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EDITORIAL

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Editorial

Carbon and terahertz nanotechnology: a promising alliance

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The equations that first linked electric and magnetic interactions to explain light celebrate their 150th anniversary this year. Now known as the Maxwell equations, their contribution to the theory of relativity led Albert Einstein to remark, ‘One scientific epoch ended and another began with James Clerk Maxwell’. They have since laid the bedrock for modern day electronics, photonics and magnetism and have been integral to a number of studies of nanoscale systems over the years. Today many key areas of development in current nanotechnology research derive from electromagnetic effects as highlighted by Satoshi Kawata, Adarsh Sandhu and Jennifer Dionne in a recent *Nanotechnology* Discussion podcast on Maxwell’s equations at the nanoscale [1]. One region of the electromagnetic spectrum where a comparatively new alliance has been forged with nanoscale research is the terahertz regime.

Although terahertz wavelengths—measuring 0.1–100 mm—exceed the dimensions of nanostructures, terahertz radiation can be useful for probing these systems because many of their dynamical processes operate around terahertz timescales. Examples can be found in the recent *Nanotechnology* special section dedicated to terahertz nanotechnology [2]. Here Hannah Joyce, Michael Johnston and colleagues at the University of Oxford in the UK and the Australian National University report studies using an optical pump-terahertz probe approach to probe carrier dynamics in semiconductor nanowires made from Group III and V compounds [3]. The technique has the advantages of being non-contact and operating at room temperature, and provided information on the carrier lifetime that may prove valuable for matching different nanowires to different applications.

The same issue includes a number of approaches for harnessing nanosystems for terahertz detection, such as nanowire-based field effect transistors [4]. Meanwhile Joo-Hiuk Son provides a review of the principle, characteristics and applications of molecular imaging with terahertz electromagnetic waves [5]. The review describes how terahertz radiation is a relatively safe imaging tool (compared with, for example, x-rays) as well as how the sensitivity to vibrational modes of water molecules can be enhanced using nanoparticles for more effective medical imaging and diagnosis.

The emergence of carbon-based nanoelectronics has already greatly modified the outlook for next-generation devices [6]. In this issue, Richard Hartmann from De La Salle University in the Philippines, Junichiro Kono from Rice University in the US and Mikhail Portnoi from the University of Exeter in the UK and Universidade Federal do Rio Grande do Norte in Brazil present an overview of what carbon nanomaterials offer for the future of terahertz science and technology [7].

As explained in the review, ‘In this frequency range, electronic transport and optical phenomena merge with one another, and classical waves (in the microwave region) make the transition to quantum mechanical photons (in the optical regime)’. It is easy to imagine that the extraordinary optoelectronic properties of carbon nanotubes and graphene might make them ideally suited to applications exploiting these frequencies.

In the review the researchers point out that both carbon nanotubes and graphene are expected to show exotic THz dynamics and that these 'can lead to innovative optoelectronic applications'. They attribute these characteristics to the unique low-dimensional band structure of carbon nanomaterials and the nature of the quantum-confined interactions between charge carriers. Electric and magnetic fields and gating can also trigger activity in the terahertz regime.

The review highlights the progress made in understanding and optimising carbon nanotube transistors, antennae and polarizers, as well as nonlinear processes, plasmonics and detectors based on graphene at terahertz frequencies. These potential avenues for applications join a long list as research activity into carbon nanomaterials attracts ever increasing interest, yet the unique characteristics of both terahertz radiation and carbon nanostructures suggests a disarmingly promising alliance.

While Hartmann, Kono and Portnoi point out that many challenges lie ahead in the field they conclude that nanocarbon THz technology has great potential for development in the coming years. Progress in the field to date certainly makes a convincing case for the future of nanocarbon THz technology, but in the words of James Clerk Maxwell himself as he contemplated his theory of the colour of light, 'time will show' [8].

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