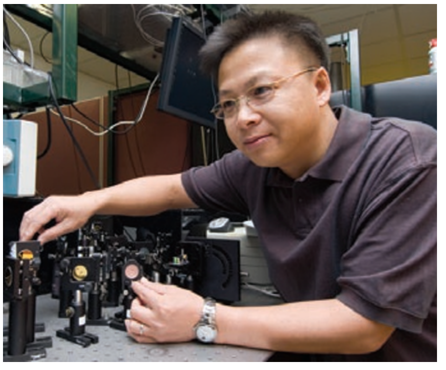
Taming the terahertz

Metamaterials have now evolved to a level where their resonant frequency can be optically tuned in the terahertz region. *Nature Photonics* spoke to Hou-Tong Chen from Los Alamos National Laboratory about the achievement.

What are metamaterials?
Metamaterials are generally defined as composite structures fabricated to have a designed resonant response to electromagnetic radiation. The typical building block of metamaterials is the subwavelength split-ring resonator, which acts analogously to an atom in natural materials. Circulating currents in the split-ring resonators are driven by either the electric or the magnetic component of the electromagnetic wave, or both. This results in a strong resonant response much like the way an electric inductive–capacitive circuit responds to a time-varying voltage. The resonance frequency is mainly determined by the effective inductance and capacitance of the split-ring resonator, both of which are tunable by simple scaling and shaping of the split-ring resonators. Therefore, metamaterials can be designed to operate over a large portion of the electromagnetic spectrum, including terahertz waves.

How are you able to make metamaterials optically tunable?
We create a hybrid terahertz metamaterial whose resonance frequency in the terahertz region can be optically tuned. The metamaterial is based on a two-dimensional array of split-ring resonators fabricated on a silicon-on-sapphire wafer, in which the silicon is selectively etched in such a way that we incorporate two silicon strips within each split-ring resonator element to act as variable capacitor plates. This provides a new technique for 'designing' the optical response of a material. When the metamaterial is illuminated by near-infrared laser pulses, photoexcitation of free charge carriers causes the silicon to behave like a metal. This behaviour changes the effective capacitance in the split-ring resonator elements, thereby tuning the metamaterial's resonance frequency. In our first attempt, we have experimentally demonstrated a tuning range of 20%, from 1.06 THz to 850 GHz. Simulation work on two other split-ring resonator architectures has also been carried out, suggesting that tuning to higher frequencies can be achieved by changing the inductance within the split-ring resonator elements.



DIXON WOLF, LOS ALAMOS NATIONAL LABORATORY

Hou-Tong Chen believes that metamaterials will make an enormous contribution to the generation, detection and manipulation of terahertz waves.

Why are your findings important?
First of all, research into metamaterials expands our fundamental understanding of electromagnetic phenomena, such as negative refraction and optical super-resolution, which are very difficult or impossible to achieve using naturally existing materials. Secondly, the resonant response of metamaterials is particularly important in the terahertz region, which is located at the interface of electronics and photonics, where technologies directly translated from microwave and optical regimes generally fail to operate. Because of their strong, narrow resonant response, terahertz metamaterials can be used as filters, modulators, laser-cavity output couplers and spectroscopic devices for medical sciences and astronomy. Our previous work demonstrated that by forming a Schottky diode in the metamaterial composite structure (split-ring resonators fabricated on top of a non-patterned semiconductor substrate), the terahertz transmission at one fixed frequency can be modulated up to 50%. This time, we demonstrate that we can tune the frequency of the terahertz response. This means that metamaterials can now be designed with dynamic tunability, which alleviates the fixed, narrow-band restrictions that have existed so far. Our findings provide new opportunities in terahertz photonics, and further optimization will improve the performance of materials to a level suitable for real-world applications, such as terahertz communications and imaging.

What role do you foresee for metamaterials in the terahertz region?
We believe that metamaterials will be important in future applications that involve the generation, detection, control and manipulation of terahertz waves. Here we should note that metamaterials offer a unique method to efficiently control terahertz radiation, as their resonant response originates from single artificial atoms. This is in contrast to photonic crystals or surface-plasmonic arrays of metal holes, where the response results from collective scattering. So even a small number of metamaterial elements can be used to control and manipulate terahertz waves, for example, in a terahertz waveguide. We feel that further fundamental understanding of metamaterials will reveal more technological opportunities and fascinating science, leading to improved manipulation of terahertz waves, such as modulation, switching, phase-shifting and beam steering.

What are the future challenges that lie ahead?
There are still many challenges, for example, creating three-dimensional, bulk terahertz metamaterials, improving their switching and modulation speeds, reducing their losses, and devising a method for real-time frequency tunability. In our case, we have achieved dynamically frequency-tunable metamaterials using optical excitation. It will be desirable and more convenient in many applications if frequency-tunable metamaterials can be realized through electrical control.

Chen and his co-workers have a letter on frequency-agile terahertz metamaterials on page 295 of this issue.

Interview by Rachel Won.