Summary for a general audience

Over a hundred years ago scientists realised that visible light was part of the electromagnetic spectrum. The colours in the rainbow correspond to various wavelengths around a half millionth of a metre. In time, other types of electromagnetic radiation (emr) were recognized, e.g.: infrared (wavelength around a millionth of a metre) and microwaves (wavelength a centimetre or so). It was recognized that emr consists of both electric and magnetic fields moving along at a characteristic speed. The speed at which they travel inside a material is governed by an important property called the refractive index. A source of emr could be, e.g., a light bulb, or a radio antenna. Normally, we are not interested in getting close to a source of emr, but instead make use of the far-field, as it is called, where energy is carried away. Recently, it has been realised that there is a great deal happening close to the source, i.e. in the near-field. This project has dealt with specially-made devices that can manipulate this near-field in a certain wavelength range. This wavelength range lies between radio and infrared, and corresponds to wavelengths about one millimetre to about one thirtieth of a millimetre. It is also known as the terahertz (THz) range, because the frequency of oscillation of the electric and magnetic fields is about one million million times a second. This radiation can sense cancers and explosives because molecules wobble, vibrate and rotate at THz frequencies.

During the course of this project we have designed, built and measured the properties of artificial materials. In these materials, the refractive index can be engineered to make filters, special lenses that can produce “perfect” images and also, perhaps, new types of devices to transport emr into and out of hard-to-reach locations (e.g. inside of the human body). Typically, these materials consist of a “forest” of elements (e.g. cylindrical pillars) that are made of an insulating material or a metal. The key feature is that the size of the structures, and their separation, are around the same size as the wavelength of the emr concerned. The structures may also have to be organized in a special way, or be placed around holes in semiconductors or metals or other materials. For terahertz radiation, we are dealing with cylinders of several tens of micrometres in diameter and similar separation. We make these using the “photoresist” procedures developed by the semiconductor industry. Other types of artificial materials can be made by making repeated holes of special design in appropriate materials. At the end of the project, we have:

- Designed artificial material structures using various theoretical techniques (e.g. plane wave photonic band structure and finite difference time domain methods).
- Devised novel methods for fabricating the structures by special semiconductor techniques (such as ultraviolet based SU8 micromachining).
- Built artificial materials, such as pillar arrays, square and round holes etched in semiconductors, and metallic structures with arrays of grooves.
- Measured the way that such structures transmit terahertz emr, and have developed filters with exceptional properties, including filters that select particular wavelengths with great accuracy or which are built on polymer bases and can be tuned mechanically.
- Developed "super transmitters" that let through far more emr than would be expected and will be valuable for building terahertz microscopes.
- Have shown that we can observe, for the first time at terahertz frequencies, negative refraction (i.e. the terahertz beam is bent "the wrong way");
- Shown that we can create special thin (non-diffractive) beams of terahertz emr that could be used to make a functioning terahertz microscope.
- Made a number of technical advances, such as predicting and observing so called Tamm plasmon-polaritons.

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