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 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. On the other side, thanks to the advent of high-power IR and THz FEL sources, it is now possible to exploit THz non-linear and time-resolved spectroscopies to the study of biological matter. Intense THz pulses can be used to transiently orient dipoles in molecules, thereby allowing for instance to address the solvation properties of liquid water, and they may also be employed to excite the low-frequency anharmonic large amplitude modes of macromolecules thereby affecting their conformational properties. High intensity THz pulses can also be used to irradiate samples of biological interest, like cells, DNA, bacteria or viruses, in order to induce irreversible modifications. This can be used either to identify possible risks related to exposure to high THz fields, but also as a potential tool for medical treatments.

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.