Infrared spectroscopy with synchrotron and FEL radiation

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The no-damaging nature of the infrared (IR) light is a unique feature in Synchrotron Radiation (SR) and FEL facilities, which allows the safe investigation of vibrational and vibro-electronic transitions for a wide variety of materials. Hence, the applications of infrared cover a wide range of research fields including material science, biochemistry, cultural heritage, forensics, geology, biomedical diagnostics, and many others. SISSI-Bio and SISSI-Mat are the two branches of the infrared beamline at Elettra Synchrotron, while TeraFERMI is the THz beamline of the FERMI Free-Electron-Laser (FEL) facility.

The present lecture is intended to present the most relevant characteristics of IR-synchrotron and FEL-THz radiation and associated instrumentations, through exemplary spectroscopy and microscopy studies, exploiting both diffraction-limited and sub-diffraction approaches. The main leitmotif of the presentation will be the applicability of the techniques in life sciences. Indeed, the understating of the structure and behaviour of the macromolecules constituting the living matter is of paramount interest for the scientific community and IR and THz spectro-microscopies may help to shed light on both complex systems, as single cells or viral particles, and in simpler ones, like solution or films. Nano-resolution and THz bio-spectroscopy are the new frontiers of this research.

On the one end, the spatial resolution associated to IR analyses has been limited up to recent years to the micrometer scale, ultimately imposed by diffraction in the far-field microscopy. Recently, technical and scientific improvements have permitted to circumvent the diffraction barrier and to improve the spatial resolution of IR microscopy down to the nanometer scale. Nano-FTIR and THz bio-spectroscopy will allow obtaining information with a spatial resolution and dynamic details not assessable with conventional approaches, preparing the stage to a new era of experiments and scientific discoveries, bridging molecular properties to functional behaviour of bio-matter.

Indeed, high-power IR and THz FEL sources allow performing THz nonlinear and time-resolved spectroscopies. Because of the extremely large fields achievable, THz light can be used to shape the properties of matter by driving materials out of equilibrium, or even in novel metastable phases. Intense THz pulses can indeed be used to manipulate several fundamental excitations of matter as free electrons, plasmons, phonons, polarons, hydrogen bondings and van-der-Waals modes between others. THz nonlinear spectroscopy is becoming vital for many technological advances such as in lasers, detectors and modulators. In biology, strong THz pulses can be used to better understand solvation properties of liquid water, or to explore conformational properties of macromolecules.