Graphene Laser Article for *Electronics Letters* issue 53 (5)

[Headline] Graphene enhanced fibre laser
[Byline] Graphene-based passively harmonic mode-locked fibre laser, with low pump threshold and high super-mode noise suppression, made using a highly repeatable process

Further reading [left of line at top]
http://www.soe.mmu.ac.uk/our-staff/profile/index.php?profile_id=2544

Further reading [right of line at bottom]
Page ***, ‘A low pump threshold CVD graphene based passively harmonic mode-locked fibre laser’, K. K. Chow

[Start of main text]
A passively harmonic mode-locked (HML) fibre laser with a low pump threshold and high super-mode noise suppression using a graphene-based saturable absorber has been produced using a process designed to be easily repeatable.

[Head] Repeated precision
Graphene-based saturable absorbers (SAs) for passively mode-locked fibre lasers are of great interest for their ultra-fast recovery time, ease of fabrication and compatibility with silica optical fibres.

Many different approaches to produce high quality graphene film coatings on optical fibres have been explored, including mechanical exfoliation from graphite, spray coating, optically-driven deposition and chemical vapour deposition (CVD). All these methods have their own merits and difficulties, but there are two general issues: repeatability and precision. In using them to create graphene-based SAs for mode-locked fibre lasers, insertion loss and optical scattering of the SAs also become important as they affect the pump threshold and performance of the resulting laser.

Dr Kin Kee Chow of Manchester Metropolitan University (MMU) explains that “as the key component of a passively mode-locked fibre laser, the quality of the SA will strongly affect the laser’s performance. In particular, high pump thresholds are generally required to generate higher order HML. In order to obtain low pump threshold HML, a SA with efficient graphene–light interaction and low optical scattering is important.”

[Head] Two step process
In this issue of *Electronics Letters* Dr Chow’s paper reports the demonstration of a passively HML fibre laser with a low pump threshold. The laser can operate from its fundamental frequency up to the 21st harmonic of its cavity length and shows good supermode noise suppression and pulse energy fluctuation from its output RF spectra. Dr Chow highlights the process used to create the laser’s graphene-based SA as key to the performances achieved.

The SA was fabricated by cold transferring a CVD-grown graphene thin-film onto the facet of a fibre connector ferrule. This method ensures accurate control of the number of layers of graphene coated onto the fibre facet, precisely controlling the modulation depth of the SA.

“Also, it has been experimentally found that the SA has a relatively lower optical scattering compared with other methods such as mechanical exfoliation or spray coating, hence achieving a lower pump threshold of passive mode-locking,” Chow adds. “With the CVD grow of high quality graphene thin-film and cold transfer of the thin film to fibre facet, one can obtain a high quality graphene-based SA with well-defined physical and optical properties.”

This is because the approach separates SA fabrication into two more repeatable steps – the CVD growth of the graphene film and its transfer onto a fibre facet through deionized water. Growing the graphene film using a standard CVD process allows better control of the coating thickness compared to other common coating methods. “Furthermore, since the fabrication and coating process doesn’t involve mechanical or solution phase exfoliation, it is believed that no extra damage to the surface of the graphene thin-film is imposed,” said Chow.

The result is a passively HML fibre laser with low pumping threshold, high supermode noise suppression and low pulse-to-pulse fluctuations. These characteristics are required for a wide range of applications including high-speed telecommunications, optical sampling, laser ranging and ultra-precise micromachining. In addition, owing to the wavelength independent absorption properties of graphene, the developed techniques can apply to ultra-short pulse generation in different wavelength ranges, for example, mid-infrared for free-space optics or range finding applications. The developed methodologies can also apply to different advanced two-dimensional materials such as molybdenum disulfide (MoS_2) or boron nitride (BN) composites for various laser applications.

[Head] Beyond simple graphene

At MMU this work is now being developed in two ways. The first is extending the work on graphene-based passively mode-locked lasers to other wavelength ranges combining current fibre technologies. In particular, ytterbium-doped fibre lasers generating 1 μm pulses and thulium-doped fibre lasers generating 2 μm pulses. The second development direction is photonic device applications leveraging their experience of fabricating high quality graphene-based fibre devices for efficient graphene-light interaction. This includes development of high performance optical fibre sensors incorporating graphene coatings for real-time environmental monitoring applications.

When asked about longer term developments Dr Chow was interested in looking beyond the application of pure graphene. “The research direction of passively mode-locked fibre lasers is developing towards long wavelength operations. Ultra-short pulses beyond 2 μm is interesting due to the potential applications in IR spectroscopy, broadband laser radar (LIDAR), remote chemical sensing, atmospheric analysis, bio-photonic diagnostics and therapeutics, etc. With reference to the vigorous research activities of graphene-related 2D materials, I would like to see the realisation of truly bandgap profile tunable 2D composite materials, which could be tailor-made for any specific wavelength and even outperform the optical or optoelectronic properties of pure graphene.”

[End]

Main image: As supplied over 2nd, caption and 3rd columns [use file ‘Graphene Laser main.jpg] Transfer of a CVD graphene thin-film floated on deionized water onto the facet of a fibre ferrule. The CVD growth of the film improves control of the thickness and repeatability.

Second image: As supplied over 2nd column [use file ‘Graphene Laser second.jpg’] CVD graphene thin-film coated on the facet of a fibre ferrule.