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TECHNOLOGY UPDATE

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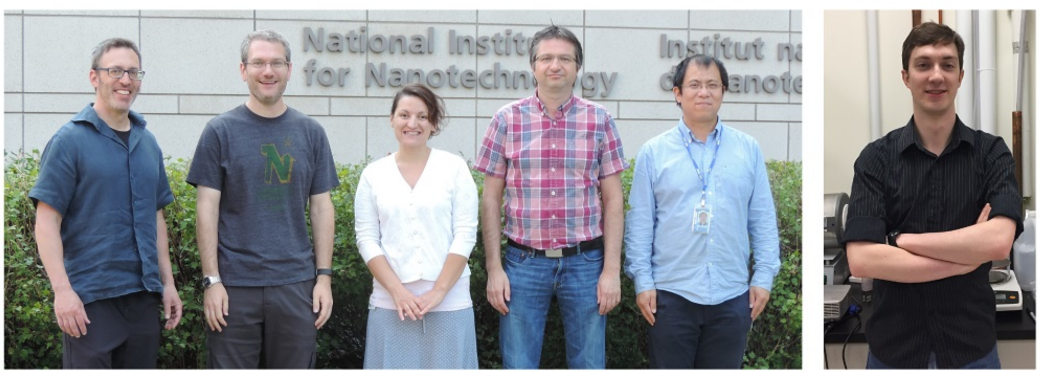
Quantum Čerenkov effect makes graphene glow

Visible and infrared light emission has been seen in graphene and its derivatives for years, but the mechanism responsible had not been identified with confidence. By observing the physical location of light emission in a graphene field-effect transistor (FET), and by measuring the influence of source-drain and gate voltages, researchers in Canada and Serbia have now attributed the phenomenon to the 2D quantum Čerenkov effect. The finding should allow greater control over the emission process, opening the door to new graphene-based optoelectronic devices.



Beltaos and colleagues have shed light on a persistent mystery.

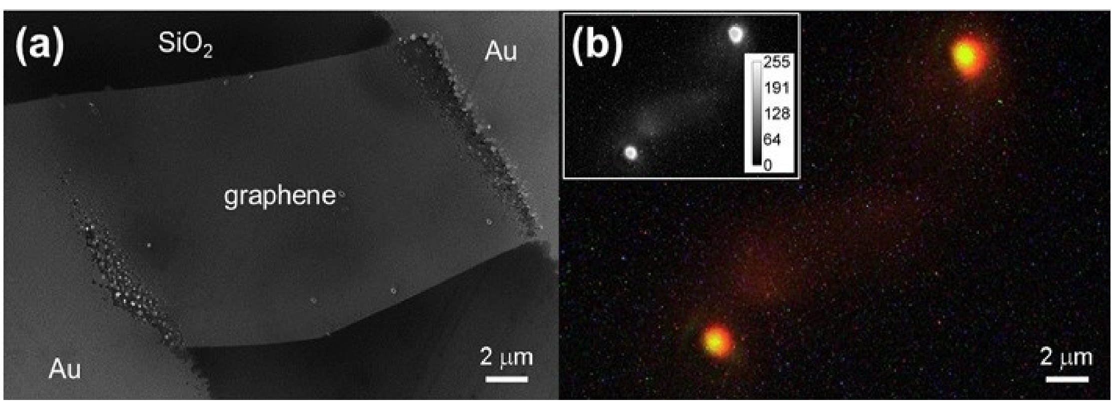
"The first couple of papers to demonstrate electroluminescence from graphene in recent years (Essig *et al* in 2010, Beams *et al* in 2014) were inspiring. They demonstrated that light emission from graphene devices in the visible wavelength range was possible, and we believed that this could be highly useful for applications. The fact that the field was so new, with much left to discover, was an exciting prospect," says Angela Beltaos, researcher at the National Institute for Nanotechnology and the University of Alberta in Canada.

The discoveries still to be made that Beltaos mentions are not mere details: despite graphene being the focus of intense study in recent years, the physics of electrically driven light emission in the material has remained mysterious. Emissions that peak in visible wavelengths have been put down to various processes, including electroluminescence and thermal "hot spots", but researchers are still to reach a consensus. Writing in *Nano Futures*, Beltaos and colleagues in Canada and Serbia demonstrate that the interaction of hot carriers with surface plasmons via the 2D quantum Čerenkov effect is the mechanism that best fits observations.

An illuminating study

To investigate the phenomenon, Beltaos and her team fabricated FETs from single-layer and few-layer samples of pure graphene. A silicon-dioxide substrate served as the gate dielectric, silicon as the back gate electrode, and vapour-deposited gold films as the source and drain electrodes. The researchers then imaged and measured the light spectra emitted by the graphene flake while they varied the voltages across the device.

The researchers found that voltages applied to the electrodes excited light emission in the graphene that was stable and repeatable, and did not appear to damage the material. Scanning electron microscopy (SEM) images of the flakes after the experiment showed that the emission was localized consistently at material edges, nanoparticles and defects – including, in one experiment, features created intentionally using an electron beam.



Emission explained.

All the FETs tested showed emission spectra with two peaks at wavelengths that varied between each device. Phonon-assisted electroluminescence would be expected to produce spectra with two such peaks, but at specific, device-independent energies, ruling out that explanation in this case. The observed spectra also excluded thermal emission as the cause of the light, since no black- or grey-body spectrum was exhibited.

Beltaos and colleagues observed that the intensity of the emitted light scaled with the number density of carriers, indicating that hot carriers were in some way responsible for the process. Tunnelling-induced hot electroluminescence would produce consistent emission throughout the graphene flake, however, which was inconsistent with the localized effect seen in the optical images.

The one mechanism that the team found could account for all these observations was the 2D quantum Čerenkov effect. This process is analogous to the conventional Čerenkov effect, in which light is emitted by charged particles moving through a dielectric medium faster than the phase velocity of light.

In the 2D version that Beltaos and her team invoke, the charged particles are represented by the hot carriers injected into the graphene from the source and drain electrodes, and surface plasmons excited by the hot carriers represent the resulting Čerenkov radiation. Like ocean waves breaking on a harbour wall, these plasmons scatter from defects in the graphene, out-coupling, and emitting their energy as visible and infrared photons. The two peaks seen in the emission spectra were interpreted as corresponding to the dual surface-plasmon energy ranges predicted for graphene.

Seeking confirmation

Next, the researchers intend to find further support for their conclusion with additional experimental and theoretical work, as Beltaos explains: "We have shown that the quantum Čerenkov effect is consistent with our results, while other theories of visible light emission from graphene are not, and although we have compared our results specifically to the theories that have been proposed thus far, we do not want to rule out the possibility of future theories."

"Our next step in this area is to fabricate graphene devices that incorporate specially-designed gratings," continues Beltaos. "According to the theory, this would allow for controllable and efficient out-coupling of the surface plasmons to light emission. By varying the grating parameters we plan to study the effects of the resulting light emission and compare the observations to the theoretical predictions. This information is important not only to clear up the mystery about light emission in graphene, but will open up possibilities for new graphene-based optoelectronics."

About the author

Marric Stephens is editor of *nanotechweb.org*