TERA (TeraHertz Era) Activity Report

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1 Summary

Terahertz radiation (1 THz=33 cm-1=4 meV=300um=48K=1ps) represents a cutting-edge scientific and technological tool in various fields of physics of interest to INFN. These range from new particle acceleration techniques (from acceleration to particle beam diagnostics), to medical physics, to dark matter detectors, to opto-electronic devices for manipulating radiation properties -phase, amplitude, polarization- , to innovative materials.

The TERA (Terahertz ERA) project is based on the development of a THz laser radiation source with unique characteristics: high intensity (associated electric field 10-50 MV / cm; short duration 50 fs, high rep rate 1 KHz, polarization modular, beam-shaping), and which is currently installed in a dedicated laboratory at the Sapienza Physics Department in Rome. Various researches are developing around this source (acceleration techniques, detectors, innovative materials, devices to control the properties of THz radiation), in synergy with the sections participating in the project: LNF, Turin, Naples. Other research bodies such as Sapienza University, CNR and IIT are participating in this initiative.

2 Activity

The Frascati National Laboratories are involved in the project with two activities:

2.1 WP2: Study of the dynamics of an electron beam in THz accelerating structures for the optimization of acceleration processes from single-stage to multistage linac and start-to-end simulations to demonstrate the feasibility of accelerating electron beams of high brilliance to drive a free electron laser (FEL) (Resp. E. Chiadroni);

The milestone foreseen for the first semester, i.e. Start-to-end simulation from the electron source up to the exit of the THz-based structure with optimized 6D phase space and THz waveguide study, has been completed, assuming a high charge relativistic electron beam (100 pC) coming from a SPARC-like high brightness electron linac in velocity bunching configuration. The THz-driven structure has been placed at about 12 m from the cathode. The beam gains 14 MeV in 10 cm, corresponding to an accelerating gradient of 142 MV/m; the beam quality is preserved, with an energy spread of 0.6pc and a normalized emittance below 1 mm mrad (Fig.1).

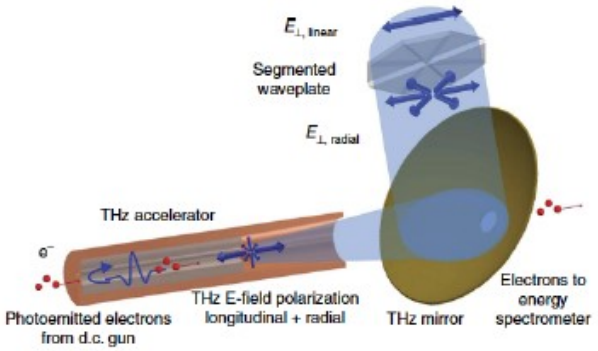

Figura 1: *Scheme of a THz linear accelerator (from Nanni et al., Nat. Comms. 6, 8486 (2015)).*

2.2 WP3: Development of two-dimensional detectors with superconducting, passive and tunable metamaterials and their spectroscopic characterization in intensity, polarization and electric field. Development of superconducting detectors and spectroscopic characterization in intensity, polarization and electric field (Resp. A Marcelli).

In the framework of WP3 the following activities were performed in 2019:

1. The apparatus was modified to facilitate insertion of the radiofrequency source simple dipole.
2. The 80x80 micron device was tested exposed to the RF radiation in the range of 7-10 GHz and the radiation power of 0-45 dbm for which a 1x10-6 is received by sample.
3. Another sample holder was manufactured to house the 2x2 mm junction arrays. Three large area samples were fabricated (in the framework of collaboration with INRiM) using colloidal lithography with the Nb islands of dimensions of 200 nm over a 30 nm layer gold film.
4. The tests were performed on two of the large area sample at 4.2 K while the it was observed that that due to slight disorders, present in the sample due to the large area, it is was not possible to reach the fully coherent state. Accordingly samples with higher precisions of the islands order should be fabricated.
5. The large area samples with higher precision in the island distance orders are in preparation within the collaboration with CNR-IFN.
6. The cryostat was modified in order to fabricate a cryogenic arm with in built optical lens with the focal length of the 20 and 30 mm.
7. The Sample holder was also modified to remove the mechanical vibrations of the samples.
8. The optical apparatus was installed and tested for mechanical and temperature endurance of the cryostat.

Within the collaboration with CNR-IFN:

1. A high sensitivity hot electron bolometer with possibility to evidence pulses in a broad THZ range and with high repetition rates were designed and fabricated.

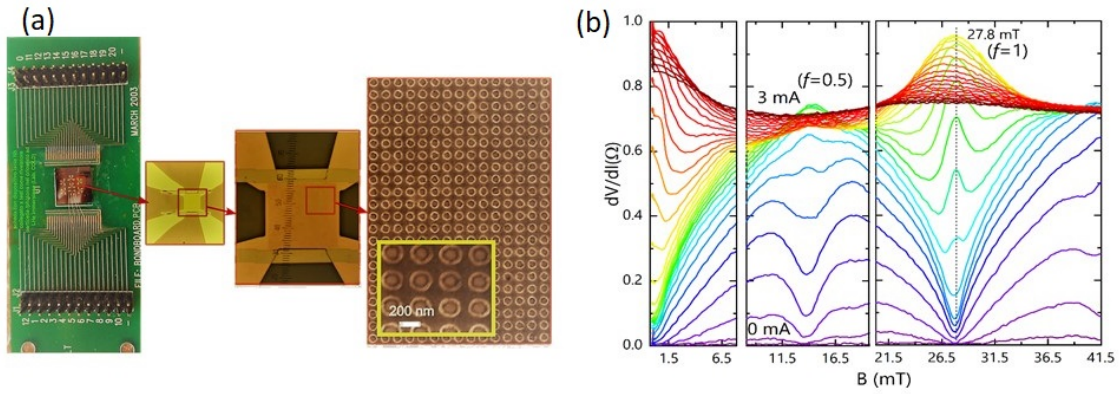

Figura 2: *(a) The image of the detector containing 90000 Nb islands formed on a gold normal layer. The sample is mounted on a PCB connected to the electrical measurement apparatus. The additional images of the PCB and the mounted PADs, show also the uniform injecting Nb stripes along with the SEM images of the Nb islands on the device; (b) Representative dV/dI vs. magnetic field curves at different bias currents. At low current bias, dV/dI minima at different B values indicate the formation of vortex Mott insulator to be used to tune the sensitivity of this detector.*

2. The bolometer is tested via quantum cascade laser and the response is characterized based on the HEB biasing.

3. A portable cryostat working at 4.2 K (liquid helium) is settled. The cryostat employs a low noise amplifier working at 4.2 K to significantly increase the S/N ratio.

3 Conference Talks and Posters

1. J. Rezvani, D. Di Gioacchino , N. Poccia, C. Ligi, S.Tocci, M. Cestelli Guidi, S. Lupi,, C. Gatti, A. Marcelli. A novel detector based on the vortex Mott insulator-to-metal transition LIV Zakopane School of Physics, Breaking frontiers; submicron structures in physics and biology. Instituite of nuclear physics PAN, 21-25 may 2019 Zakopane, Poland.

2. S.J. Rezvani, THz detectors based on tunable vortex dynamics in proximity junction arrays: Spectroscopy and Imaging with THz Radiation using Ultimate Radiation Sources, 10-12 December 2019, Sapienza University of Rome, Rome, Italy

3. M. Marongiu, Electromagnetic and Beam Dynamics Studies for High Gradient Accelerators at Terahertz Frequencies, 4th European Advanced Accelerator Concepts (EAAC2019), 15-21 September 2019, La Biodola, Isola D'Elba, Italy