

# Laser Welding/Joining of Graphene

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Research Exchanges with China/India

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## Aim

The exchange visits (1 July 2011 – 30 June 2012) aim to develop joint research between the two research groups in laser joining, machining and modification of graphene and laser interactions with graphene for engineering applications.

## Research Motivation and Context

In 2010, two professors (Andre Geim and Konstantin Novoselov) at The University of Manchester won the Nobel Prize in physics for their ground-breaking experiments regarding the two-dimensional material: graphene. Graphene is a flat monolayer of carbon atoms tightly packed into a two-dimensional honeycomb lattice. As a material it is completely new – not only the thinnest ever but also the strongest. As a conductor of electricity it can sustain current densities 6 orders of magnitude higher than copper. It is almost completely transparent, yet so dense that not even helium, the smallest gas atom, can pass through it. However, although individual graphene flakes (a few  $\mu\text{m}$  to several mm across) have unusual properties, when they are applied in multiple quantities to form a surface layer for large area applications such as transparent conducting electrodes to replace indium tin oxides (ITO) in liquid crystal displays and to form impermeable films, their individual properties are not necessarily translated to bulk properties. A major barrier to large scale, practical applications of graphene is the connection between individual graphene flakes. Tsinghua University has recently developed a technique for joining carbon-nanotubes by electrical current assisted laser radiation. The University of Manchester has considerable experience in laser micro/nano fabrication, modelling of laser interaction with materials and has state of the art laser processing facilities. This joint research in laser processing of graphene will enable accelerated progress in machining, joining and processing of graphene for wider engineering applications.

## Initial Results (1 July – 30 Aug. 2011)

**Fig.1** shows a continuous wave 20W CO<sub>2</sub> laser (3 mm beam diameter) irradiated graphene (the bright illuminated spot) on a quartz substrate (the dark larger square) in vacuum at *Tsinghua University* and the Raman spectra of the laser radiated graphene at different radiation periods (**Fig.2**) that give information on the changes of the properties of the graphene.

**Fig. 3** shows the scanning electron microscopic images of laser processed graphene flakes on a copper substrate using a 80 femto-second pulsed Ti-Sapphire laser in Ar gas environment at The University of Manchester. The tough material has been cut by this laser at very high precision. **Fig.4** shows some holes drilled in graphene using the fs laser at The University of Manchester.

**Figs. 5 and 6** show the fs laser scanned line on graphene and Raman spectrum peak distribution across the line. These show us the characteristics of laser/graphene interactions.

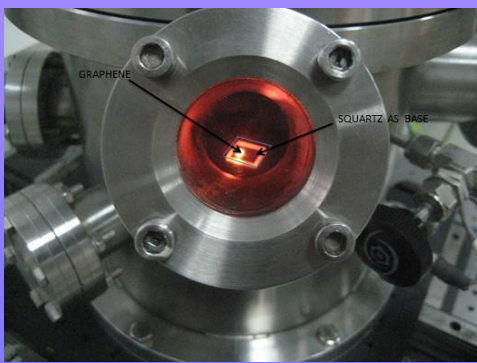


Fig.1. CO<sub>2</sub> laser radiating graphene on quartz.

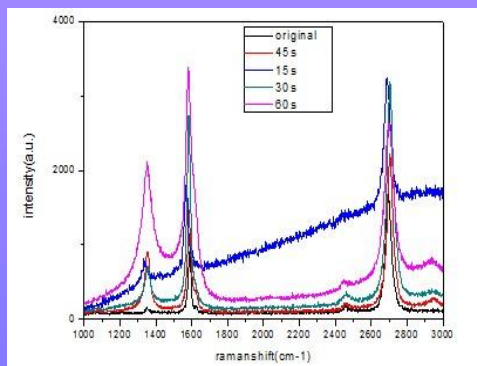


Fig.2. Raman spectra of laser radiated graphene.



Fig.3. fs laser radiated graphene sheets on copper.

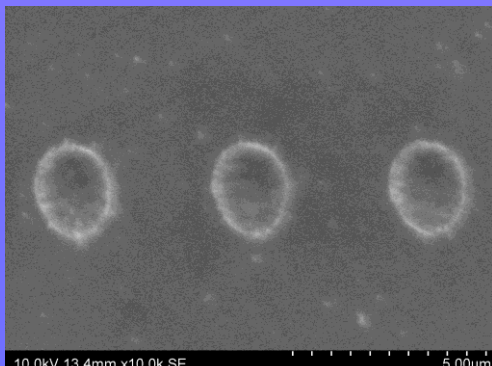


Fig.4. Holes drilled in graphene by the fs laser.

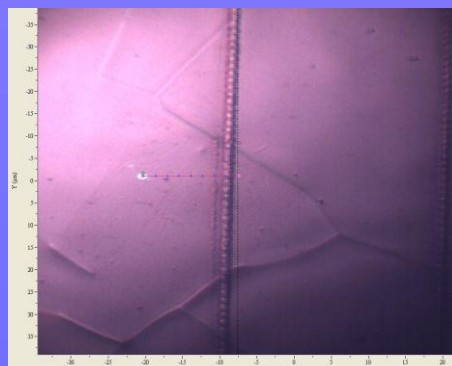


Fig. 5. A fs laser scanned line on graphene

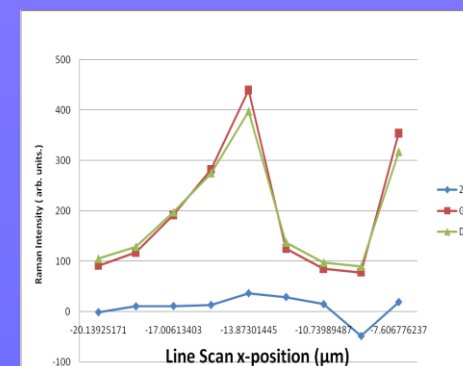


Fig. 6. Raman spectrum peaks across laser scanned line.