The Generation of Coherent Terahertz Radiation at Semiconductor Surfaces, and Its Applications in Biomedical Imaging and Spectroscopy

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The recent demonstration of quantum cascade lasers operating at terahertz (THz) frequencies is set to open up a wide range of new opportunities across the physical and biological sciences. Yet, many issues still need to be addressed for the successful implementation of this technology. For example, can THz quantum cascade lasers operate above cryogenic temperatures (ideally operating at room temperature)? Can designs between 1–3 THz be realised? What solid state detectors are available for use in conjunction with these sources? For these reasons, many of the applications for the THz spectral range are currently being explored using coherent pulsed THz systems, based on a femtosecond laser technology. Indeed, it is with such systems that the imaging of basal cell carcinomas (the most common form of skin cancer) has recently been achieved, together with the identification of dental caries in human teeth. The success of such research has led to the marketing of commercial pulsed THz systems, and the possibility of undertaking clinical trials of the technology.

After reviewing these potential application areas, I will present a detailed discussion of our current femtosecond laser based THz research programmes. I will start by outlining our research on both photoconductive antennae and surface-field emitters. This research aims to produce high power and high bandwidth THz sources, which are both compact and robust. I will then discuss how we have used such sources in the design and construction of a vacuum-capable broad-bandwidth THz spectroscopy system, and show how this system has been used to obtain THz spectra of a range of bio-molecules. These include (L- and D-) glucose, sucrose, uric acid, allantoin, and amino acid monopolymers, together with nucleic acid bases and nucleosides. These experimental results highlight the need for detailed theoretical simulations of molecular vibrational modes in the THz spectral range. I will also show how it is possible to set up a time-resolved THz differential spectrometer in which near-infrared radiation is used to excite selectively part of a molecule (for example, copper pathancyonine), and THz difference spectroscopy is used to probe the local response. I will conclude my presentation by reviewing likely areas for future technological development, identifying key topics that still need to be addressed. Throughout, I will draw comparisons between pulsed femtosecond THz systems and alternative technologies such as those based on quantum cascade lasers, or the mixing of continuous wave near-infrared radiation.