_2 bilayers with homogeneous in-plane strain*
11:30 – 12:00	**Viktor Rindert** *High Frequency Magnetic Resonance using Terahertz Generalized Spectroscopic Ellipsometry*
12:00 – 12:30	**Yan Sun** *Temperature-Dependent Terahertz Electrodynamics and Coupled Excitonic-Lattice Modes in Ta_2NiSe_5*
12:30 – 16:00	LUNCH
16:00 – 16:40	**Vincent Harris** *Impedance-Engineered Magnetodielectrics: A New Paradigm in RF Materials Impedance Matching to Free Space*
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FRIDAY, JULY 3rd

09:30 – 10:10	**Enrique del Barco** *Adiabatic Spintronics with Topological Magnetic Insulators*
10:10 – 10:40	**Chao Chen Ye** *Double quantum spin Hall phase in bilayer $ZrTe_5$*
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12:00 – 12:30	**Pol Forn-Díaz** *Tony Leggett's influence on superconducting qubits: Coherent Quantum Dynamics and Macroscopic Realism*
12:30 – 12:45	CLOSING REMRKS

Applications of Focused Electron and Ion Beams for nanofabrication

José María De Teresa,[a] Soraya Sangiao,[a,b] Lucía Herrer,[a]

[a]*Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza, Zaragoza (Spain)*
[b]*Laboratorio de Microscopías Avanzadas (LMA), Universidad de Zaragoza, Zaragoza (Spain)*

In this contribution, I will describe recent results obtained by the Nanomidas group at INMA in the topic of nanofabrication using focused electron and ion beams. Focused electron beams are produced in a Scanning Electron Microscope and are mainly used for imaging or for electron beam lithography, whereas the Focused Ion beam (FIB) is mostly popular for nanopatterning via the local removal of material [1, 2]. Interestingly, if one combines focused electron or ion beams with a precursor material, a local deposit can be grown, and the techniques are respectively named Focused Electron Beam Induced Deposition (FEBID) and Focused Ion Beam Induced Deposition (FIBID). The talk will describe the fundamentals of these techniques and a few examples of application across several fields. One of such examples is the growth of ultra-sharp tips on cantilevers by FEBID, with applications in Atomic Force Microscopy (AFM) and Magnetic Force Microscopy (MFM). In AFM, these FEBID nanotips are used to image biomolecules in liquid environment with a very high spatial resolution [3], whereas in MFM, the FEBID nanotips are utilized not only for their very high spatial resolution, but also for their great performance to image the magnetic textures of soft magnetic materials [4]. Another example of nanofabrication is the extraction of micro-crystals by means of FIB and their electrical contacting by means of FIBID, which has been used for a magnetotransport study of bismuth micro-crystals [5]. By means of FIBID, it is possible to grow 3D superconducting nanostructures such as the W-C nanohelix shown in Figure 1, with anomalous magnetotransport properties [6]. In a final example, FIB irradiation of palladium acetate spin-coated films gives rise to conductive Pd-enriched structures that can be used for electrical contacts [7], whereas the FIB irradiation of silver butyrate spin-coated films gives rise to a Ag-enriched patterned structure for application as a SERS (Surface Enhanced Raman Spectroscopy) substrate [8].

[1] Nanofabrication, book edited by J. M. De Teresa, IOP (2020), https://iopscience.iop.org/book/edit/978-0-7503-2608-7
[2] K. Höflich et al., Appl. Phys. Rev. 10, 041311 (2023)
[3] F. Allen, J. M. De Teresa, B. Onoa, ACS Appl. Mater. & Inter. 16, 4439 (2024)
[4] A. T. Escalante-Quiceno et al., Low Temp. Phys. 50, 825 (2024)
[5] A. Sáenz-Hernández et al., Advanced Functional Materials 36, e17475 (2026)
[6] R. Córdoba et al., Nano Letters. 19, 8597 (2019)
[7] A. Salvador-Porroche et al, ACS Appl. Mater. & Inter. 14, 28211 (2022)
[8] J. Ocaña-Parral et al., submitted to Small Methods (2026)

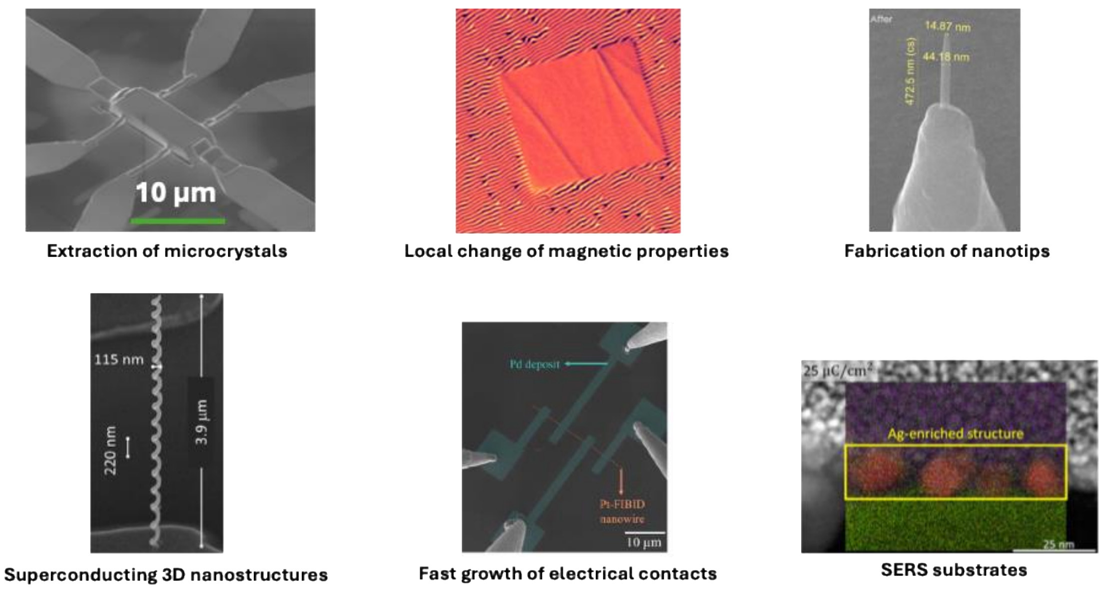

Figure 1. Some examples of nanofabrication carried out at the Nanomidas Group

Forty years of HTS: the long and winding road to high current conductors

X. Obradors [a] , T. Puig [a], J. Gutiérrez [a]

[a] *Institut de Ciència de Materials de Barcelona, ICMAB-CSIC*
Campus de la UAB, 08193 Bellaterra, Catalonia, Spain

In 1986 Johannes Georg Bednorz and Karl Alexander Müller opened a new era in the field of superconductivity with the discovery of superconductivity in a copper oxide material that had already been previously identified, with the composition $La_{1-x}Ba_xCuO_4$. A few months later, Paul Chu et al. crossed the psychological and practical threshold of the liquid nitrogen temperature in terms of the superconducting transition temperature in $REBa_2Cu_3O_7$ (RE = rare earth or Y, REBCO), thereby initiating the era of High-Temperature Superconductivity (HTS). The discovery of the cuprates was rapidly recognized with the Nobel Prize in Physics and generated an immense wave of challenges in physics, chemistry, materials science, and materials engineering.

After 40 years of intensive research into the many unresolved aspects of these materials, it is timely to review in which areas they have opened entirely new paths in science and technology, and which fundamental questions still remain unanswered.

In this presentation, we will summarize some of these issues, focusing on the extremely challenging objective of using cuprates as high-current conductors. The first developments were associated with clarifying the complex crystal chemistry of these materials, as well as the discovery of a significant number of new superconducting families, driven by the goal of understanding the physical origin of HTS.

We will first show that a major challenge from a materials science perspective arises from the extremely short coherence length of these superconductors, which causes grain boundaries in polycrystalline materials to behave as weak links. As a consequence, it became essential to develop previously non-existent methodologies to fabricate uniaxially or biaxially textured materials over long lengths. A second major challenge in cuprates is their strong anisotropy. This led to the emergence of a new area of physics—vortex matter—to address the highly complex behavior of vortices in HTS.

A first major breakthrough in the development of high-current cuprate conductors came with the discovery of coated conductors based on REBCO [1], i.e., the cuprate system with one of the lowest intrinsic anisotropies [2]. After more than 20 years of intensive research and development, these materials can be regarded as kilometer-long single crystals grown on metallic substrates, representing perhaps the most extended manifestation of quantum behavior in any material system [1,3]. A second major advance in HTS conductors was the development of nanotechnological approaches to fabricate nanocomposite REBCO coated conductors, in which vortex pinning became an efficient strategy to reduce vortex creep at high magnetic fields and elevated temperatures [4-6].

In this presentation, we will summarize the most promising approaches to expand the use of coated conductors through high-throughput growth techniques and through the maximization of their superconducting performance. In particular, we will show how epitaxial growth can be achieved at extremely high growth rates (>1000 nm/s) using the novel non-equilibrium methodology known as Transient Liquid-Assisted Growth (TLAG) [6–10], whose mechanisms can be elucidated through advanced in situ characterization using synchrotron radiation. It is also worth noting that precise knowledge of the electronic phase diagram of HTS materials enables the optimization of vortex pinning in these systems [10,11].

The current commercial availability of these materials, with annual production reaching thousands of kilometers, has finally opened the door to a wide range of large-scale superconducting applications (medicine, energy, transport, high energy physics), which will be summarized in this presentation [12].

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[2] J. Figueras et al, Nature Physics 2, 402 (2006)
[3] J. Gutiérrez et al, Nature Materials 6, 367 (2007)
[4] A. Llordés et al, Nature Materials 1, 329 (2012)
[5] X. Obrados et al. Supercond. Sci. Technol. 37, 053001 (2024)
[6] L. Soler et al, Nature Communications 11, 344 (2020)
[7] S. Rasi et al, Advance Science, 9, 2203834 (2022)
[8] L. Saltarelli et al., Advanced Materials (2026), doi/10.1002/adma.202510660
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[11] A. Stangl et al., Scientific Reports 11, 8176 (2021)
[12] L. García-Tabarés et al., Il Nuovo Cimento 48, 435 (2025)

Surface Acoustic Waves assisted manipulation of spin and orbital currents in ferromagnetic/light-metal bilayers

Quim Badosa[1,2] , Marc Rovirola[1,2], Julia Òdena[1,2] , Anna Castellví-Picanyol[1,2] , Joan Manel Hernández[1,2] , Blai Casals[2,3] , Saul Vélez[4,5] , Ferran Macià[1,2]

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[2]Institute of Nanoscience and Nanotechnology (IN2UB), University of Barcelona, 08028 Barcelona, Spain
[3]Dept. of Applied Physics, University of Barcelona, 08028 Barcelona, Spain
[4]IFIMAC and Departamento de Física de la Materia Condensada, Universidad Autónoma de Madrid, 28049 Madrid, Spain
[5]Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, 28049 Madrid, Spain

Spin and Orbital angular momentum are promising information carriers in solids; however, their efficient and controllable generation remains an active area of research. In this work we will review our recent experiments demonstrating the phonon-induced generation of spin and orbital currents in ferromagnet/non-magnet heterostructures driven by surface acoustic waves (SAWs).
Two main mechanisms can drive spin and orbital currents in our system (Fig. 1a). First, in the ferromagnetic layer, SAWs can drive magnetization precession through magnetoelastic coupling, which can pump spin and orbital currents into the non-magnetic layer. This acoustic pumped (AP) current can then be converted into a charge current via Inverse Spin Hall Effect (ISHE) or Inverse Spin Orbit Effect (IOHE).
Second, in the non-magnetic layer, the elliptical lattice motion from the SAWs can couple to the orbital degree of freedom of electrons through the acoustic orbital Hall effect (AOHE), generating an oscillating orbital current. When an adjacent ferromagnetic material interacts with the current, it generates a rectified dc orbital current that can be converted into charge current via the IOHE.
Here, we explore different pumping mechanisms in FM/NM bilayers driven by acoustically excited magnetization waves. Our hybrid devices consist of a piezoelectric substrate patterned with two facing interdigital transducers (IDTs) to generate and probe SAW transmission. FM/NM bilayers are deposited in various geometries along the acoustic path between the IDTs (Fig. 1b), enabling the detection of both transverse and longitudinal voltages under SAW excitation. We compare light-metal caps with different orbital-to-charge conversion efficiencies—strong (Cr, Ti) and weak (Al)—and ferromagnets with contrasting emission behaviours: Ni, which can efficiently generate orbital currents, and Co, which does not. We observe large signals in Ni/Cr and Ni/Ti bilayers, whereas Ni/Al exhibits an almost vanishing response. In contrast, Co-based bilayers show negligible voltages, consistent with their weak coupling to orbital angular momentum.

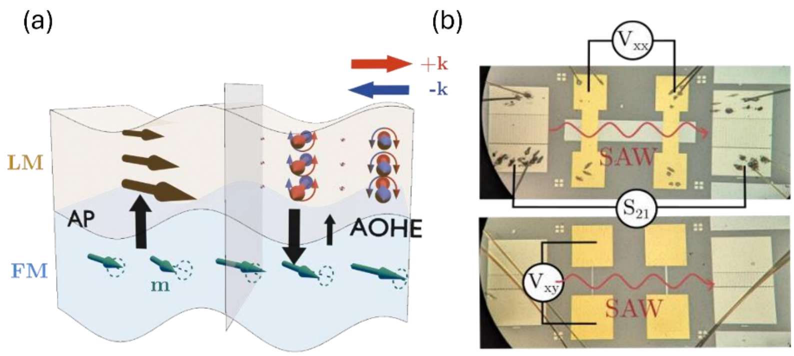

Fig1. (a) Schematics of AP (left side) and AOHE (right side). (b)Experimental set up for longitudinal (Vxx) and transversal (Vxy) voltage

[1] B. Casals et al., Phys. Rev. Lett. 124, 137202, (2020)
[2] M. Rovirola et al., Phys. Rev. Research 6, 023285 (2024).
[3] Marc Rovirola, et al., arXiv: 2512.08385

Subwavelength Microwave and MM-Wave Resonators as a Platform for Next-Generation Multifunctional Sensors

Oleksandr Malyuskin,[a] Christopher Larmour,[a]

[a] *Centre for Wireless Innovation, Queen's University Belfast, UK*

Subwavelength microwave and mm-wave resonators offer unique opportunities for new sensing modalities across a wide range of applications, including mechanical impact and vibration sensing, robotic sensing, and environmental sensing. A number of sensor concepts based on resonant microwave technology have been proposed for nondestructive testing and evaluation [1], [2], water and soil quality and contamination detection [3], and industrial embedded sensors for the aircraft, automotive, and green energy sectors [4], [5].

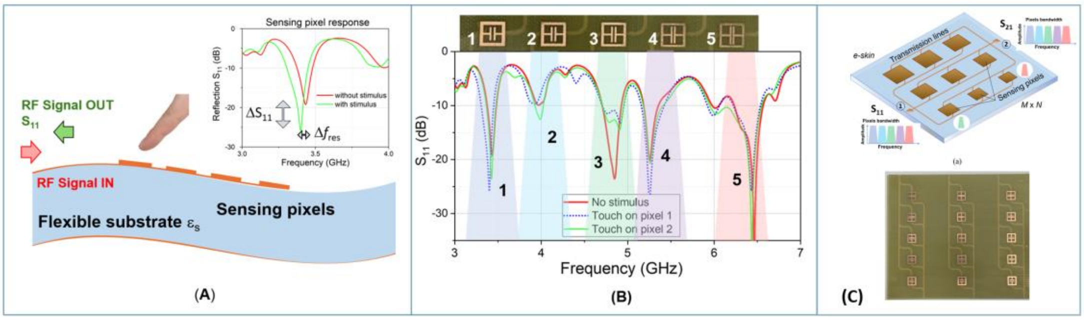

Fig.1. (A) The concept and operating principle of the flexible e-skin (B), experimental demonstrator of the e-skin response to human touch (C), experimental e-skin patch demonstrating simultaneous access to multiple sensing pixels using a single-line interface.

This presentation will discuss the theoretical fundamentals of near-field resonance interaction between an electromagnetic sensor and a dielectric or conductive medium or object, and elaborate on accurate analytical or semi-analytical models for interpreting sensed data using measurable resonance frequency shifts and the magnitudes of S_{11} and S_{21} responses. Next, we discuss how to improve the sensor's dynamic range and sensitivity by leveraging electromagnetic resonance-induced near-field enhancement and engineering the resonator's frequency response. Finally, several novel applications, including robotic e-skins (Fig.1), environmental sensing (Fig. 2) and merging microwave resonator technology with functionalized nanomaterials (particularly, functionalized carbon nanotubes) and quantum nanomaterials to develop new macroscopic sensors utilising micro and nanoscopic effects, will be discussed in detail.

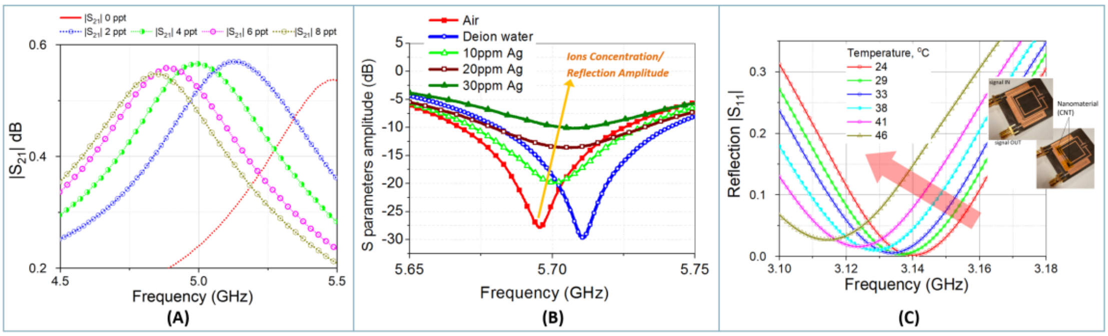

Fig.2. Experimental environmental sensing prototypes. (A) Water-in-oil detection sensor data, (B) heavy metal ion detection in water, (C) microwave resonator sensor with functionalized nanomaterials for temperature sensing.

[1] O. Malyuskin, V. Fusco, High-Resolution Microwave Near-Field Surface Imaging Using Resonance Probes, IEEE Transactions on Instrumentation and Measurement, 65 (1), 189–200 (2016).
[2] K. Samolej et al., Radio-frequency sensor for non-destructive evaluation of composite materials, Scientific Reports, 15, 31825 (2025).
[3] O. Malyuskin, Microplastic Detection in Soil and Water Using Resonance Microwave Spectroscopy: A Feasibility Study, IEEE Sensors Journal, 20 (24),14817-14826 (2020).
[4] M. S. ur Rahman et al., A review on microwave non-destructive testing (NDT) of composites, Engineering Science and Technology, 58, 101848 (2024).
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A Waveguide Bandpass Filter Using Periodic Cylindrical Cavities and Double Ridges in *D*-Band

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The upcoming 6G wireless communication systems are expected to support ultra-high data rates, low latency, and high-resolution sensing, thereby necessitating the use of higher frequency bands to accommodate the increasing bandwidth demands [1]. The *D*-band, with the frequency range of 110-170 GHz, offers a wide available spectrum capable of supporting the aforementioned performance requirements, making it a promising candidate for next-generation wireless communications, high-resolution sensing, and radar applications [2]. In these systems, bandpass filters (BPFs) are essential components for selecting desired frequency bands and suppressing out-of-band interference. However, the design of *D*-band waveguide BPFs remains challenging due to high insertion loss, limited design flexibility, and stringent fabrication tolerance. Several D-band BPFs based on rectangular waveguides have been reported. For example, a waveguide BPF using high-order modes have been explored in [3], because filters utilizing high-order modes have larger dimensions compared to their fundamental-mode counterparts for the same operating frequency, which helps alleviating manufacturing resolution for terahertz devices with typically small dimensions. However, the fatal drawback of the work in [3] is the lack of transmission zeros.

In this work, a *D*-band waveguide BPF based on periodic cylindrical cavities and double ridges is proposed, as shown in Fig. 1(a) and (b). The main geometric parameters of the unit cell are p = 2080 μm, r = 800 μm, h_0 = 258 μm, h_1 = 155 μm, h_2 = 237 μm, w_1 = 170 μm, and w_2 = 620 μm. The introduction of bottom and top ridges can yield additional transmission poles and zeros simultaneously, which significantly enhance the frequency selectivity and out-of-band suppression performance. The simulated results in Fig. 1(c) show that the D-band waveguide BPF has a center frequency at 139.8 GHz with a bandwidth of 127.3 -152.3 GHz, and the minimum insertion loss within the passband is 0.17 dB. Two transmission zeros are created at 152.5 GHz and 153.5 GHz, respectively.

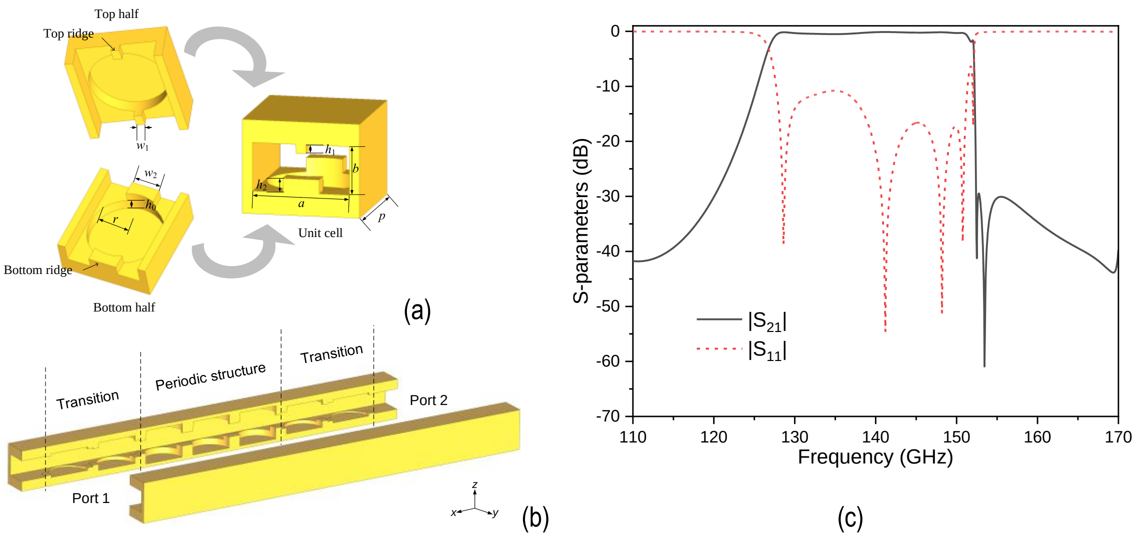

Fig. 1: The proposed D-band waveguide BPF. (a) Unit cell, (b) the whole structure, and (c) the frequency response.

[1] S. Dang, O. Amin, B. Shihada, and M.-S. Alouini, "What should 6G be?," *Nat. Electron.*, vol. 3, no. 1, pp. 20-29, Jan. 2020.
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Macroscopic Quantum Phenomena in Magnetism: Experimental Developments Inspired by Leggett and Chudnovsky

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The theoretical framework introduced by Anthony J. Leggett has played a central role in shaping our understanding of macroscopic quantum phenomena, particularly regarding coherence and tunneling in systems beyond the microscopic scale. While originally developed in the context of superfluidity and superconductivity, these concepts have found a natural extension in magnetism, largely through the theoretical work of Eugene M. Chudnovsky.

In this contribution, we present a focused overview of key experimental developments in magnetism demonstrating quantum behavior in mesoscopic and nanoscopic systems, with particular emphasis on magnetic relaxation experiments as a direct probe of magnetization dynamics.

Early studies on magnetic particles, clusters, and granular systems revealed a crossover from thermally activated relaxation at high temperatures to temperature-independent behavior at low temperatures. This transition is clearly observed in the magnetic viscosity, whose low-temperature plateau provides a direct experimental signature of quantum tunneling of the magnetization (Fig. 1, left). From an experimental perspective, this behavior can be viewed as the magnetic analogue of macroscopic quantum tunneling previously observed in Josephson junctions.

Further advances were achieved in molecular nanomagnets, where discrete spin levels lead to resonant quantum tunneling. In these systems, an external magnetic field tunes level crossings, resulting in sharp enhancements of the relaxation rate at specific fields (Fig. 1, right), establishing a direct link between energy level quantization and magnetic dynamics.

Microwave techniques and low-temperature measurements play a key role in enabling these experiments, allowing access to the relevant time and energy scales. These approaches have made it possible to explore quantum phenomena in magnetic systems with increasing precision.

This contribution provides an experimental perspective on how macroscopic quantum coherence and tunneling, originally developed in other areas of condensed matter physics, have been extended to magnetism, opening new directions for both fundamental research and quantum technologies.

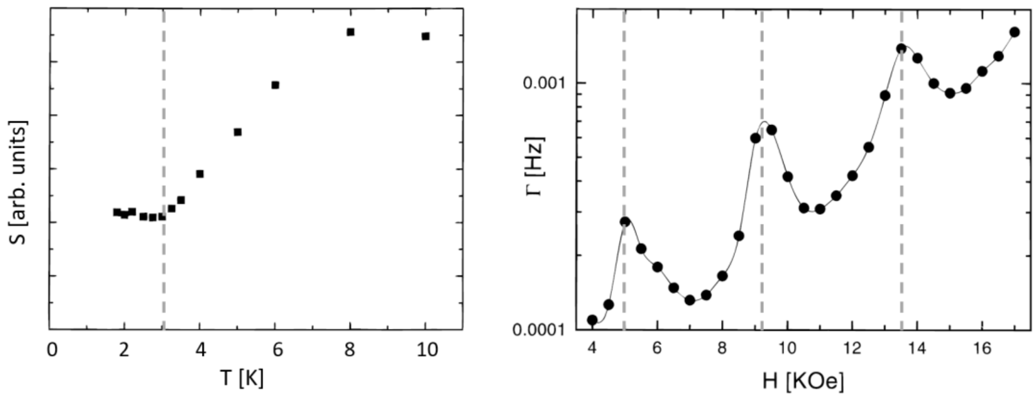

Figure 1. Experimental signatures of quantum tunneling of magnetization. Left: Temperature dependence of the magnetic viscosity showing the crossover from thermally activated to temperature-independent relaxation (quantum regime). Right: Field dependence of the relaxation rate in Mn_{12} molecular nanomagnets, evidencing resonant quantum tunneling through level crossings.

Spin-boson models under strong ac-driving

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Quantum two-level systems interacting with the surroundings are ubiquitous in nature. The coupling suppresses quantum coherence and forces the system towards a steady state. Such dissipative processes are captured by the paradigmatic spin-boson model [1], describing a two-state particle, the ”spin”, interacting with an environment formed by harmonic oscillators. I will discuss to what extent intense coherent driving impacts the dynamical and stationary properties of the strongly driven spin-boson model, in the case of Ohmic dissipation and for a structured bath [2]. Theoretical predictions will be benchmarked to experiments with platforms based on superconducting qubits coupled to an electromagnetic environment [3]. These results advance fundamental understanding of open quantum systems and bear potential for the design of entangled light-matter states.

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Quantum computing with magnetic systems

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Magnetic materials provide a versatile platform for quantum information processing, combining coherent spin dynamics with scalable solid-state architectures. In this talk, I will explore several emerging directions in quantum technologies based on magnetic structures and spin systems.

First, I will discuss domain-wall qubits in magnetic racetracks, where quantum information is stored in the chirality of the domain wall [1,2]. These domain walls could function both as stationary qubits and as fast “flying qubits” that are shuttled along the racetrack, enabling single- and two-qubit gates compatible with existing spintronic device technology.

I will outline possible new research directions to control the quantum state and couple domain walls to other excitations, such as magnons or domain-wall vibrational modes. This also includes approaches to implement one-way quantum information flow using nonreciprocal magnonic amplifiers, where spin waves propagate asymmetrically and signals can be directionally amplified [3].

Finally, while materials platforms continue to advance toward the realization of magnetic quantum devices, I will discuss the use of semiconductor spin qubits in quantum dots as controllable quantum simulators to probe microscopic coherence phenomena emerging in magnetic systems. These devices provide precise control over interactions and enable the exploration of many-body spin dynamics and decoherence mechanisms relevant for scalable quantum technologies [4].

Together, this talk illustrates how engineered magnetic structures—ranging from topological spin textures to magnonic excitations and quantum-dot spins—can be harnessed to realize new paradigms for quantum computation, quantum simulation, and coherent information transport in solid-state systems.

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[3] Zou, Bosco, Thingstad, Klinovaja, Loss Physical Review Letters 132 (3), 036701
[4] Jirovec, Reale, ... , Bosco, Vandersypen arXiv:2511.04310 Science, in press

Sharing secrets in superconducting quantum networks

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Sharing secrets has been an important avenue of communication through the entire history of humanity. In particular, the question of security is of paramount importance for communicating secrets. Here, quantum communication offers the concept of unconditional, or information-theoretic, security, as opposed to many modern communication protocols based on the computational asymmetry of certain mathematical problems. In multipartite networks, quantum secret sharing (QSS) is an important cryptographic protocol which provides an unconditionally secure way to share information between n players, where at least $k > n/2$ of players must collaborate in order to faithfully reconstruct the original secret.

We experimentally investigate a particular, entanglement-based, $((k, n))$ protocol in a superconducting microwave network with $n = 3$ players, from which $k = 2$ players perform a joint secret reconstruction. We use microwave two-mode squeezed states generated by Josephson parametric amplifiers as an entanglement resource, while the secret is represented by a codebook of coherent states. We demonstrate the unconditional security of our QSS scheme by exceeding the asymptotic no-cloning state fidelity of $F = 2/3$ with the reconstructed secret states. Moreover, we analyze the security of our protocol against an internal adversary attack and demonstrate a secure parameter regime in the presence of an omnipotent dishonest player. Furthermore, we experimentally explore inherent connections between QSS and other fundamental quantum information processing tasks. In particular, we show that the QSS protocol can be adapted to accomplish quantum dense coding, by consuming the entanglement resource in order to increase the amount of communicated classical information beyond the classical limit. From a different perspective, the QSS scheme may also exploit its multipartite nature in order to perform the elementary quantum error correction, which is experimentally demonstrated by correcting for channel erasure errors. Finally, I discuss the QSS potential to be extended towards the blind quantum computing paradigm, thus, illustrating the capability of QSS acting as a "Swiss Army knife" protocol in multipartite quantum networks and distributed quantum computing architectures.

Macroscopic Quantum Tunneling in Magnets and Superconductors (The Legacy of Tony Leggett)

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Milestones in theory and experiments on macroscopic quantum tunneling and tunneling with dissipation will be reviewed in applications to magnets and superconductors. Principles of Josephson-junction-based qubits will be discussed, together with magnetic tunneling and prospects of building spin-based quantum computers.

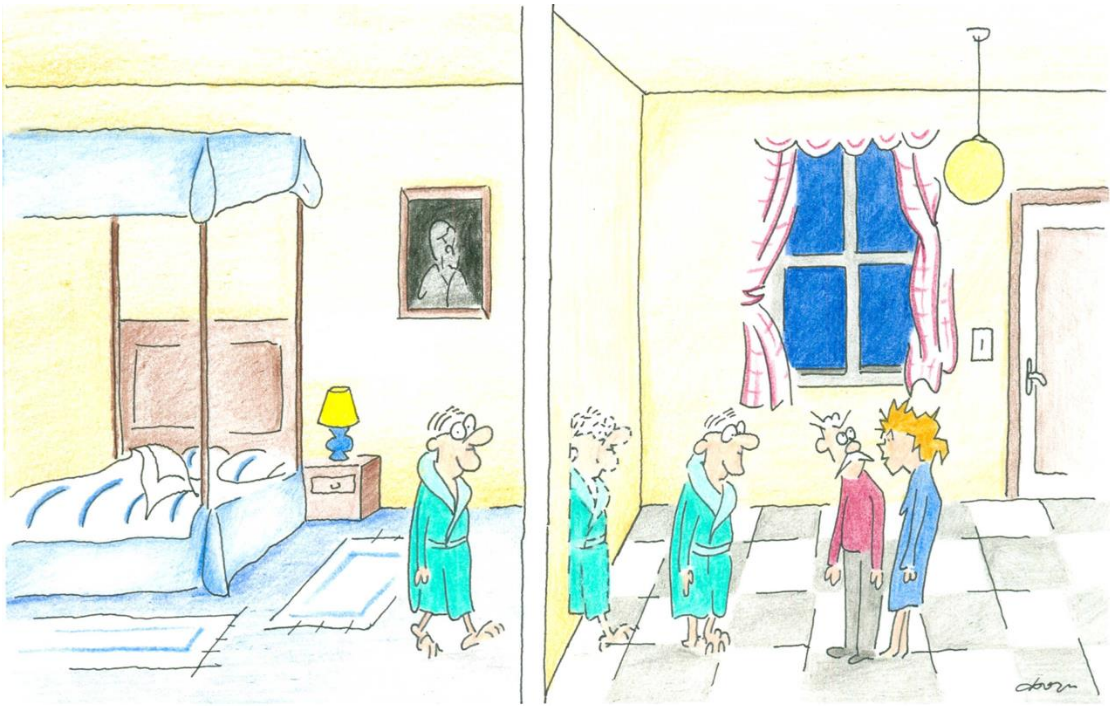

Fig. 1: Macroscopic Quantum Tunneling

Quantum information transfer through atomic arrays

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The recent fabrication and control of semiconductor quantum dot arrays opens the possibility to use these systems as quantum links between distant sites in a quantum processor. Their task is the transfer of quantum information between distant sites, an indispensable part of large scale quantum information processing [1,2]. Also, the recent implementation of quantum dot arrays has shown their feasibility as quantum simulators of complex lattices[3]. Recently, It has been shown how to imprint non trivial topology in a quantum dot array by means of Floquet engineering[4].

In this talk I will review the different protocols to transfer particles and quantum states in quantum dot arrays. Then, I will discuss an alternative way to transfer information with high fidelity, by using robust edge states in systems with non-trivial topology [5,6].I will discuss the long range particle transfer mediated by edge states in different atomic array configurations and the role of topological domain walls to speed up the transfer.

Finally, a protocol for entanglement generation between distant qubits mediated by a topological lattice, the stub-SSH, will show the feasibility of these systems to transfer information and generate entanglement with high fidelity.

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[4] B. Pérez-González et al., Phys. Rev. Lett., 123, 126401 (2019)
[5] N. Lang et al., npi, QI, 3,47 (2017).
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Quantum Information Processing with Superconducting Microwave Electronics

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[a]*Qilimanjaro Quantum-Tech*
[b]*Karlsruhe Institute of Techonology (KIT)*
[c]*University of Stuttgart*

Superconducting microwave circuits have emerged as one of the most prominent platforms for the development of novel quantum technologies [1]. Owing to the absence of resistive dissipation and to their accessible operational frequencies, these systems can be engineered to exhibit quantum mechanical behavior at macroscopic scales [2] by leveraging the extensive body of knowledge developed for microwave telecommunications. These advantages have positioned this platform as a preferred choice for applications such as quantum computing, quantum sensing, and quantum cryptography. In this talk, we review the key concepts and theoretical framework underlying the design of microwave quantum circuits. We focus on two state-of-the-art applications: the development of quantum processing units and low-noise amplifiers. We conclude with a brief outlook on emerging technologies that will be enabled by further advances in this platform.

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Symmetry-protected states of interacting qubits in superconducting quantum circuits

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Superconducting circuits are one of the leading candidates for storing and manipulating quantum information. Among them, qubits embedded with intrinsic noise protection have seen rapid advancements in recent years. This noise protection is typically realized by isolating the computational states from local sources of noise. Here, we propose an interacting spin model that requires at least four spins with nearest-neighbor and next-nearest neighbor couplings, where the two lowest eigenstates form a symmetry-protected qubit manifold, which is robust to both relaxation and dephasing from local perturbations. We map the spin model to a superconducting circuit, which consists of resonant quantum electrical elements operating in the microwave range of frequencies, and show that such a circuit can reach coherence times exceeding several milliseconds in the presence of realistic environmental noise. Our work [1,2] opens a pathway to realizing qubits with long coherence times in a new generation of quantum devices.

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Towards single spin magnetic spectroscopy with superconducting quantum circuits

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Electron spin resonance (ESR) is a well-established spectroscopic technique for studying paramagnetic species. It is widely used in materials science, chemistry, and molecular biology to characterize reaction products and complex molecules [1], and it has recently emerged as a promising platform for quantum information processing, where spin qubits can be manipulated and read out with high fidelity [2]. To enhance detection sensitivity and improve quantum control of spins, circuit quantum electrodynamics (cQED) has been established as an effective platform [3], in which a spin ensemble is coupled to a superconducting microwave resonator. However, conventional resonator geometries do not achieve strong magnetic coupling at the single-spin level, which limits the scalability of this platform for quantum computing applications [4]. In this work, we investigate a novel resonator geometry consisting of two inductors and two capacitors connected in series. The properties of this design are characterized through electromagnetic simulations and on-chip device fabrication. Our results show improved performance compared with standard resonator architectures. Furthermore, experiments with coupled spins demonstrate an enhanced collective spin–photon coupling strength, bringing this system closer to the strong-coupling regime at the single-spin level. These results open new possibilities for using individual molecules as error-protected qubits [5] and for exploring novel regimes of ultra strong collective spin–photon coupling [6, 7].

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[5] A Chiesa, P Santini, E Garlatti, F Luis, S Carretta, Reports Prog. Phys. 87, 034501 (2024).
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Lattice quantum electrodynamics with molecular emitters in microcavities

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Light-matter interfaces lie at the core of many quantum phenomena and technologies. At the single emitter level, they enable strong photon-photon interactions instrumental to engineering gates for photonic quantum computing as well as non-classical states of light for metrological purposes. In the multi-emitter regime, the exchange of photons between them can lead to long-range photon-mediated interactions which can be harnessed for quantum simulation, as well as to obtain super/subradiant phenomena.

In this presentation I will introduce a platform for lattice quantum electrodynamics based on the coupling of dibenzoterrylene (DBT) quantum emitters to an open microcavity with in-built hemispheric photonic resonators. In a lattice quantum electrodynamics context, we show single photon interference that steer the emission and localization of light emitted by the DBT molecules.

Given the low variability of the emission energy of DBT molecules in our platform [1], we anticipate a high potential for the study of lattice sub and superradiance and cavity mediated long range coupling of emitters [2].

[1] M. Colautti et al., ACS Nano 14, 13584 (2020).
[2] A. González-Tudela and I. Cirac, Phys. Rev. Lett. 119, 143602 (2017).

Topological properties of discrete step quantum walks

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Topological phases give rise to edge states that can be used for technological applications. Among them, Floquet phases, which are obtained by periodically driving the system, have been shown to be exceptionally rich and externally tunable. In this talk, I will discuss extrinsic topology, which is a particular type of topology that emerges in Floquet systems that follow a discrete time evolution. Finally, I will show the existence of these topological phases in photonic lattices using a double fiber-ring setup and the manipulation of their edge states.

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Circularly Polarized Terahertz Radiation as a Mechanism for the Control and Manipulation of Quantum States in Superconducting Rings

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[c] *University of Bordeaux, LP2N, F-33405 Talence, France*

The Inverse Faraday Effect (IFE) is a magneto-optical phenomenon in which circularly polarized light induces magnetization in various materials. The characteristic energy scale for superconductors is determined by their critical temperature (Tc), which corresponds to radiation frequencies on the order of THz. We demonstrate that circularly polarized THz radiation can act as an effective external magnetic field for superconductors [1]. Using the time-dependent Ginzburg-Landau (TDGL) equation, we describe the response of superconducting rings to circularly polarized electromagnetic waves, illustrating the influence of the IFE on the generation of current states.
We provide a theoretical analysis of the possibility of using circularly polarized radiation to switch between two different quantum states of a superconducting nanoring subjected to the half quantum flux. Numerical modeling, performed in the framework of the time-dependent Ginzburg–Landau equation, reveals the condition for on-demand switching between current-carrying states with different helicities with 100% probability [2,3].
These results pave the way for utilizing radiation pulses in the high-speed operation of superconducting quantum devices.

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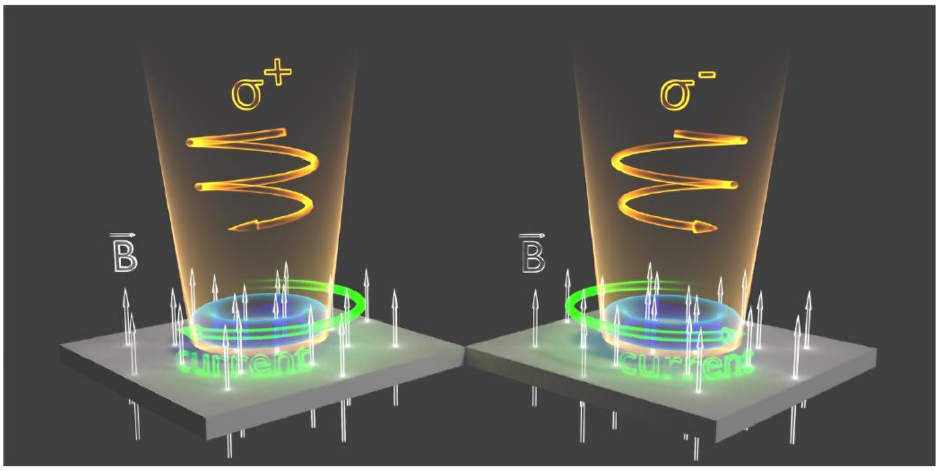

Hawking time crystals

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After a brief introduction to black-hole lasers and continuous-time crystals, we propose a time crystal based on a quantum black-hole laser, where the genuinely spontaneous character of the symmetry breaking stems from the self-amplification of spontaneous Hawking radiation [1]. The resulting Hawking time crystal (HTC) is characterized by the periodic dependence of the out-of-time density-density correlation function, while equal-time observables are time independent because they embody averages over different realizations with a random oscillation phase. The HTC provides a nonlinear periodic analog of the Andreev-Hawking effect, exhibiting anticorrelation bands resulting from the spontaneous, quantum emission of pairs of dispersive waves and solitons into the upstream and downstream regions. Remarkably, we prove that any parametric amplifier has associated a time operator, which leads to a unique characterization of the time-crystal formation in terms of two time operators: one associated with the initial black-hole laser and another associated with the final spontaneous Floquet state.

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Using Electrical Dipole Resonance to Generate Broad-Band Microwave Absorption

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By introducing metallic-ring structural dipole resonances in the microwave regime, we have designed and realized a hierarchical metamaterial absorber that achieves an average reflection loss of −19.4 dB across 3–40 GHz. The measured performance is polarization-independent at normal incidence, and the absorber maintains strong effectiveness for oblique incidence angles up to 45°. Our design concept is grounded in a mechanism that converts a capacitively coupled in-plane electrical dipole resonance—through interaction with the image current—into two distinct magnetic resonances. Broadening these magnetic resonances by incorporating patch resistors into the current rings produces a wide frequency interval between the two resonance frequencies that is impedance-matched to free space, enabling near-perfect broadband absorption. To further extend the absorption bandwidth into the ultra-broadband regime, we employ a double-layer self-similar architecture and leverage absorption of diffracted waves at higher frequencies. The final structure has a total thickness of 14.2 mm, only 5% above the theoretical minimum imposed by the causality limit.

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Enhanced Magnon Damping via Acoustic Fabry-Pérot Resonances in YIG/GGG Bilayers

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The damping of magnons (spin excitations within a crystal lattice) is a critical parameter in magnetism, as it dictates spin precession coherence and magnon lifetimes. Low damping is a prerequisite for modern magnonic applications, ranging from the exploration of novel states of matter [1] to the development of hybrid systems and high-sensitivity sensors [2]. Consequently, identifying and controlling damping mechanisms is essential for advancing these technologies.

In this work, we investigate the influence of phonon-mediated relaxation on magnon damping in a series of four Yttrium Iron Garnet (YIG) thin films of varying thicknesses grown on Gadolinium Gallium Garnet (GGG) substrates. We demonstrate that due to the strong magnetoelastic coupling in YIG, the double-polished GGG substrate functions as an acoustic Fabry-Pérot cavity. This mechanical confinement allows phonons at resonant frequencies to couple intensely with the film's magnetization. This interaction manifests as both enhanced magnetic damping and a distinct frequency shift in the magnon resonance. Notably, our results reveal that these resonant phonons significantly alter magnon dynamics even when their discrete signatures remain invisible in the Ferromagnetic Resonance (FMR) transmission spectrum. We provide a systematic characterization of these damping and shift effects as a function of the external magnetic field and YIG layer thickness, offering insights into the limits of coherence in magnetoelastic systems.

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An Equivalent Circuit Approach for Characterizing Magnetodielectric Composites with Microwave Resonant Sensors

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Magnetic materials have unique properties for microwave applications, such as high permeability, nonreciprocity, and nonlinear behavior. These characteristics arise from their tensor-based permeability and the interaction between electromagnetic and spin waves, which introduces significant complexity in both analysis and device design. Traditional full-wave simulators cannot properly capture nonlinear effects or spin wave dynamics, while micromagnetic tools become computationally impractical at larger device dimensions. To contribute to the development of microwave circuit design including magnetic materials, this work proposes an equivalent circuit model based on the Landau–Lifshitz–Gilbert equation, which includes spin precession and spin wave propagation in a straightforward way. Furthermore, these models help to explain the impact of material characteristics, including biasing fields, saturation magnetization, and sample geometry. Employing this methodological approach, this work examines magnetodielectric composites composed of Fe_3O_4 nanoparticles integrated within an epoxy matrix and presents an extraction parameter technique to determine the effective permeability of the sample through the analysis of the equivalent circuit model derived from a custom designed resonant sensor. The resulting models can be integrated with standard tools like Advanced Design System (ADS), enabling complete system-level simulations.

Acknowledgment:
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Investigating novel heterogeneous bilayer structures for broadband radar absorption

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The development of radar absorbing materials (RAMs) has followed multiple strategies aimed at increasing the absorbed power and, more importantly, extending the effective absorption bandwidth. Recent research has focused on the use of materials with different natures (such as magnetic ferrites, metals, and carbon-based compounds [1], [2], [3], [4]) as well as on the design of multilayered structures [5], [6], [7], [8].
However, most experimental approaches and the theoretical models supporting them assume perfectly homogeneous systems, both in terms of intrinsic material properties and geometric configuration. In contrast, this contribution explores an alternative scenario based on the deliberate introduction of inhomogeneities tailored to broaden the absorption bandwidth. The proposed strategy relies on integrating the absorption contributions arising from a distribution of material properties, rather than optimizing absorption for a single, specific condition.
Specifically, this work investigates how controlled distributions of permeability, permittivity, and layer thickness influence the overall absorption bandwidth, demonstrating the potential of induced heterogeneity as a design paradigm for broadband RAMs.

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Skyrmion Cyclotron Resonance in Ferrimagnets

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We show that a resonance due to gyroscopic motion of skyrmions, conceptually similar to the electron cyclotron resonance in metals, can be excited in a ferrimagnetic film by a spin current or microwaves. It must permit unambiguous measurement of the skyrmion mass for which a universal expression depending solely on the exchange interaction between spins belonging to two different ferrimagnetic sublattices is derived. The dependence of the skyrmion cyclotron frequency on parameters is computed for a TM/RE ferrimagnet, using CoGd as an example. The cyclotron frequency exhibits a dip near angular momentum compensation, where it hybridizes with the ferromagnetic resonance, Fig. 1. The skyrmion cyclotron mode is studied for individual skyrmions and for skyrmion lattices, where the effect must be strong enough to be observed in microwave and spin-current experiments.

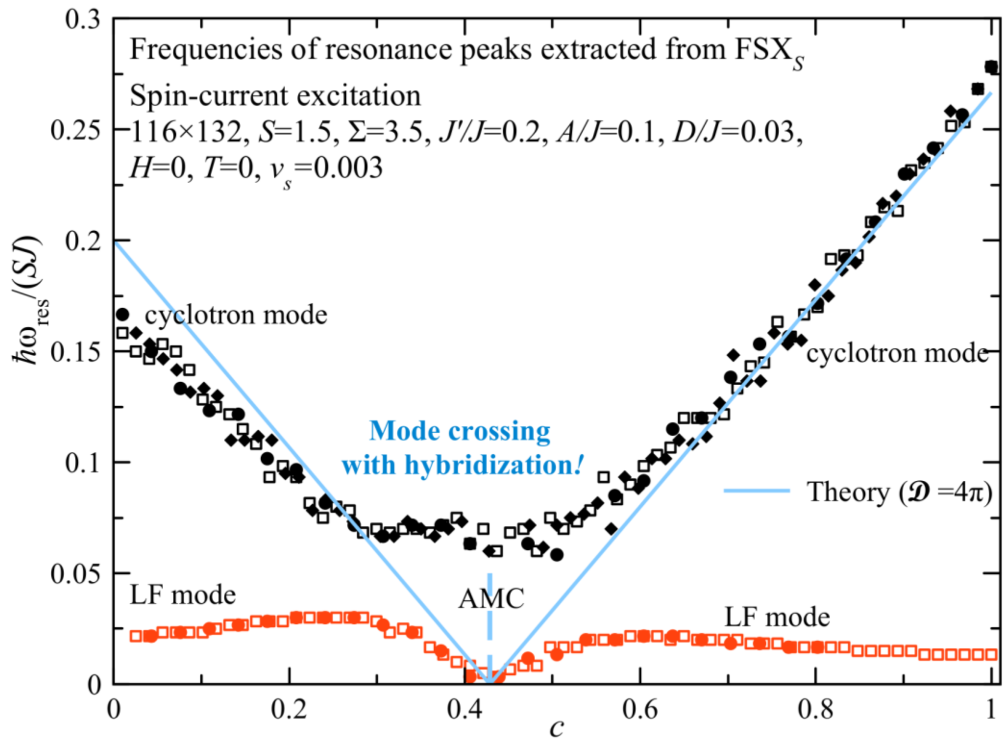

Figure 1: The dependence of the skyrmion cyclotron resonance and low-frequency ferrimagnetic resonance modes on the concentration of Gd in a model of CoGd ferrimagnet. Strong repulsion of the modes is seen near the angular momentum compensation (AMC). Results for individual skyrmions and skyrmion lattices are similar [1].

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Circuit quantum electrodynamics near spin clock transitions

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The onset of a quantum level splitting Δ between two classically degenerate states separated by a potential energy barrier is one of the most characteristic, yet also extraordinary consequences of the quantum tunneling effect [1]. Systems defined by an anisotropic spin, like magnetic nanoparticles or magnetic molecules, offer the ability to study the presence of such a quantum gap at the mesoscopic scale [2]. Even for molecules formed by a few magnetic atoms, such as Fe_8 and Mn_{12}, both with spin S = 10, Δ values generated by their off-diagonal magnetic anisotropy remain below 1 μK (or 20 kHz), thus the gap can only be detected indirectly, by means of Landau-Zener relaxation experiments [3], or directly by tuning it with an external magnetic field perpendicular to the anisotropy axis [4,5]. By contrast, in molecules that encapsulate individual atoms, the avoided level crossings generated by intrinsic quantum tunneling reveal a much larger Δ, in the range of 0.3 K to 5 K (or 6 to 100 GHz), which has been measured by means of spin resonance [6,7] and heat capacity experiments [8]. Besides, such 'spin-clock' transitions are of relevance for the design of spin qubits, since they shield the electronic spins against magnetic field fluctuations and enhance the spin coherence time T_2 [6,7]. Here, I discuss the coupling of model molecular systems with large quantum tunneling gaps, HoW_{10} ([9], Figure 1), VO-porphyrin [10] and Ni-imdipa [8], to microwave photons confined in superconducting circuits, either coplanar waveguides or lumped element resonators. This hybrid platform allows exploiting methods developed for superconducting qubits to wire up spins into a scalable quantum architecture [11]. The experimental results show that the spin-photon coupling G becomes also maximum at these transitions, thus providing a rare situation where the spin control and readout can be optimized while also maximizing its decoupling from dipole-dipole and hyperfine interactions. Engineering spin-clock states of molecular systems therefore offers a promising strategy to combine sizable spin-photon interactions, e.g. in concentrated molecular crystals, with a sufficient isolation from unwanted magnetic noise sources.

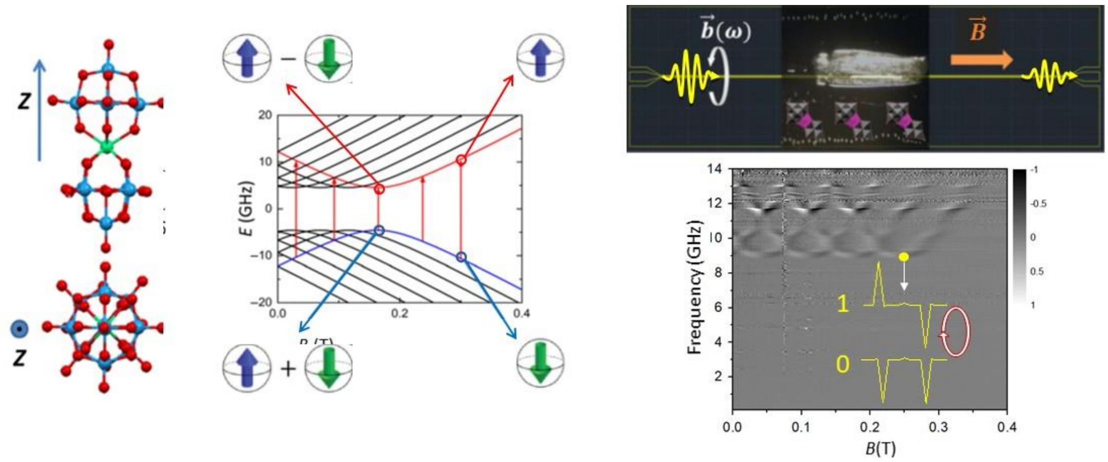

Figure 1. Left: spin level scheme of HoW_{10}, showing field induced avoided level crossings that arise from quantum tunneling between opposite projections $m_J = \pm 4$ of the Ho^{3+} angular momentum, for different orientations of the nuclear spin. Right: the microwave transmission through a superconducting waveguide coupled to an HoW_{10} single crystal directly maps all spin transitions and provides the field-dependent spin-photon coupling G. Adapted from [9].

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Terahertz Nondestructive Evaluation of Advanced Microelectronics Packaging

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Despite the fact that limits to transistor gate lengths are being approached, functionality of microelectronics continues to follow Moore's law. This is due largely to the exploitation of new architectures for the assembly of chips—or chiplets—globally reducing communication times enabled by advanced microelectronics packaging. Nonetheless, verifying the integrity of such assemblies remains a stubborn problem. Time-domain terahertz (THz) imaging enables 3D imaging, including the interior, of many electrically insulating materials and structures down to the 10-micron scale, and as such is a potentially important nondestructive-evaluation (NDE) tool for complex advanced microelectronics packaging, such as interposers, stack-ups, and embedded chips. We present two sets of THz imaging results for the NDE of heterogeneous packaging (1) an 8-layer interposer involving a glass core and multiple Ajinomoto Build-up Films (ABF) with complex metalization at various levels and (2) embedded dies in glass substrates. For (1), Fig. 1 shows below an example of a nondestructive THz B-scan revealing missing metalization below the surface layers. We also show that polarization-resolved THz imaging can provide information about what lies below certain metal structures. For (2), Fig. 2 shows an embedded die with vias in a glass substrate coated above and below by ABFs. In curing the ABFs, there is flow and consequent thinning of the ABF into the vias and gaps around the embedded die. We discuss the roles of signal processing and machine learning in obtaining these results.

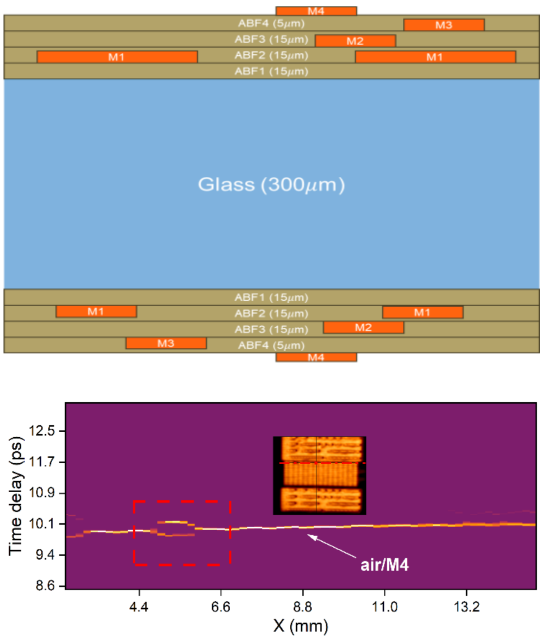

Fig. 1: Top: Schematic cross section of 8-layer interposer, showing glass core, ABFs, and metalization. Bottom: THz B-scan showing subsurface missing metalization.

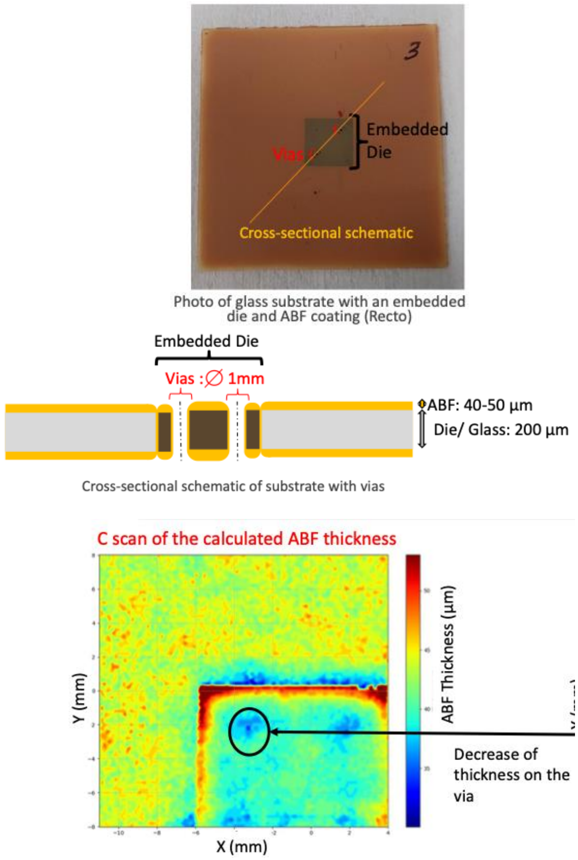

Fig. 2: Top: Top view of glass substrate with embedded die coated with ABF. Middle: Schematic cross section showing ABFs on top and below as well as vias in die. Bottom: THz C-scan showing thinning of ABF near vias and edges of embedded die indicating ABF flow into gaps.

Spin Dynamics in Ferrimagnetic Insulators Across Time & Length Scales

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Understanding and controlling magnetism across disparate length and time scales is central to the design of next generation spintronic devices. In this talk, I discuss how frequency, element, and time resolved spectroscopic probes reveal the quantum degrees of freedom (spin and orbital angular momentum, and exchange interactions) that ultimately govern magnetic behavior from the atomic scale to collective spin dynamics.

I will discuss static and dynamic x-ray spectroscopy investigations of low-damping magnetic insulators based on spinel ferrites. Static x-ray absorption spectroscopy (XAS) and x-ray magnetic circular dichroism (XMCD) reveal how epitaxial strain lowers crystal symmetry and redistributes orbital occupations. X-FMR studies, which combine XMCD and FMR, uncover coherent, exchange-locked precession across point-symmetry and chemically distinct sublattices in insulating ferrimagnetic oxides, confirming that these systems behave as single collective dynamical objects under resonant excitation. Complementary time-resolved scanning transmission x-ray microscopy measurements visualize spin-wave amplitude and phase in ultra-low-damping ferrimagnetic insulators. Microspectroscopy reveals how local variations in cation oxidation states act as magnonic waveguides that channel propagating spin waves, as well as their field-driven transition from Damon-Eshbach modes to backward volume spin waves.

Finally, I discuss ultrafast studies of ferrimagnetic Ni ferrite using high-harmonic-generation spectroscopy, which probe the limits of spin dynamics far from equilibrium. Element-specific femtosecond measurements reveal rapid demagnetization, oscillatory reflectivity, and delayed spin-lattice dynamics that depend critically on defect density.

Terahertz Imaging of Art and Archaeology

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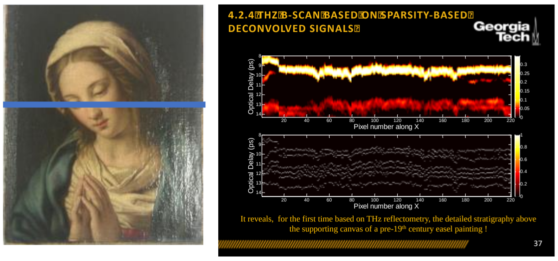
Time-domain terahertz (THz) imaging enables 3D imaging, including the interior, of many electrically insulating materials and structures. THz imaging is emerging as a potentially important nondestructive-evaluation (NDE) tool in the study of art and archaeological objects. We present THz imaging results of a range of art and archaeological objects, including paintings and book mockups. In the former, we show how THz imaging can be used nondestructively to reveal multiple paint layers in easel paintings. In the latter (Fig. 2), we employ machine-learning approaches to read text for the first time on individual sides of pages in stacks of paper. This project moves toward reading of new texts and variants in paper fragments in the bindings of early modern books. Finally, we discuss UNVEIL[3], a new Marie Skłodowska-Curie Doctoral Network where we have two open fully funded doctoral positions in the area of THz imaging of art and archaeology.



Section for B-scan indicated

Fig. 1: Left: Painting studied. Right: THz B-scans. Top shows raw data, bottom deconvolved B-scan showing five preparatory paint layers.

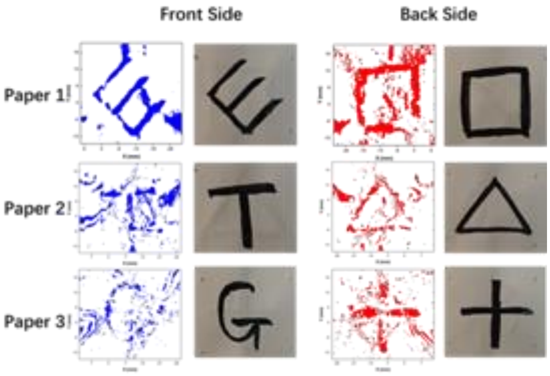


Fig. 2: THz images of individual overlapping characters written in iron-gall ink on each side of three leaves of paper in a stack.

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[2] https://unveil-dn.eu/

THz photostriction in van der Waals multilayers

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Layered van der Waals (vdW) materials offer exceptionally large light-matter interactions in atomically thin platforms, which could be tuned by a suitable design. In the case of monolayer transition metal chalcogenides (TMDs), a combination of optical interference and substrate strain could enhance the second harmonic generation efficiency by an order of magnitude [1]. A natural question is what design opportunities arise when we go beyond the monolayer limit. In bilayer MoS_2, for example, interlayer breathing modes are significantly hardened due to the in-plane tensile strain [2]. This contrasts with the case of monolayers, where tensile strain only causes softening of phonon modes [3], and offers an approach to tune vdW interactions in multilayers.

Here, we study optomechanical response in a multilayer version of a prototypical 2D ferroelectric SnS, where large photostriction was predicted in the monolayer limit [4]. Through pump-probe reflectance spectroscopy, we observe ultrafast anisotropic reflectance modulation induced by lattice modulation – one axis shrinks, while the orthogonal axis expands in picosecond timescales – however in direction opposite to the theory prediction [5]. A central assumption underlying theoretical works has been that photoexcitation primarily induces screening of spontaneous polarization, leading to an inverse-piezoelectric contraction of the polar axis. Our work instead demonstrates that deformation-potential-driven electronic stress can dominate even in systems with ferroelectric stacking. This insight is likely applicable across a broad class of van der Waals ferroelectrics and provides a new design principle for photo-driven actuation and ultrafast optomechanical transduction in low-dimensional materials.

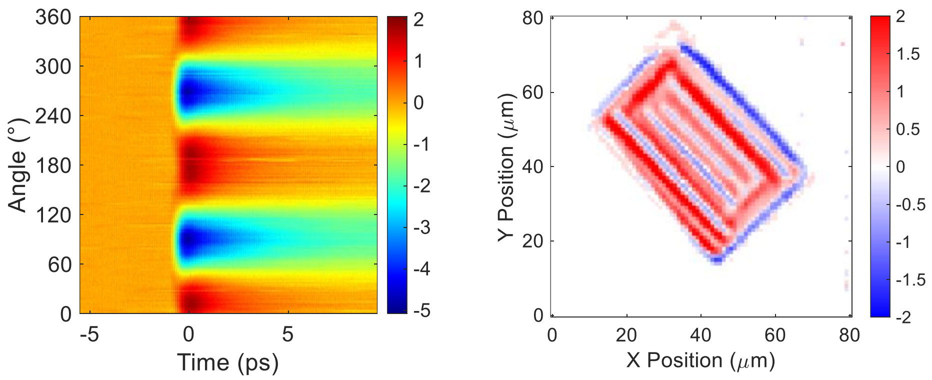

Fig. 1. Ultrafast reflectance modulation in multilayer SnS.

[1] S. Puri, S. Patel, J. L. Cabellos, L. E. Rosas-Hernandez, K. Reynolds, H. Churchill, S. Barraza-Lopez, B. Mendoza, H. Nakamura, Nano Lett. 24, 13061 (2024).
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[4] R. Haleoot, C. Paillard, T.P. Kaloni, M. Mehboudi, B. Xu, L. Bellaiche, S. Barraza-Lopez, Phys. Rev. Lett. 118, 227401 (2017).
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Tunable terahertz opto-mechanics of MoS_2 bilayers with homogeneous in-plane strain

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[b]*Institute for Solid State Physics. The University of Tokyo*

How does strain [1] transmit across the monolayers of a few-monolayer 2D material? Can in-plane strain become a knob for tuning the frequency of addressable vibrations on these materials? In this presentation, we address the issue of strain transfer across monolayers of a prototypical layered material (MoS_2); strain is created on the first monolayer grown on typical substrates [2]. Focusing on bilayers, we observe more than one growth sequence; we determine the symmetry of these bilayers through second-harmonic generation. Raman spectra are used to determine the evolution of vibrations within these bilayers within the terahertz regime. The experimental findings are supported by calculations. The results [3] open a window for controllable terahertz vibrations in ultrathin materials.

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[2] S. Puri, S. Patel, J. L. Cabellos, L. E. Rosas-Hernandez, K. Reynolds, H. O. H. Churchill, S. Barraza-Lopez, B. S. Mendoza, and H. Nakamura, Substrate interference and strain in the second-harmonic generation from MoSe2 monolayers, *Nano Lett.* **24**, 13061 (2024).

[3] S. Patel, Jose D. Mella, S. Puri, Salvador Barraza-Lopez, H. Nakamura. Tuning Terahertz Optomechanics of MoS2 Bilayers with Homogeneous In-plane Strain. arXiv:2602.03996 (2026).

High Frequency Magnetic Resonance using Terahertz Generalized Spectroscopic Ellipsometry

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[c]*Department of Physics, Chemistry, and Biology (IFM), Linköping University, Linköping, Sweden*

We present a groundbreaking advancement of magnetic-resonance spectroscopy into the terahertz range using polarization-resolved ellipsometry at high magnetic fields. This method enables precise testing of existing models and uncovers new phenomena, such as the magnetic Lyddane-Sachs-Teller relationship. Furthermore, our approach provides detailed insights into the quantum properties and interaction with the local environment of defects and dopants in semiconductors like SiC,[1] GaN,[2] and Ga2O3,[3] and is applicable to paramagnetic and ferromagnetic resonances. This advancement addresses the limitations of current methods, which often ignore polarization properties and are restricted to fixed frequencies.

Using this method, we discovered a magnetic counterpart to the dielectric Lyddane–Sachs–Teller relation, derived from Bloch's nuclear induction model.[4] The magnetic LST relation links the static magnetic permeability to the product of the longitudinal and transverse optical modes of magnetic excitations, in contrast to the dielectric version, which depends on the squares of resonance frequencies. We experimentally verify this relationship using terahertz electron magnetic resonance spectroscopic ellipsometry on an iron-doped gallium nitride crystal under an external magnetic field, thereby establishing the existence of a magnetic analogue to the LST relation.

Moreover, we used our method to investigate Mn^{3+} impurities in Gallium Nitride. The technique enabled precise mapping of spin-resonance features across magnetic field and frequency, revealing both zero-field and Zeeman splitting. We also observed strong forbidden transitions, induced by a strong coupling to the vibrational modes of the nuclei. Furthermore, temperature-dependent measurements reveal dynamic Jahn-Teller effects. As such, the Jahn-Teller distortions of this impurity is unequivocally determined.

[1] M. Schubert, S. Knight, S. Richter, P. Kühne, V. Stanishev, A. Ruder, M. Stokey, R. Korlacki, K. Irmscher, P. Neugebauer, and V. Darakchieva, Appl. Phys. Lett., 120, 102101 (2022).
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Temperature-Dependent Terahertz Electrodynamics and Coupled Excitonic-Lattice Modes in Ta_2NiSe_5

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Excitonic insulators provide a unique platform for investigating collective quantum phases arising from robust electron-hole correlations. Among candidate materials, Ta_2NiSe_5 has emerged as a primary focus due to its quasi-one-dimensional electronic structure and proximity to the semimetal-semiconductor transition, where excitonic instability is predicted to be most pronounced [1,2]. Below approximately 326 K, the system enters a symmetry-broken insulating state widely attributed to excitonic ordering [3,4]. However, a critical open question remains: is this low-temperature state rigidly lattice-locked, or does it support phase-sensitive excitonic dynamics that are experimentally accessible?

In this work, we present temperature-dependent terahertz (THz) spectra of Ta_2NiSe_5 spanning 70 K to 400 K. We observe a systematic evolution of the low-energy electrodynamic response between 0.7 and 1.2 THz, characterized by significant shifts in resonance positions, depths, and overall line shapes. Specifically, a spectral dip near 1 THz intensifies and shifts throughout the low-temperature regime, while a distinct feature near 0.7–0.8 THz undergoes marked modification at elevated temperatures. These trends signify a substantial temperature-driven reconstruction of the low-energy excitations across the phase transition.

Our findings indicate that the THz response does not reflect a trivial background phonon spectrum; rather, it reveals a clear redistribution of spectral weight within the temperature window associated with excitonic insulation [5].

[1] Y. Wakisaka et al., Phys. Rev. Lett. 103, 026402 (2009).
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[4] K. Kim et al., Nat. Commun. 12, 1969 (2021).
[5] D. Werdehausen et al., Sci. Adv. 4, eaap8652 (2018).

Impedance-Engineered Magnetodielectrics: A New Paradigm in RF Materials Impedance Matching to Free Space

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A new class of multifunctional RF magnetoceramic materials, termed impedance-engineered magnetodielectrics (ZEMs), is introduced and discussed. ZEMs embed impedance control directly within the constitutive electromagnetic properties of a material through simultaneous engineering of magnetic permeability (μ) and dielectric permittivity (ε). This materials-centric approach enables intrinsic impedance matching and represents a fundamental shift from external matching networks toward materials-defined electromagnetic functionality.

ZEMs provide tailored impedance responses suitable for antennas, radomes, electromagnetic absorbers, metamaterials, and adaptive RF structures. By minimizing the need for discrete loading elements and complex geometrical compensation, these materials can substantially reduce component size, weight, and system complexity while improving radiation efficiency, bandwidth, and environmental robustness. Controlled processing strategies—including compositional tuning, cation substitution, and microstructural densification—have produced materials in which μ ≈ ε, yielding a normalized impedance approaching that of free space, $Z^*_{ZEM} = Z_{ZEM}/Z_0 \approx 1$. Under this condition, electromagnetic waves enter the material with minimal reflection, enabling efficient transmission, absorption, or phase manipulation without conventional matching layers.

Demonstrated ZEM materials currently operate over frequencies from approximately 1 MHz to 1 GHz, with bandwidths approaching 1 GHz, size-reduction factors exceeding 15, magnetic loss tangents ($\tan \delta_\mu$) of 0.01–0.05, and dielectric loss tangents ($\tan \delta_\varepsilon$) around 0.002. These properties enable compact broadband electromagnetic components and low-profile protective structures.

Extension of ZEM functionality to frequencies above 1 GHz remains a principal challenge, requiring mitigation of magnetic relaxation losses, suppression of permeability limits, and advanced microstructural architectures. The successful realization of high-frequency, broadband ZEMs would enable conformal apertures, multifunctional structural electromagnetic materials, and integrated protection layers for communications and sensing systems. ZEMs therefore represent a pathway toward next-generation electromagnetic systems in which performance is governed fundamentally by materials design rather than by circuit architecture.

Free-space EM characterization measurements with temperature control and machine learning implementation

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[b] *DIOPMA research group, Dept. de Ciència de Materials i Química Física, Universitat de Barcelona, 08028, Spain.*
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Continuing from our previous work on free-space electromagnetic characterization of materials, we have implemented a temperature-controlled measurement system aimed at reproducing more realistic operating conditions, particularly for microwave absorption applications in magnetic composite materials [1,2]. The setup is based on horn antennas (15 dBi directivity) and a Vector Network Analyzer (VNA) to generate and measure the electromagnetic response. Measurements are carried out inside an anechoic chamber in the X and Ku frequency bands, while ambient parameters such as temperature and humidity are monitored.
The system allows for stable measurements using a proportional-integral-derivative (PDI) system over a temperature range exceeding 60 °C, from sub-zero conditions up to approximately 50 °C. In addition to controlling the sample environment, the temperature of the VNA is also considered to ensure that calibration remains valid throughout the measurement process. This is an important aspect when comparing results obtained under different thermal conditions. Results show a significant frequency shift in absorption peaks at different temperatures, highlighting the importance of a dedicated measurement system.
To support the free-space measurements, waveguide measurements are used as a reference, following well-established procedures reported in the literature [3]. This provides a consistent comparison point and helps assess the reliability of the free-space results. Furthermore, we are exploring the use of machine learning techniques to improve the extraction of material parameters. A High-Gradient Boosting Regressor (implemented in *scikit-learn*) is trained using both simulated data (CST Microwave Studio) and experimental measurements, with the objective of obtaining more accurate estimates of complex permittivity and permeability than those provided by the classical Nicolson–Ross–Weir method [4,5].
Overall, this work proposes a combined experimental and data-driven approach to bring free-space electromagnetic characterization closer to real operating conditions, while improving the robustness of parameter extraction for microwave absorbing materials.
This work was supported by the U.S. Air Force Office of Scientific Research (AFOSR) under Grants No. FA8655-22-1-7049, FA8655261B013, and by the project PID2024-157160OB-I00 funded by the Agencia Estatal de Investigación (AEI) of the Spanish Ministry of Science, Innovation and Universities (MCIN).

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Wireless Multi-Parametric Sensing of Hydrogel Scaffolds via Giant Magnetoimpedance in Amorphous Magnetic Microwires

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Hydrogels are highly hydrophilic polymeric networks widely used as scaffolds to organize cells into 3D architectures for tissue engineering. The density and alignment of polymer fibers dictate the mechanical properties that regulate cell interactions [1]. However, monitoring these properties in situ remains a significant challenge as cells reorganize the scaffold, inducing local strains. Developing non-invasive methods to record these internal changes is crucial for engineering functional tissues [2,3].

In this work, we leverage the potential of Amorphous Magnetic Microwires (AMWs) for microwave-based wireless sensing. At GHz frequencies, the scattering properties of a single AMW depend strictly on its magnetic permeability, enabling the detection of the Giant Magnetoimpedance (GMI) effect [4]. We demonstrate that the dipolar resonance frequency of the AMW is highly sensitive to the dielectric constant of the surrounding medium, while its magnetoelastic response is modulated by mechanical stress due to the wire's intrinsic magnetostrictive nature [5].

By embedding a centimeter-sized AMW into the hydrogel and recording its response via a GHz antenna and a Vector Network Analyzer (VNA), we achieve the wireless detection of hydrogel concentration and structural changes induced by temperature and pressure. Furthermore, we explore the use of magnetic nanoparticles to orient collagen fibers, using the AMW to detect the resulting anisotropy. This dual-sensing approach proves the potential of AMWs to report real-time, internal environmental changes in scaffolds during cell growth and tissue maturation.

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Adiabatic Spintronics with Topological Magnetic Insulators

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I will present the experimental demonstration of electrically induced antiferromagnetic resonance in the topological antiferromagnetic insulator $MnPS_3$, providing direct validation of a transformative theoretical framework in spintronics [1,2]. This framework, based on the concept of adiabatic spintronics, predicts that magnetic dynamics in certain topological materials can be driven by a pure voltage, eliminating the need for electrical currents and thereby avoiding Joule heating. Such a mechanism carries far-reaching implications for future information technologies, particularly as data processing is projected to become a dominant contributor to global energy consumption.
Our results demonstrate that Néel spin-orbit torques can be generated electrically within a single insulating magnetic crystal, removing the need for external spin sources or engineered heterostructures. The experiments were conducted at frequencies around 100 GHz using a home-built quasi-optical sub-THz microwave spectrometer. By continuously tuning the polarization of the microwave excitation from linear to circular in both Faraday and Voigt geometries, we achieved controlled switching of the resonance driving mechanism from conventional magnetic (Zeeman-type) excitation to a purely electrical origin via Néel spin-orbit torque. This polarization-resolved approach enables the unambiguous identification of the electrically driven contribution, providing direct evidence of the adiabatic pumping effects predicted by theory.
In this presentation, I will report updated results from a new series of detailed experiments carried out over the past year on newly synthesized crystals, further expanding and reinforcing the original findings. Supported by the W. M. Keck Foundation, this work establishes topological magnetic insulators as a compelling platform for dissipationless control of magnetism and next-generation spintronic devices. I will conclude by outlining emerging directions in materials discovery, device implementation, and large-scale research initiatives aimed at addressing the growing energy demands of modern computing.

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Double quantum spin Hall phase in bilayer $ZrTe_5$

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Quantum spin Hall (QSH) insulators are a promising material platform for low dissipative quantum devices [1]. They are two-dimensional topological phases with helical edge states protected by time-reversal symmetry. Within the conventional Z_2 classification, only phases with an odd number of edge-state pairs ($Z_2 = 1$) are topologically nontrivial, whereas even-channel systems ($Z_2 = 0$) lie beyond this framework but can host robust edge transport characterized by a spin Chern number [2, 3]. Experimentally accessible realizations of such phases remain rare, particularly in systems with sizeable band gaps [1, 4]. Here, we show that bilayer $ZrTe_5$ realizes such an even-channel (double QSH) phase in its energetically stable structure. Using first-principles calculations, we demonstrate that uniaxial strain drives a transition from this phase to a single-pair QSH phase with $Z_2 = 1$. The double QSH phase hosts two pairs of helical edge states, resulting in enhanced edge conductance and a quantized spin Hall response that remains robust over an energy window of up to ~100 meV. These results establish bilayer $ZrTe_5$ as a minimal and tunable platform that connects Z_2 and spin-Chern topologies within a single material. More broadly, they demonstrate that van der Waals multilayers provide a route to engineering topological phases beyond the conventional classification, enabling tunable and scalable topological functionalities.

arXiv Preprint:

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Simulating New Phases of Quantum Matter with Superconducting Qudits

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New phases of matter naturally arise when symmetries in condensed matter are broken—the formation of crystalline order being ubiquitous, and a manifestation of the spontaneous breaking of translational symmetry in space. Recently, time crystals, where a time-dependent Hamiltonian is present and results in the breaking of time translational symmetry, have been simulating using qubits, and exhibit a transition from a thermal phase to an ordered, localized phase. The hallmark of the latter has been the presence of robust sub-harmonic oscillations across the entire quantum system in response to a periodic perturbation, say in a kicked Ising chain of spin ½ particles. We now observe this type of phenomenon in a spin-1 system, realized by a chain of superconducting qutrits insolated in a 20-element quantum processor. Period tripling, a clear phase transition, and the presence of new types of topological excitations emerge in this higher spin system.

Non-Resonant Magnetoacoustic Waves Imaged by Stroboscopic MOKE

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Spin waves play a crucial role in spintronics, enabling low-power information transport without charge currents. Their controlled excitation and propagation are essential for applications in non-volatile memory, magnetic logic, and wave-based computing. Among the different excitation mechanisms, surface acoustic waves (SAWs) efficiently couple to magnetostrictive materials through magnetoelastic interactions, giving rise to magnetoacoustic waves (MAWs) [1]. Different behaviors arise depending on whether the magnetization is on or off resonance: on resonance, the interaction is energy-transfer dominated; off resonance, it is predominantly dispersive.

In this work, we demonstrate the simultaneous imaging of SAWs and MAWs in thin ferromagnetic layers using a stroboscopic wide-field magneto-optical Kerr effect (MOKE) microscope. This approach provides time-resolved, micrometer-scale visualization of both the acoustic excitation and the induced magnetization dynamics. From the magnetic contrast, we extract the oscillation amplitude and phase of the magnetoacoustic waves as a function of the applied magnetic field and propagation angle. Phase-resolved measurements allow us to identify resonant and non-resonant regimes of magnetoelastic coupling. The experimental results are quantitatively reproduced by a macrospin model, which captures the field dependence of both amplitude and phase, confirming the underlying magnetization dynamics.

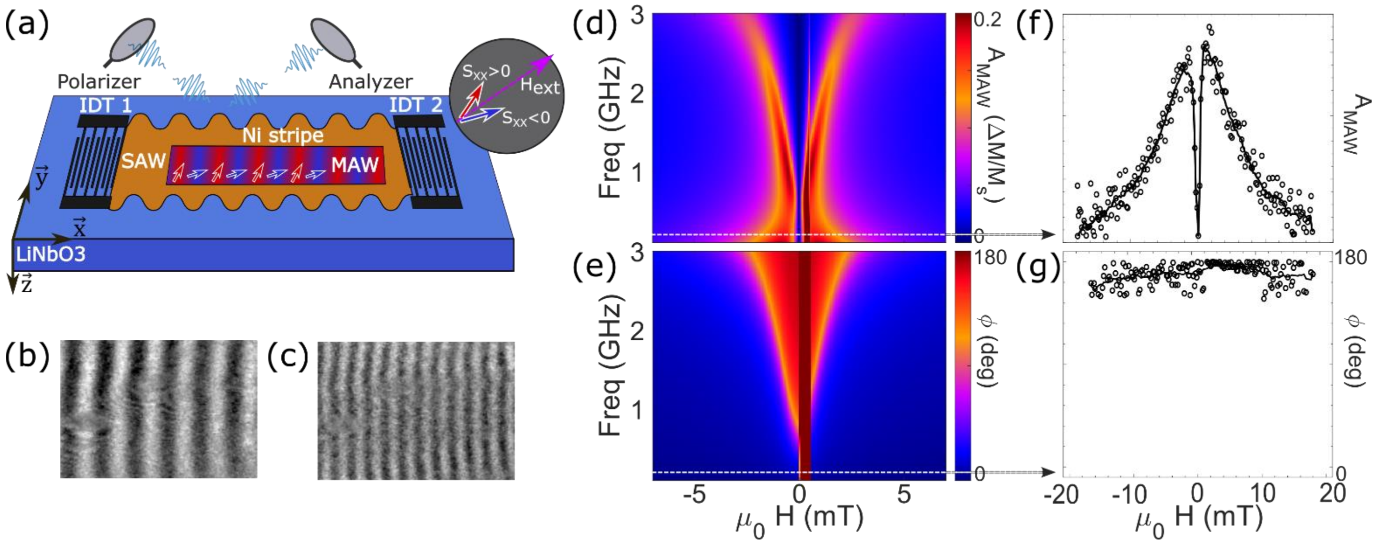

Figure. (a) Experimental set-up showing the generation and propagation of surface acoustic waves (SAWs) in nickel, the resulting magnetoacoustic wave (MAW), and its detection via stroboscopic illumination. Real-space images of the MAWs at (b) 124 MHz and (c) 248 MHz. (d,e) Color plots of the Macrospin model showing the MAW amplitude (d) and phase (e) as a function of frequency and magnetic field. (f,g) Experimental maps of the MAW amplitude A_{MAW}(f) and phase φ (g) measured at 124 MHz.

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Tony Leggett's influence on superconducting qubits: Coherent Quantum Dynamics and Macroscopic Realism

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Tony Leggett had a profound impact in many areas of physics. In one of those areas he carefully looked at the problem of quantum coherence in superconducting circuits, particularly under which conditions specific circuits such as the radio-frequency SQUID could exhibit quantum coherence while at the same time display observable macroscopic signals, such as the magnetic flux. This led to the development of several landmark works: the spin-boson model [1], the concept of quantum macroscopicity [2], and the Caldeira-Leggett model of quantum dissipation [3]. Notably, all these conceptual developments happened at a time when the concept of superconducting qubits was not even in people's minds.

The advent of superconducting qubits has had a very strong impact in quantum computation with the possibility to build a universal superconducting quantum computer. On top of such a remarkable technological boost, superconducting qubits allow at the same time the the investigation of fundamental aspects of quantum mechanics, in particular several of Tony's theories regarding coherent quantum dynamics and macroscopicity. With the accurate control of the circuit Hamiltonian, one can nowadays put together experiments and observe phenomena predicted decades ago.

In this talk, I will describe my experience with Tony Leggett during his summer stays at IQC Waterloo where I worked as a postdoc. In particular, I will explain how his insightful views helped me put together an experiment that investigated the spin-boson model in a superconducting circuit to a regime of ultrastrong dissipation that had not been explored until then [4]. I will also describe an experiment that was conducted at about the same time at NICT in Japan led by Prof. W. J. Munro where the macroscopicity of a superconducting qubit was tested [5], following the well known Leggett-Garg inequalities.

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POSTER

4th International Workshop on Microwave Research and Applications

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Ecofriendly Frequency Selective Surface Absorbers design based on laser ablation and additive manufacturing techniques

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Electromagnetic absorbers are key components for Radar Cross Section reduction, and therefore the seek for new materials and heterostructures able to contribute to this field constitute a hot research topic. Recently, we demonstrated that laser-induced graphene (LIG) can be used for the development of broadband Frequency Selective Surface Absorbers (FSSAs), from Ku-band to Q-band [1]. The technique is based on the controlled ablation of a precursor polyimide (PI) layer: when an appropriate light fluence is applied, carbon atoms rearrange themselves into a graphene-like morphology, the conductivity of which can be designed in a wide range. This allowed us to precisely control the surface resistivity of LIG patches which, appropriately connected to a metallic FSS, could be used for the FSS design.

The technique proposed in Ref. [1] is leveraged in this work, in conjunction with additive manufacturing techniques, in order to demonstrate the viability of fabricating FSSAs in which: (i) the highly conductive sections; (ii) the substrate; and (iii) the resistive patches, are composed of biodegradable or compostable materials. To this end, the metallized substrates are replaced by very conductive LIG layers or, preferably, other conductive materials such as biodegradable conductive inks based on thermosensitive hydrogels [2]. This technique, together with laser ablation, can be used in order to accurately design the resistive patches. Finally, ecofriendly options are chosen for the dielectric layer of the FSSA. As an example, Fig. 1 presents a sketch of the developed designs, together with the absorption results achieved in WR-75 band.

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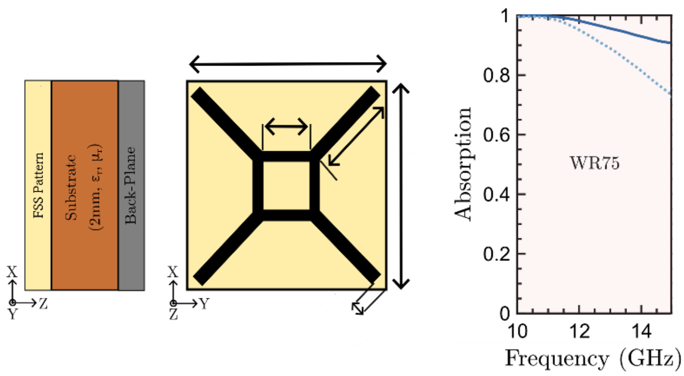

Fig. 1. FSS absorber design (left) and characterization results with WR-75 measurement setup. The dashed line shows the absorption with a PEDOT-based back-plane, while the solid line stands for a metallic one.

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4th International Workshop on Microwave Research and Applications

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Metamaterial Based Microwave Absorbers Engineered Using 3D-Printing Technology

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Microwave absorbers are of interest for both civilian and defense applications, where a reduction in the amplitude of an incident wavefront is required. Historically, these absorbing structures were loaded with aluminum flakes or carbon black to introduce the conditions required for the impinging wavefront to be absorbed. The Salisbury screen is another configuration that allows for absorption and operates by placing a resistive sheet a quarter-wavelength from a conductive plane. The bandwidth of this can be improved by cascading multiple resistive sheets to create the Jaumann absorber. One method of implementing these resistive sheets is through the use of periodic structures, such as Frequency Selective Surfaces.

With the advance of additive manufacturing technology, additional degrees of freedom such as a height profile can be taken in consideration during the design process of periodic structures, offering further improvement to the bandwidth and angular stability of microwave absorbers. It is also possible to introduce conductive particles such as Carbon Black [1] or Carbon Nano Tubes (CNTs) [2,3] to the printer filament, thus allowing for ohmic losses to occur.

This work presents an investigation into a periodic structure with a cavity-based unit cell designed for operation as an ultrabroad band microwave absorber. The structure itself consists of concentric looped walls, where the heights gradually decrease from the outermost to the innermost wall. Wall height has been selected using the quarter-wavelength principle to allow for the formation of standing waves within the structure, thus aiding overall microwave absorption. The 3D-printer filament used to manufacture the structure has been loaded with CNTs, with a comparison of the impact on the electromagnetic performance of different concentrations presented.

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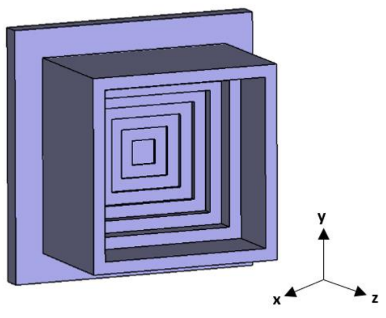

Unit Cell Considered in this Investigation

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Transparent, flexible, single layer conductive film for ultra- wide band microwave stealth surface

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The ability to effectively control and suppress microwave radiation is necessary for modern communication systems, electromagnetic compatible systems, and stealth technologies [1,2]. With the rapid expansion of wireless networks, radar platforms, and interconnected electronic devices, electromagnetic congestion in the microwave spectrum has become a growing challenge. Microwave absorbers provide an effective way to mitigate unwanted electromagnetic signals. However, conventional absorbers are multilayer metal- dielectric stacks or magnetic materials [2]. Although they can achieve strong absorption but require complex fabrication methods and are bulky in nature with limited mechanical flexibility, restricting their integration into modern lightweight and conformal electronic systems. Recent advances in metasurfaces and transparent conductive materials have opened new possibilities for controlling electromagnetic waves using ultrathin structures. Though several studies have explored indium tin oxide (ITO) based microwave absorbers and metasurfaces [3], they require multilayer designs, dielectric spacers, or metallic ground planes to achieve efficient impedance matching and absorption [3,4]. Those with flexible design operate only within relatively narrow microwave bands, limiting their applicability in broadband stealth applications [4].

Here we demonstrate a simple and effective approach for broadband microwave stealth-based absorber made by conductive ink patterning on flexible ITO coated polyethylene terephthalate (PET) substrate with perforations. Figure 1 (a) shows the schematic of a unit cell and Fig. 1 (b) shows the photograph of the metasurface. The pattern consists of a square loop made of silver ink on ITO coated side of PET. The substrate thickness is 0.127 mm, and the thickness of silver ink is 3 μm. Within each printed square loop, one rectangular perforation is made. The overall size of a unit cell is 12mm x 12mm. In this configuration, the ITO film acts as a resistive layer that dissipates microwaves, while the conductive loops of silver ink provide resonant interactions that enhance broadband absorption of microwaves. The perforations (white region in Fig. 1 (a)) also help to control the effective inductance and capacitance of the loop structure, improve the impedance matching of silver resonator structure and stronger coupling with the resistive ITO layer. Together, these effects significantly broaden the microwave absorption bandwidth. Unlike conventional multilayer absorbers, the present design employs a single layer, flexible substrate configuration, and a significantly simplified fabrication process while offering strong microwave suppression over the broad frequency range of 1 GHz to 30 GHz. Both simulation (using CST Microwave Studio software) and experimental measurements show broadband suppression of reflection (S_{11}) and transmission (S_{21}) coefficients below -10 dB across the L- Ka band (1–30 GHz) frequency range, indicating efficient absorption over an ultra- wide band as shown in Fig. 1 (c). The combination of a resistive ITO layer and a printed conductive metasurface with perforation provides a lightweight, flexible, and large- area scalable material for microwave stealth. This approach opens opportunities for integrating broadband electromagnetic suppression into conformal surfaces, flexible electronics, and next-generation stealth and communication systems. In addition, this type of patterned surface opens an opportunity for the study of dual or multi-spectral stealth applications.

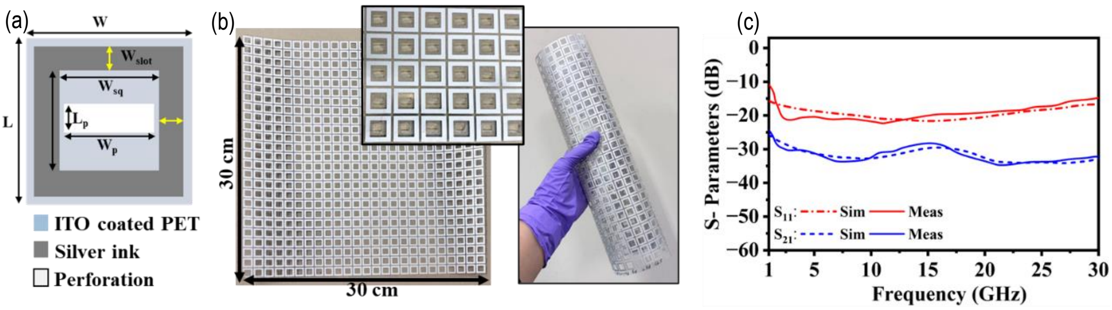

Figure 1. (a) Schematic of unit cell. (b) Photograph of the broadband microwave absorber with insets showing its zoomed view and conformal nature through folding. (c) Simulated and measured reflection coefficient (S_{11}) and transmission coefficient (S_{21}).

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Cryogenic THz Spectroscopy for Materials Studies

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Electromagnetic radiation with THz frequency presents a technologically challenging, yet important domain for materials science. Superconducting gap of BCS and unconventional superconductors, plasmons in 2D gas, soft phonons in ferroelectrics and other low-energy excitations appear in the THz range [1]. Recently, the pulse-driven time-domain THz spectroscopy has become a prominent tool for the studies of these excitations [2]. However, it´s limited spectral resolution and pulsed nature makes it unsuitable for the studies of narrow resonances as well as the application of the steady state treatment.

Here we present a layout of a simple continuous-wave, frequency-domain THz spectroscopy set-up, which is coupled to a cryostat and allows us to conduct THz spectroscopy of solid-state samples at temperatures down to 15 K.

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UAPO Diffraction Contribution by a Discontinuity between Chiral Materials

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Advanced materials play appealing roles in microwave research and applications today. In particular, artificial chiral materials with an increased chirality parameter can be used to enhance the electromagnetic coupling and to design new metamaterials [1,2]. This also motivates efforts to study the interaction of electromagnetic waves with chiral materials. The Uniform Asymptotic Physical Optics (UAPO) approach was recently applied to two-dimensional propagation scenarios [3] for evaluating the plane wave diffraction by a planar junction of uniaxial anisotropic chiral materials covering a perfect electrical conductor (PEC).

This abstract is devoted to compute the UAPO diffraction contribution due to the discontinuity of a PEC-backed junction formed by two uniaxial anisotropic chiral sheets with the same thickness *d* and surmounted by free space. The incidence direction of plane waves is assumed to be arbitrary with respect to the discontinuity and the propagation scenario is three-dimensional (see Fig. 1a). Accordingly, the diffraction problem solved in [3] can be considered as a particular case.

The Geometrical Optics (GO) field at any observation point in the upper half-space is given as superposition of the incident field and the field contribution reflected by the involved chiral layer *A* or *B*. Because chiral materials with different values of the parameters are used, diverse non-diagonal reflection matrices are assigned to *A* and *B*, and then a discontinuity characterizes the GO field at the reflection boundary (see Fig. 1b). The evaluation of such matrices requires taking into account that the incident plane wave produces two eigenwaves propagating into the chiral medium in accordance with a bouncing mechanism [3,4].

The evaluation of the UAPO diffracted field requires knowledge of the reflection matrices to determine the electric and magnetic PO surface currents to be used as equivalent sources in the scattering integral at the first stage of the methodology. Next steps include analytical evaluations, integral representations, and a final asymptotic evaluation of the resulting integral to obtain the UAPO solution for the diffracted field, which is expressed in terms of the transition function of the Uniform Geometrical Theory of Diffraction (UTD) [5] and the entries of the reflection matrices. According to numerical tests (see Fig. 1b as example), the UAPO diffracted field yields a continuous total field when added to the GO field.

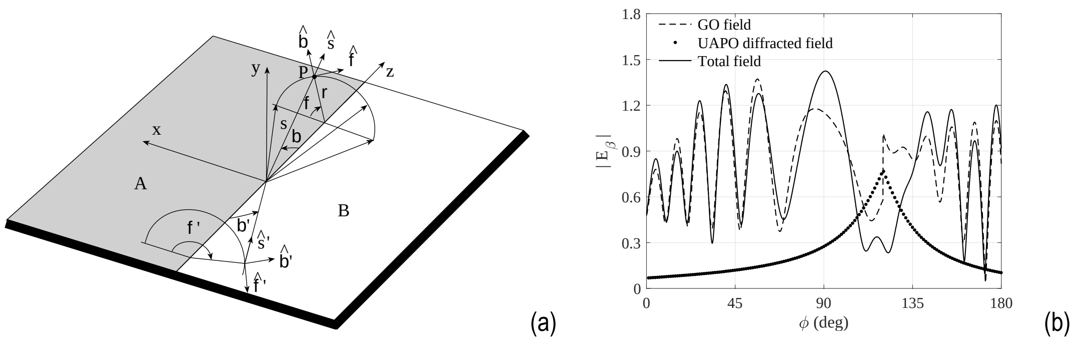

Figure 1. (a) Geometry of the problem. (b) GO field, UAPO diffraction field, and total (GO+UAPO) field when $d = 0.05\lambda$, $E^i_{b'} = 1, E^i_{f'} = 0$ and $b' = 30°, f' = 60°$.

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Absorption and shielding properties of hexaferrites and spinel ferrites determined by planar transmission lines

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In this contribution, we employed two types of transmission lines for studying material properties: grounded coplanar waveguide (CPW) and microstrip line (MSL). Using these devices loaded with a sample and connected to the vector network analyzer, we acquired complex transmission and reflection spectra (up to 50 GHz), and their dependence on temperature and/or magnetic bias field. From these spectra we then calculated microwave absorption and shielding efficiency spectra of selected samples.

The materials under test were $Sr_{4.5}CoZnFe_{36}O_{60}$ U-type hexaferrite (CoZn-U) ceramics [1,2] and $Ni_{0.5}Zn_{0.5}Fe_2O_4$ (NZF) spinel ferrite ceramics [3,4]. Spectra of both compounds include the ferromagnetic resonance and several magnons which manifest themselves as broad absorption bands, tunable by temperature or weak magnetic field. CoZn-U is even more sensitive to small temperature changes near room temperature, as one of its phase transitions takes place at 305 K.

We show in this contribution that the studied materials provide high absorption and shielding efficiency in the GHz range, and thus are suitable for applications at the 5G and 6G communication frequencies.

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Triphasic WS_2/magnetic oxide nanocomposite for electromagnetic interference shielding and microwave absorption applications

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Electromagnetic interference (EMI) shielding and microwave absorption are the two most important domains of microwave research. EMI is a cause of serious concern due to the rapid growth of wireless communication technologies. EMI can cause device failures, and data corruption. Critical equipment in aviation and health sectors are extremely vulnerable to EMI [1–4]. The adverse effects of EMI pollution on wildlife have also been highlighted by researchers [5]. The effects of EMI can be mitigated by EMI shielding materials that block stray electromagnetic waves. Materials with good reflection and absorption capabilities are suitable as EMI shields. However, reflection must be minimized for defense applications where the goal is to avoid radar detection. In this regard, microwave absorbing materials (MAMs) with high dielectric and magnetic loss factors are preferred for microwave absorption research. The most commonly studied frequency range is the X-band (8.2 – 12.4 GHz) due to its widespread applications for broadband networks, radar, satellite, and space communications. Multiphasic composites involving ferrites, and two-dimensional materials like reduced graphene oxide (r – GO), and transition metal dichalcogenides have been reported to exhibit high shielding effectiveness (~ 19.26 dB, thickness 1.4 mm) [6]. $LiFe_5O_8/MoS_2$ composites achieved excellent reflection loss minima (RL_{min}) of - 63.61 dB for a thickness of 2.18 mm [7]. The improved shielding and absorption performance of these composites have been attributed to interfacial polarization loss, high conductivity, and magnetic loss. In this work, a composite material made of biphasic lithium iron oxide (α-$LiFe_5O_8$/α-$LiFeO_2$) and WS_2 flakes has been prepared by hydrothermal method. The composites showed excellent shielding effectiveness (~ 50 – 55 dB) and reflection loss minima (RL_{min} ~ - 55 dB) within the X-band for a sample thickness of 3 mm [3]. The absorption capability was improved significantly by optimizing the weight fraction (wt.%) of the ferrite and WS_2 phases with an optimal composition of 67 wt.% α-$LiFe_5O_8$/α-$LiFeO_2$ and 33 wt.% WS_2. Transmission electron microscopy (TEM) revealed the formation of interfaces between ferrite grains and WS_2 flakes which lead to significant interfacial polarization loss resulting in higher absorption in the composites. Due to its high shielding effectiveness and excellent reflection loss values the composite is suitable for both EMI shielding and microwave absorption applications.

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Tailored Design of Composite Materials for Microwave Absorption

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This work focuses on the synthesis of magnetic functional materials embedded in a polymeric matrix for microwave absorbing purposes. These composite materials can be easily tailored modifying physical parameters such as particles charge, thickness and functional phase to exhibit microwave absorbing behavior.

Selected materials acting as the functional phase have been Fe, Fe_3O_4, $BaFe_{12-x}Cu_xO_{19}$ and $CoFe_2O_4$, all in powder form. Synthesis routes used are Coprecipitation and Sol-Gel as wet-chemical methods provide excellent control in particle size and morphology, operating at low-cost. As polymeric matrix, epoxy resin with specific additives is used. Filler materials were selected by the excellent magnetic properties, and additives were chosen to make a stable suspension with certain thixotropy. Moreover, they are designed with the particularity of being able to be sprayed into plastic sheets.

Different experimental characterization techniques are applied to the samples. Firstly, XRD analysis reveals different stoichiometries for barium ferrites were formed depending on synthesis route and purity from commercial materials and cobalt ferrite was verified. Later, PSD analysis ensure that nano-micro particles are obtained due to the impact of this to the rheological properties of final composite material. In addition, different volume filling factors (ff_v) of functional phase mixtures undergo a rheological study, where differences are observed that highly impact later during the painting process.

For electromagnetic properties characterization, measures of physical constants such as electrical permittivity and magnetic permeability are obtained for the final composite material. Clear signs of correlation between ff_v of the mixtures and their magnitudes are discovered, opening the door to produce microwave absorbing materials with specific electromagnetic properties. These results are used for a simulation of R_L coefficient showing absorption of -50 dB for a thickness of 17 mm. Also, a relation between ff_v, thickness and functional phase is revealed and studied with the aim of determining the optimal conditions for maximum absorption. Finally, far-field measurements in an anechoic chamber are employed to contrast results for the sprayed sheets. Results show confirm the theoretical calculations and revealed absorptions of -20 dB in the X-Band region implying 99% microwave absorption.