Single shot femtosecond laser sub-micron patterning of CVD graphene

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Graphene is an important material for next-generation technologies, but the development of applications in the field of photonics and optoelectronics require micro and nanostructuring of the graphene films [1]. Femtosecond laser ablation is a promising technique because it can process large surfaces at extremely high speed and is easily reconfigurable.
Previous studies of fs-laser ablation of graphene in accumulative thermal regime (burning) have shown high accuracy (down to <100 nm) but it is a slow process [2]. Single shot femtosecond pulse ablation experiments were carried out on graphene but only at scales larger than typically 1 µm [3,4]. We have developed a novel technique to measure the ablation threshold and the ablation repeatability for single shot illumination of CVD graphene, that is size independent. Our technique is based on accurate comparison of a complex beam fluence pattern with the one of SEM image of the damaged graphene monolayer (fig. 1a-b).

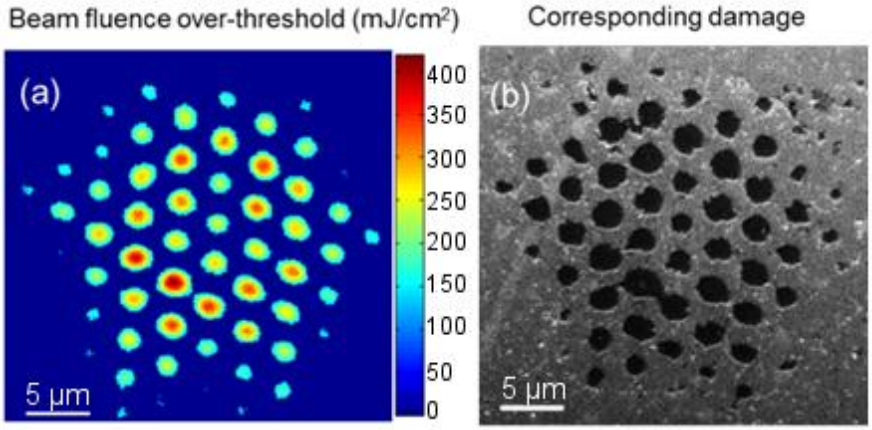

Fig 1. Comparison of fluence distribution over threshold (a) with the SEM image of the damage (b) for a given intensity distribution, pulse duration (130 fs), and input pulse energy (1.3 µJ).

We report a sudden drop of the ablation probability when the over-threshold diameter is below 1 µm. With non-diffracting Bessel beams, we have investigated the limits of nano-drilling with high-angle focusing. We show the diameter limit of ablated holes in CVD graphene using single shot ultrafast laser is approximately 550 nm for both quartz and fused silica substrates.
We also report a strong difference in ablation probability depending on the presence or absence of grain boundary in the vicinity of the illuminated zone, which can be a major constraint when patterning CVD graphene at sub-micron scale.
Our results can be explained by the high free-carrier diffusion in the graphene film and show the needs for more complex strategies for laser structuring of graphene at nanometric scale.

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[1] F. Bonaccorso, Z. Sun, T. Hasan, and A.C. Ferrari, *Nature Photon.* **2010**, 4, 611
[2] R. J. Stohr, R. Kolesov, K. Xia, and J. Wrachtrup, ACS Nano. **2011**, 5, 5141.
[3] J-H.Yoo, J.B. In, J.P. Park, H. Jeon, and C.P. Grigoropoulos, App. Phys. Lett. **2012**, 100,233124.
[4] B. Wetzel, C. Xie, P.-A. Lacourt, J. M. Dudley, and F. Courvoisier, Appl. Phys. Lett. **2013**, 103, 241111.
[5] A. Gil-Villalba, C. Xie, R. Salut, L. Furfaro, R. Giust, M. Jacquot, P. A. Lacourt, J. M. Dudley, and F. Courvoisier, Appl. Phys. Lett. **2015**, 107, 061103