The Tera-Days Workshop *"Spectroscopy, Imaging and Innovative Technologies for THz Radiation"* is organized to enhance the collaboration and exchange of ideas between Italian researchers around different Terahertz radiation topics.

The event is coordinated by the Sapienza THz group and INFN

Workshop Chairs

Prof. Stefano Lupi
Department of Physics, Sapienza University of Rome and INFN

Prof. Massimo Petrarca
SBAI Department, Sapienza University of Rome and INFN

Workshop Secretariat

Dr. Luca Tomarchio and Dr. Salvatore Macis
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The Physics & SBAI Department of Sapienza University of Rome

Istituto Nazionale Fisica Nucleare

The workshop takes place at the Sala Lauree room in the “Marconi” building, the main structure of the Department of Physics at La Sapienza, University of Rome. The Physics Department consists of two buildings, the Marconi building and the Fermi building, and the Segrè Laboratories, located within the University City of Rome - Sapienza, p.le Aldo Moro 2, and the Bruno Pontecorvo Laboratories, located in Via Tiburtina 205.

The Department of Physics is the natural heir of the tradition of **Enrico Fermi, Ettore Majorana** and **Edoardo Amaldi** (School of Rome), and is renowned throughout the world for high quality research, international prestige and the diversity of the courses offered.

The Physics Department has been hosting an intense research activity in the major areas of Modern Physics, both as for fundamental and applied research as: Particle Physics, Matter Physics, Astrophysics and Cosmology, Theoretical Physics, Mathematical Physics and Statistics, Photonics and Quantum Information, Biophysics, Medical Physics, Atmospheric Physics, Physics and Cultural Heritage, with a number of research fields bigger than one hundred.

Workshop Keyword: Terahertz Radiation

Recent theoretical and experimental research is triggering interest to technologies based on radiation in the region from ~0.1 to 20 Terahertz (THz). Today, this region of the electromagnetic spectrum is a frontier area for research in many disciplines. The technological roadmap of the THz radiation considers outdoor and indoor communications, security, drug detection, biometrics, food quality control, agriculture, medicine, semiconductors, and air pollution, and demands high-power and sub-ps compact sources, modern detectors, and new integrated systems. There are still many open questions regarding working at THz frequencies. In particular, it is important to invest in new methodologies and in novel materials exhibiting unconventional THz properties to develop new and more performing THz emitters, detectors and beam shapers. In this workshop results related to this research will be reported with particular regard for applications in biomedicine, cultural heritage, technology. Moreover, the use of THz radiation in high-energy particle applications like new acceleration technologies of particular interest for INFN will be presented.

Program Day 1 (11/17/22)

Afternoon

14:00-14:30 **Opening**

S. Lupi, Dipartimento di Fisica e INFN, Sapienza Universita' di Roma

M. Petrarca, Dipartimento SBAI e INFN, Sapienza Universita' di Roma

A. Nisati, Direttore della Sezione di Roma Sapienza dell'INFN

L. Palumbo, INFN and Sapienza, Prorettore alla Pianificazione Strategica, Sapienza Universita' di Roma

A. Quaranta, Presidente Gruppo V, INFN e Universita' di Trento

THz Infrastructures Session

14:30-15:00 Massimo Petrarca

15:00-15:30 Vittoria Petrillo

15:30-16:00 Salvatore Macis

16:00-16:30 Mariangela Cestelli Guidi

16:30-17:00 **Coffe Break**

New THz Techniques

17:00-17:30 Annalisa D'Arco

17:30-18:00 Gianluca Galzerano

18:00-18:30 Antonello Andreone

18:30-19:00 Bruno Piccirillo

19:00-19:30 Gian Paolo Papari

20:30 **Social Dinner**

Casa dell’Aviatore, Viale dell’Universita’ 20, 00185, Rome

Program Day 2 (11/17/22)

Morning

THz Science

08:30-08:50 Lorenzo Mosesso

08:50-09:20 Salvatore Macis

09:20-09:50 Mauro Missori

09:50-10:20 Luca Tomarchio

10:20-10:50 David Marsh

10:50-11:10 **Coffee Break**

11:10-11:30 Maria Chiara Paolozzi

11:30-12:00 Sara Cibella

12:00-12:30 Laura Pilozzi

12:30-13:00 Round Table and Conclusion

Abstracts

THz spectroscopic image system for basic and applied sciences

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[1] “Sapienza” University of Rome, SBAI Department ‘Rome, Italy
[2]INFN – Section of Rome ‘Sapienza’, Rome, Italy

The terahertz spectrum (0.1-10 THz) is a rich source of material information and its important characteristics are: unique spectral absorption that allows high resolution spectroscopy at these frequencies to be a powerful analytical tool for investigating the structure and the energy levels of molecules and atoms; moreover terahertz is non-ionizing thus it is considered harmless, and it has the ability to propagate through many types of dielectric materials whereas it is strongly absorbed by polar molecules and reflected by metals.

For all those reasons, this radiation is of great interest for many different research areas as biology, medicine, physics, nondestructive evaluation technology, pharmaceutical industry, defense, environmental monitoring where in the last years it has been used in many applications as spectroscopy, imaging and tomography.

In my talk I will give and overview of the “SapienzaTerahertz” facility that has been funded by the “Sapienza” University of Rome to carry on the THz R&D activity; the facility is open to external users; it is located at the SBAI department and it is managed in great collaboration between the SBAI and the Physics departments.

The facility host THz Quantum Cascade Laser sources (QCL) and room-temperature microbolometers camera that represents the state-of-the art of THz high power (mW levels) and high sensitivity (pW/√Hz) detectors allowing for fast spectral-imaging at these frequencies. The laser hosts 4 QCL modules; 3 of them emit extremely narrowband (MHz) radiation centered respectively at 2.2, 3 and 4.4 THz and slightly tunable while the last module emits several peaks simultaneously over a broad spectral range of (1.8-5) THz.

The optical set-up allows for simultaneous transmission and reflection measurements also in a raster-scan type methodology. Moreover, in the same laboratory it is also available a CW high resolution THz coherent spectrometer based on photo antennas technology and operating in the range (0.05-3) THz.

Acknowledgements: This facility was funded by Sapienza competitive grants “Grandi Attrezzature di Ateneo” and “Progetti di Ricerca Grandi di Ateneo”. We acknowledge also the support: Ph. D. funding in the framework of "Programma Operativo Nazionale (PON) - Ricerca e Innovazione 2014-2020 - Azione IV.5 - Dottorati su tematiche green – FSE REACT-EU.

High brilliance Free-Electron Laser Oscillator operating at multi-MegaHertz repetition rate in the short-TeraHertz emission range

V. Petrillo, A. Andreone, A. Bacci, A. Bosotti, F. Broggi, I. Drebot, G. Galzerano, D. Giannotti, D.Giove, C. Koral, L. Monaco, M. Opromolla, R. Paparella, B. Piccirillo, M. Rossetti Conti, A.R. Rossi, M. Ruijter, P. Russo, S. Samsam, L. Serafini, and D. Sertore

We present the design study of an innovative scheme to generate high repetition rate (multi-MHz-class) THz radiation pulses by using an Energy Recovered Super Conducting Linac operating in Continuous Wave mode driving a Free-Electron Laser Oscillator. The FEL performance is illustrated for one and two color operation. Start-to-end simulations are presented to assess the capability of this scheme for typical values of wavelengths of interest in the 10-50 um (6-30 THz) range.

High electric field damages from THz radiation: a new technique to test surfaces of RF cavities

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A. D’ Elia - *INFN, Laboratori Nazionali di Frascati, Via Enrico Fermi 40, 00044, Frascati (Rome), Italy* and *Rome International Centre for Materials Science Superstripes, Via dei Sabelli 119A, 00185 Rome, Italy*
M. Petrarca, Department of Physics, Università Sapienza, Piazzale Aldo Moro 5, 00185 Rome, Italy and INFN – Section of Rome ‘Sapienza’, Rome, Italy
S. Lupi, - *Department of Physics, Università Sapienza, Piazzale Aldo Moro 5, 00185 Rome, Italy* and INFN – Section of Rome ‘Sapienza’, Rome, Italy
A. Irizawa - *The Institute of Scientific and Industrial Research (ISIR), Osaka University, 8-1 Mihogaoaka, Ibaraki, Osaka 5670047, Japan*
A. Marcelli - *INFN, Laboratori Nazionali di Frascati, Via Enrico Fermi 40, 00044, Frascati (Rome), Italy* and *Rome International Centre for Materials Science Superstripes, Via dei Sabelli 119A, 00185 Rome, Italy*

High intensity THz pulsed radiation was used to investigate the angular dependence of the damage induced on low roughness copper substrates and thin films deposed on copper. Using the THz Free Electron Laser of at ISIR facility of the Osaka University [1], we irradiated in air these samples surfaces with an energy density of ~100 GW/cm^2, inducing a reproducible electric field gradient of ~4 GV/m. At this intensity breakdown phenomena are clearly visible on the irradiated surfaces.
In the case of copper, since at these wavelengths the reflectivity is ~99 % the irradiation at normal incidence does not induce any damage and no signature of discharge is detectable on the surface. Decreasing the angle of incidence a clear deformation of the copper surface occurs with a central area of ~200 μm diameter, surrounded by a visible corona associated to a strong heating. In the central region small tips made by copper oxides induced by multiple breakdowns can be recognized by Raman microscopy [2]. We also tested thin films deposed on copper to probe the hardness and to attempt to reduce the damage induced by breakdowns. In this contribution we will present the results of thin MoO_3 coatings on copper. This natural van der Walls material, is characterized by a high work function (6.7 eV) and, with its higher mechanical resistance compared to copper, it is an optimal candidate to reduce the damage of the copper surface [2,3].
We will present the results of MoO_3 thin films deposed by thermal evaporation on copper substrates and exposed in air to the FEL THz pulsed radiation at different incidence angles. In spite of the low thickness (~100-200 nm) these coatings significantly reduce the damage of the copper surface. Films survive to this extremely high electric field, no tips are formed on the central irradiated region and no copper oxidation is also detected by Raman microscopy.

References

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2. S. Macis, J. Rezvani, I. Davoli, G. Cibin, B. Spataro, J. Scifo, L. Faillace, A. Marcelli Structural Evolution of MoO3 Thin Films Deposited on Copper Substrates upon Annealing: An X-ray Absorption Spectroscopy Study, Condens. Matter 2019, 4, 41 (2019).
3. S. Macis, C. Aramo, C. Bonavolontà, G. Cibin, A. D’Elia, I. Davoli, M. De Lucia, M. Lucci, S. Lupi, M. Miliucci, A. Notargiacomo, C. Ottaviani, C. Quaresima, M. Scarselli, J. Scifo, M. Valentino, P. De Padova, and A. Marcelli, MoO_3 films grown on polycrystalline Cu: Morphological, structural, and electronic properties, Journal of Vacuum Science & Technology A 37(2), 021513 (2019).

The LNF IR-THz beamline @Dafne: case studies and perspectives

M. Cestelli Guidi
INFN-LNF

The INFN-LNF DaΦne storage ring is a powerful source of Synchrotron Radiation in the THz domain. The brilliance of SR in this region is up to three orders of magnitude, and the flux increases with the electron current stored, opening the possibility to perform experiment in the solid, liquid and gas phase with application from material science to biology and chemistry. Case studies of experiments that are currently performed at Sinbad are presented.

Portable advanced Terahertz continuous wave spectroscopy for atmospheric gas sensing

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Volatile organic compounds (VOCs), produced by natural and/or anthropogenic activities, are considered indoor and outdoor contaminants of the air. Due to the high volatility and toxicity, their detection is a topical issue for the air-quality monitoring. Various conventional and innovative methodological approaches are proposed, including optical techniques based on Terahertz (THz) radiation. Motivated by the increasing demand to monitor the air-quality, our study proved the feasibility of a new compact and portable experimental approach based on THz continuous wave high resolution spectroscopy, to detect the presence of the air’s contaminants as VOCs. In this specific work, we first characterized, determining their molar absorption coefficient in the spectral region (0.06-1.2) THz, the pure optical response of the vapor of five VOCs: methanol, ethanol, isopropanol, 1-butanol and 2-butanol. In particular, 1-butanol and 2-butanol are characterized, under controlled conditions of temperature and pressure, for the first time in literature at THz frequencies [1]. In addition, we studied the optical behavior of various mixtures of two VOC components: including 1-butanol/ethanol and 2-butanol/air by increasing progressively the air content. The results show that it is possible to distinguish single components by describing their spectral absorption in terms of the linear combination of pure compounds absorption [1]. To our knowledge, this is the first high resolution characterization for BuOH-1, BuOH-2 and the mentioned mixtures in this THz spectral region. The results of this study prove that this methodology is capable of gas sensing in a fashionable and compact set-up which can be carried on for in-situ atmospheric measurements.

Acknowledgements: This research was supported by the Ph. D. funding in the framework of "Programma Operativo Nazionale (PON) - Ricerca e Innovazione 2014-2020 - Azione IV.5 - Dottorati su tematiche green – FSE REACT-EU and by "Sapienza" University of Rome grant. This research was carried out also in the framework of the BRIC-INAIL project ID12. This work was also supported by the NATO Science for

Peace and Security Programme under grant No. G5889 – "SARS-CoV-2 Multi-Messenger Monitoring for Occupational Health & Safety-SARS 3M" and by LazioInnova "Gruppi di Ricerca 2020" of the POR FESR 2014/2020 - A0375-2020-36651 project titled "DEUPAS - DEterminazione Ultrasensibile di agenti PAtogeni mediante Spettroscopia".

Reference

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Versatile OSCAT time-domain THz spectrometer

L. M. Molteni[1], J. Manzolli[2], F. Pirzio[3], A. Agnesi[3], G. Piccinno[4], P. Laporta[1,2], and G. Galzerano[1,5]

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Time-domain spectroscopy (TDS) in the terahertz (THz) region is becoming a fundamental and useful tool in a large variety of applications in the fields of nondestructive testing, imaging and microscopy, security, material science, biomedicine, analytical and molecular spectroscopy, and communications. Conventional THz-TDS systems use a femtosecond laser and electro-optical or photo-conductive sampling to reconstruct the THz electromagnetic field using mechanical delay line for tuning the time delay between the received THz pulse and the sampling optical pulse [1]. Here, we present a versatile implementation of a THz-TDS based on a low-energy laser source emitting 70-fs pulse-train at 1 μm with tunable pulse repetition frequency (more than 1% of its average value) and photo-conductive antennas (PCAs). Fast delay-time tuning covering more than 100 ps with a rate of 10 scan/s is achieved by using the optical sampling by cavity tuning (OSCAT) method [2]. The OSCAT method relies on the use of a fixed delay line to combine pulse pair on the receiver PCA with different order (many pulse repetition periods) and change their temporal superposition by acting on the laser pulse repetitionfrequency. The spectrometer, see Fig. 1, also allows the effective implementation of the delay time modulation (DTM) technique to retrieve the first time derivative of the THz pulse, which turns out to be extremely interesting for sensing methods related to the phase variations of the THzfield. The complete characterization of the developed THz-TDS will be presented together with the comparison of the OSCAT and DTM methods with respect tothe classical implementation of THz TDS. In addition, the fast scanning performance, single scan OSCAT measurements in 80 ms acquisition time and signal-to-noise ratio (SNR) of 56 (35 dB) for 1 ms lock-in integration time, will be also reported together with the measurements of the refractive index and absorption coefficient of a GaAs plate, water vapor, and glucose sample.

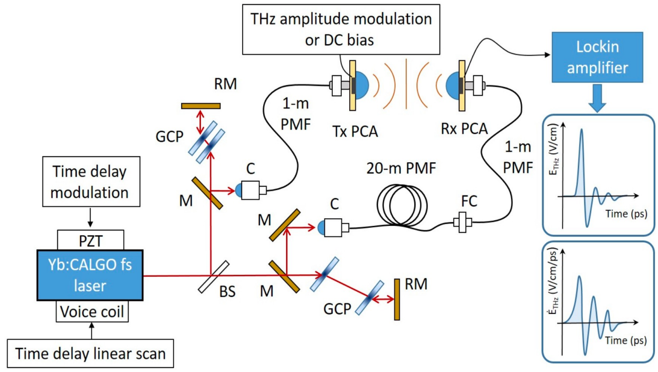

Fig. 1. Experimental layout of the THz TDS. BS: beam splitter; C: fiber collimator; FC: fiber connector; GCP: grating compressor pair; M: mirror; PCA: photoconductive antenna; PMF: polarisation maintaining fiber; PZT: piezoelectric; RM: roof mirror.

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THz Time Domain Ellipsometry

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Ellipsometry is extensively used in the optical regime to investigate the properties of many materials as well as to evaluate with high precision the surface roughness and thickness of thin films and multilayered systems. Due to the inherent *non-coherent* detection technique, data analyses in optical ellipsometry tend to be complicated and require the use of a predetermined model, therefore indirectly linking the sample properties to the measured ellipsometric parameters. Time-domain techniques recently developed in the THz region make possible instead ellipsometry based on a *coherent* detection approach that provides in a simple and direct way the measurement of the material response. By measuring the beam temporal profile impinging on the sample surface and using fast Fourier transform (FFT), both amplitude and phase of the signal are independently acquired, and from here the ellipsometric parameters can be simply measured as a function of frequency. Expanding the ellipsometry operational frequency window to smaller energies enables to explore new complex phenomena and to fully characterize active and passive polarization sensitive devices such as metasurfaces. Additionally, THz time domain ellipsometry (THz-TDSE) might successfully operate as a characterization technique for the study of challenging materials such as polar fluids or highly conducting thin films and multilayers grown on a dielectric substrate [1]. We present here the THz-TDSE apparatus developed at the Department of Physics of the University of Naples “Federico II” and INFN Naples and operating in the range 0.1– 0.6 THz. Figure 1 shows a pictorial sketch (a) and a picture (b) of the setup. After explaining the main optical components, we briefly introduce the necessary steps for accurate calibration, by using a fast and effective algorithm-assisted compensation technique [2]. At the end, to validate the technique, we report experimental measurements of the complex dielectric constant of a liquid binary solution based on water and isopropyl alcohol with different volume concentrations. The setup is capable to detect small changes in the optical response of the mixture within a single measurement. Results nicely agree with an effective Debye model, from which the relaxation parameters associated with different activation energies can be consistently extracted [3].

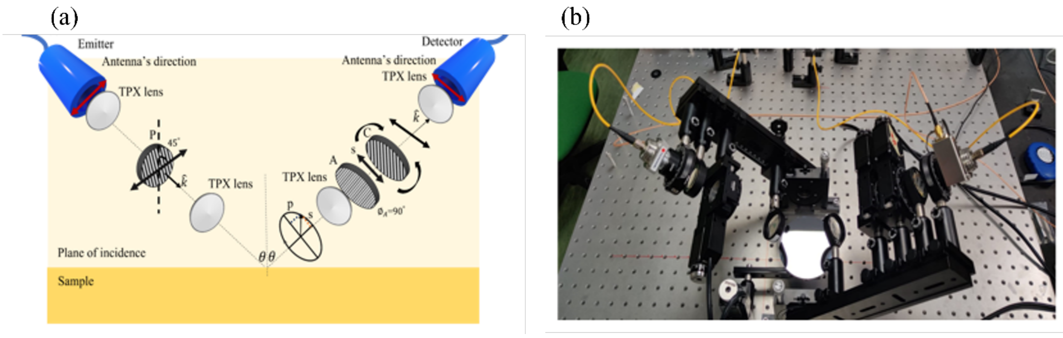

Figure 1: (a) Sketch and (b) picture of the fiber-coupled THz optomechanical system for ellipsometric measurements.

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Sculpting polarization and wavefront of Terahertz radiation with Liquid-Crystals based Electrooptical devices based on Geometric Phase

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In 1984, almost 30 years after Pancharatnam [1] first noticed a geometric phase in light polarization, Berry [2,3] discovered that quantum systems acquire not only a dynamic phase due to time evolution but also a geometric phase dependent on the path taken in their parameter space. This geometric phase, known also as the Pancharatnam-Berry phase, depends only on the parameter space’s geometry. Geometric phases have undergone extensive generalizations, led to many applications [4-6], and become a unifying concept in physics. Geometric phases of light appear in many scenarios, such as polarization [1] and changes in the propagation direction. More specifically, in the last decade, Geometric Phase has proved to be a powerful mechanism to efficiently reshape electromagnetic radiation wavefronts mainly in the optical domain [5,6] (Fig. 1). Some efforts have been recently made to extend geometric phase applications to the terahertz domain [8]. However, there is still a great deal more to do along the way. We present here recent achievements and future perspectives in this field, based on the extension to the terahertz domain of the electrically tunable liquid-crystal devices successfully operating in the optical domain. Results corroborate the expectation that this technology could be profitably exploited to greatly enhance the yet developing toolbox required for handling terahertz radiation.

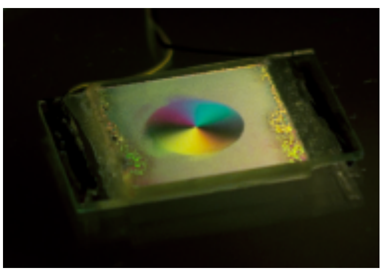

Fig. 1 – A liquid-crystal retardation waveplate with topological charge q=1/2 observed with visible *white* light between crossed-polarizers.

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Laser ablated metasurfaces

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In the last decade the number of applications of metasurfaces (MSs) thrived, thanks to the compactness, versatility, and the relative low cost that this technology offers. MSs are designed to work on specific spectral bands and to manipulate the electromagnetic field, with the possibility to work also in a harsh environment like accelerating structures [1]. Nevertheless, the standard lithographic patterning is a time consuming and expensive technique when number and size of samples increase. We report here on the characterization of MSs operating in the THz band and directly patterned using an Au film, 200 nm thick, deposited over a Si substrate. Samples are fabricated employing a laser ablation process that uses structured light produced via q-plates [2]. Transmission measurements have been carried out employing time domain spectroscopy and results are furtherly validated through full-wave simulations. The experimental results, recorded on a consistent variety of meta-atoms, prove the high-quality of resonances ($Q{\sim}100$) whereas the support of simulations show the relevant extension of evanescent field of (spoof) surface plasmons which can be as high as hundreds of μm. The latter property makes the THz MS an ideal candidate for surface sensing or near field imaging. In Fig.1 two samples ((a), (d)) are shown [3] along with the corresponding transmission data (black open circles) and full-wave simulations (red continuous lines) in the frequency band 0.3 – 1.3 THz, in uncoupled (with respect to the impinging electric field) or coupled configuration ((b), (e) and (c), (f) respectively).

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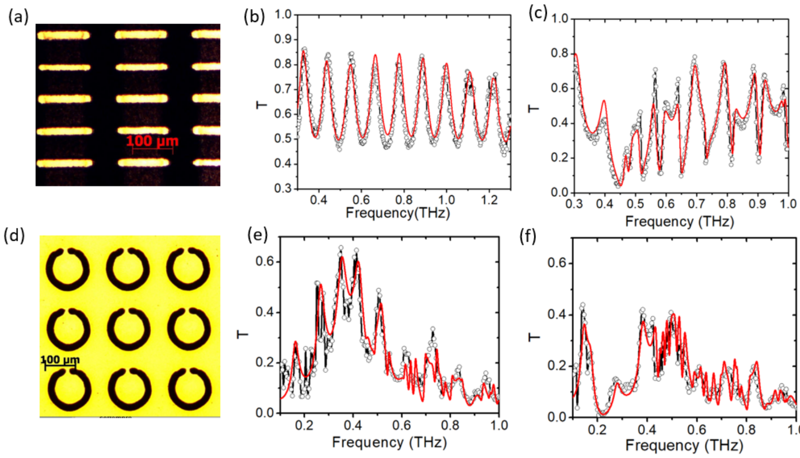

Figure 1: In (a) [(d)] the optical image of a laser ablated metasurface without [with] the use of a q-plate. In panels (b), (e) and (c), (f) the corresponding transmission data in uncoupled and coupled mode respectively are shown. Black circles represent the experimental results, red curves the full-wave simulations.

Electrodynamics in Topological Magnetic Kagome Metal FeSn Thin Films

L. Mosesso, L. Tomarchio, and S. Lupi
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The theoretical and experimental investigation of kagome networks is highly desirable due to the emergent electronic excitations hosted by their special geometry, where the interplay of lattice symmetry, spin–orbit coupling, and unusual magnetism sets an ideal stage for novel topological phases. At variance with the s or p orbital-based topological systems, this complex picture can be granted by the use of binary and ternary intermetallic compounds to populate with low-energy 3d electrons the kagome networks, providing a platform to study the interplay of electronic topology and strong correlations. Exotic features in the band structures of these materials can be found in the coexistence of Dirac cones and flat bands near the Fermi level.
Semimetals that order in a kagome geometry have been found in Fe-based compounds such as Fe_3Sn or Fe_3Sn_2. Differently from these, having one kagome layer per unit cell, FeSn is a kagome semimetal closer to the 2D limit owing to the large separation between the neighboring kagome layers. FeSn is also a planar antiferromagnet with a Néel temperature of 365 K. It crystallizes in the CoSn-type hexagonal structure, where single Fe_3Sn layers are separated by layers of Sn (stanene). Due to the spatial decoupling of the Fe kagome layers, the magnetic order becomes complicated, exhibiting ferromagnetic order within each layer, with a magnetization parallel to the kagome plane. The layers are then exposed to an AFM coupling along the stacking direction. The presence of Dirac bands in FeSn has been proved by ARPES spectroscopy in single crystals. Moreover, AFM FeSn has not only 3D massless Dirac fermions in the bulk but also topologically protected surface states on the (100) surface.
These features on the electronic states include FeSn in the more general family of Dirac and Weyl Semimetals (DSMs and WSMs), which nowadays appear to be among the ideal candidates for the development of THz technologies. Due to their unusual EM properties, intrinsically related to the presence of non-trivial topology, these materials can be engineered as robust opto-electronic devices capable of manipulating, generating, and detecting THz radiation. In particular, DSMs/WSMs show substantial advantages for THz photonics if compared with mainstream narrow-gap semiconductors, graphene and Tis. These advantages includes: good response to THz radiation, broadband photon absorption and emission involving bulk states, topologically protected high carrier mobilitiy and non linear properties that are responsible for high efficiency THz conversion.
We present a systematic study of both the temperature and frequency dependence of the optical response in FeSn thin films in a wide frequency range from THz ($\sim 1\,THz \sim 33\,cm^{-1} \sim 4\,meV$) to Visible-Ultraviolet ($\sim 25000\,cm^{-1} \sim 3\,eV$). Our results reveal that the optical conductivity of FeSn features two Drude responses that can be linked to both linear and parabolic dispersive states, with a dominance of the former to the DC conductivity at low temperatures. The weight of the Drude response shifts

toward lower frequencies upon cooling due to a rapid increase in the Dirac electrons mobility, which we associate to a photon-drag effect.

The Sabina Terahertz/Infrared beamline at SPARC-Lab facility

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Following the EU Terahertz (THz) Road Map [1], high-intensity, ps-long, THz)/Infrared (IR) radiation is going to become a fundamental spectroscopy tool for probing and control low-energy quantum systems ranging from graphene, and Topological Insulators, to novel superconductors [2,3]. In the framework of the SABINA project a novel THz/IR beamline based on an APPLE-X undulator emission will be developed at the SPARC-Lab facility at LNF-INFN. Light will be propagated from the SPARC-Lab to a new user lab facility nearly 20 m far away. This beamline will cover a broad spectral region from 3 THz to 30 THz, showing ps- pulses and energy of tens of μJ with variable polarization from linear to circular. The corresponding electric fields up to 10 MV/cm, are able to induce non-linear phenomena in many quantum systems. The beamline, open to user experiments, will be equipped with a 5 T magnetic cryostat, and will be synchronized with a fs laser for THz/IR pump, VIS/UV probe experiments.

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Low frequency dynamics of solid saccharides using THz time-domain spectroscopy and ab-initio simulations

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Terahertz time-domain spectroscopy (THz-TDS) is a powerful tool for probing collective vibrational modes of biomolecules [1]. In this study, we used THz-TDS [2] to investigate the low-energy vibrational modes of a group of organic molecules belonging to saccharides in their solid state. THz-TDS measurements were performed at room temperature on pellets made by saccharides and polyethylene. A careful preparation and characterization of pellets and the removal of the residual Fabry-Perot oscillations in the measured spectra allowed obtaining the absorption coefficient in cm^{-1} and the refractive index of the studied compounds [3]. Differences in the low-energy vibrational modes were explained in term of molecular structure, H-bonding network schemes and presence of water in the crystallographic structure.
Ab-initio simulations based on density functional theory (DFT) were carried out by employing a method for the calculation of the weak intermolecular forces driving the collective motion of organic molecules [4]. Simulation results provided the vibrational modes frequencies in the harmonic oscillator approximation and their infrared activity (IR A) in $(D/A)^2$/amu. The agreement between experimental and theoretical THz peaks was reasonable and the mode assignment was performed on the basis of frequency and IR activity. Modes analysis [5] showed that the low-energy vibrations of the studied compounds are mainly due to intermolecular libration and intramolecular vibrations, with a small percentage of intermolecular traslations of molecular units in the crystal phase

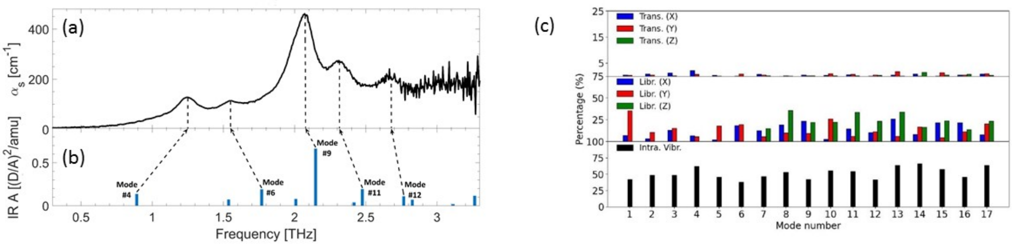

Figure. Experimental THz absorption spectrum of cellobiose (a), where α_s is the absorption coefficient in cm^{-1}. Calculated peak frequencies and their IR A (b); mode number is reported for each calculated peak. Percentage contributions of intermolecular translations and librations, and intramolecular vibrations for each mode (c).

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THz and Optical Spectroscopy of Co_2MnGa Topological semimetal

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Topological materials occupy an important place in the quantum materials family due to the interplay between their bulk and surface states. Depending on their symmetries and band structure near the Fermi level, these materials can be classified into Topological insulators, and Dirac, Weyl, or nodal line semimetals. The Berry curvature due to their peculiar topology leads to anomalous effects in the electronic transport, such as the chiral anomaly, the anomalous Hall effect (HAE), the Nernst effect, and linear and non-linear magneto-optical responses. The study of these materials in the thin-film limit is recently being addressed due to the need of characterizing the interplay between the bulk and surface states, while also covering the demand for their exotic properties to produce novel electro-optical devices. In this context, optical linear and nonlinear THz spectroscopy are key tools for the characterization of the topological features of these semimetals. In this talk, I will give an overview of the topological materials playground and discuss recent experimental results for the spectroscopic study of a novel topological nodal line semimetal, Co_2MnGa, grown as thin films of different thicknesses on a MgO substrate. I will briefly show how the spectroscopic characterization permits highlighting the modifications attained by the electronic band structure at various thicknesses, to then focus on the nonlinear THz response of the films. THz emission results, linking to the topological features of the band structure, will be presented along while pump-probe responses, with the latter highlighting a strong polaronic formation after strong optical illumination.

Detecting Axion Dark Matter with Novel Materials

David J. E. Marsh – *King’s College London*

Axions are a class of dark matter candidate, which, due to the very small particle mass, display macroscopic wavelike behaviour. The frequency of the waves is unknown, but for canonical models spans roughly from kHz to THz. Axions interact with ordinary matter very weakly, via parity violating couplings to electrons, nucleons, or directly to the electromagnetic field. One can detect axions if they resonantly excite ordinary matter. I will briefly review the theory of axions, and describe various possible detection methods currently in use, including microwave cavities, ferromagnetic resonance, and NMR. I will then focus on a new proposal for detection via axion dark matter interaction with "axion quasiparticles", a hypothetical THz antiferromagnetic excitation of certain topological insulators. The detection principle I describe can also be applied to phonon-polaritons and plasmons.

Terahertz Resonators based on $Y_1Ba_2Cu_3O_7$ High-Tc Superconductor

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Metamaterials are artificial engineered systems exhibiting a geometrically scalable electric and/or magnetic resonant response in a broad spectral range, extending from microwave to visible frequencies. Indeed, thanks to specific patterning, the optical response of these systems can be engineered at will with respect to the one of the original material, paving the way to innovative and exotic phenomena. The most widely-spread metamaterials are composed of subunits spatially repeated inside the material with a given periodicity, as it is the case for the metamaterial presented in this talk.

In this talk I describe the optical properties of superconducting split ring resonator arrays working in the Terahertz (THz) spectral range, showing that their optical response (transmittance) exhibits tunable artificial plasmonic resonances. More in detail, these arrays allow to overcome two main limitations affecting metallic metamaterials resonating in the Terahertz (THz) range: Ohmic losses and tunability of their optical response. Two arrays are experimentally characterized: direct and complementary, to assess the validity of Babinet’s principle. The main purpose of this talk is to show how the metamaterial resonances can be tuned by temperature (T) when crossing the superconducting transition temperature Tc of YBCO. The tuning property can be quantified by describing the THz transmittance of the patterned YBCO films vs. T through a model of coupled resonators. This model allows to estimate the THz resonances of split-ring arrays and their interaction, showing how the kinetic inductance L_k in the superconducting state is the main parameter affecting the metamaterial properties.

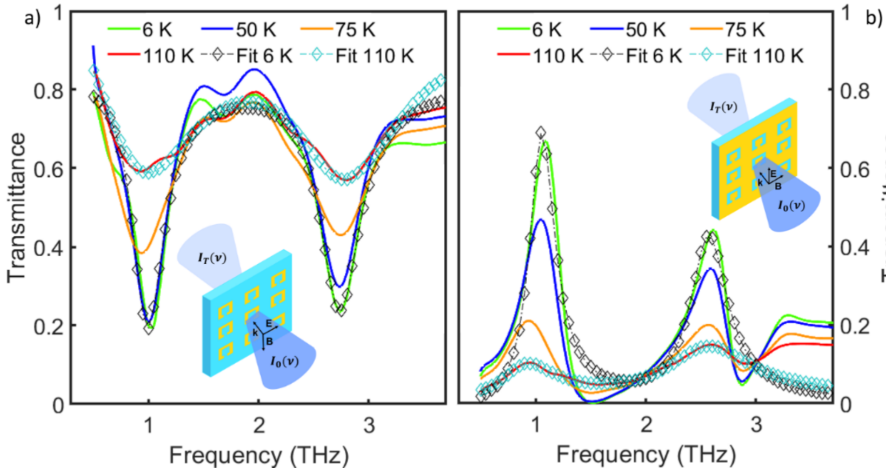

*Fig. Experimental transmittance spectra for direct (**a**) and complementary (**b**) SRR arrays at different temperatures. In both cases, the fitting curves (empty symbols) at 6 K and 110 K are reported, too. The insets show a sketch of the optical measurement configuration for direct (**a**) and complementary (**b**) SRR arrays with the corresponding electric field polarization: perpendicular with respect to the SRR gap (**a**), and parallel with respect to the complementary SRR gap (**b**). Yellow areas indicate YBCO, and light-blue areas indicate Al_2O_3substrate. $I_0(\nu)$ indicates the incoming radiation, whereas $I_T(\nu)$ indicates the transmitted one.*

THz optical beatnote detection with a fast Hot Electron Bolometer operating up to 31 GHz

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In the THz frequency range, fast detectors are receiving increasing attention, boosted by revived interestin several applications ranging from the field of the ultrafast THz physics [1] to the new studies in the frequency comb technology [2]. In this scenario ultrafast THz receivers are strongly recommended and to date superconducting hot electron bolometers (HEBs) are considered an excellent solution thanks to theirextreme sensitivity and fast response beyond tens of GHz [3]. Moreover, the nanostructured NbN thin- film technology is a high versatile technology allowing the detection of light from THz to visible wavelengths [4].We studied the performance of hot-electron bolometers (HEBs) operating at THz optical frequencies based on superconducting niobium nitride films. We report on large optical bandwidth measurement of the voltage response of the detector carried out with different THz sources. We show that the impulse response of the fully packaged HEB at 7.5 K has a 3 dB cut-off around 2 GHz, but a considerable detectioncapability is also observed above 30 GHz recorded in mixing mode operation by using a THz frequency comb quantum cascade laser. Besides, the HEB sensitivity has been evaluated and a noise equivalent power NEP= 0.8 pW/√Hz has been measured at 1 MHz. We will show that the response of our detector, in terms of bandwidth, responsivity and IV curves, can be described with the two temperatures (2T) model. The HEB optimized in this configuration had concrete impacts in many technological applications [5].

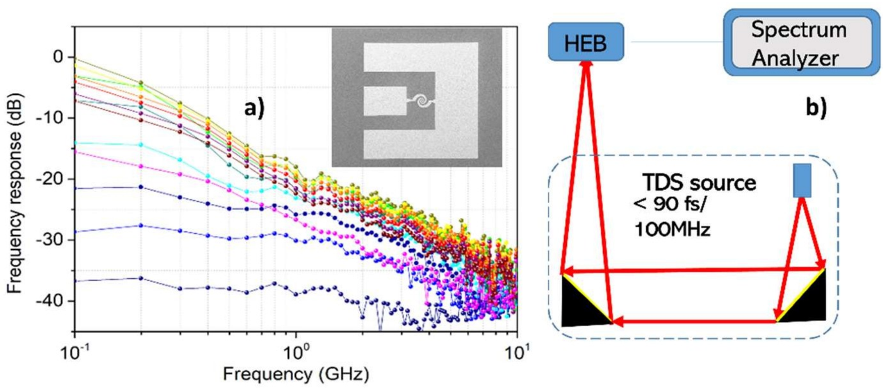

Figure 1: a) Frequency response of the mode locked telecom fiber laser at T=7.50 K . Inset micrograph of the fabricated device.b) The experimental setup used for measuring the impulse response of the HEB using ps THz pulses.

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BIC mechanism of light localization in THz 3D printed photonic structures

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Bound states in the continuum (BIC) are light states that remain localized despite their energy resides in the continuous radiation spectrum of propagating modes [1,2]. BIC have been the subject of recent intensive research in both fundamental physics and practical applications [3,4], since they enable strong confinement of light, which results in high-quality factor resonances.

In our work, we experimentally and theoretically investigate the transition regime from Fano resonances to bound states in the continuum at THz frequencies of a one-dimensional photonic slab. By looking into the nature of such modes we manage to design and realize, by a 3D printing technique, gratings made of polimeric material possessing high-quality factor resonances in view of their use as a tool to achieve light localization with topological protection [5].

The structures under consideration are free-standing photonic slabs composed of dielectric rods made of acrylonitrile styrene acrylate, realized by the low-cost, rapid, and versatile fused deposition modeling 3D-printing technique [6]. They are characterized by a filling factor $f_f=L_x/d_x$, given by the ratio between the width of the rods L_x and the grating pitch d_x that can be used to tune the coupling strengths of the photonic resonances and engineer their quality factors (Q).

Using THz time-domain spectroscopy transmission measurements [6], which show vanishing features, we demonstrate that strong mode coupling results in resonances related to BIC.

We investigate their dependence on the grating filling factor and show how two interacting resonances in periodic arrays may produce a scattering resonance with vanishing width.

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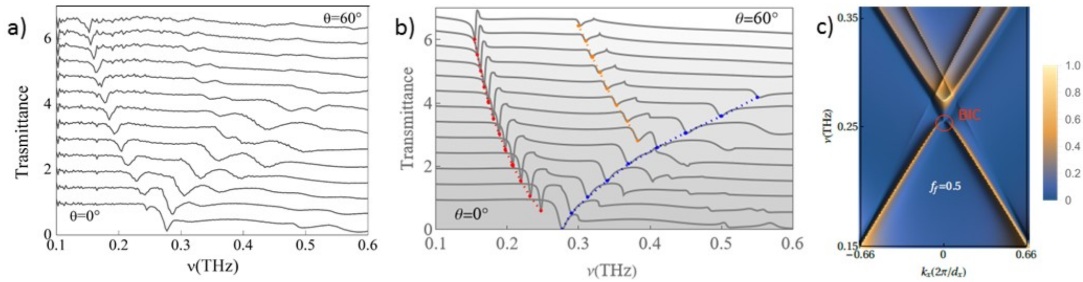

Figure. Experimental (a) and theoretical (b) transmittance as a function of the incident angle for a rods array with f_f =0.5. Reflectance map as a function of frequency (ν) and k_x of a rods array with f_f =0.5.