Diamond quantum photonics platform enabled by femtosecond laser processing

Toney T. Fernandez[1], Vibhav Bharadwaj[1], Belén Sotillo[1], J. P. Hadden[2], Masaaki Sakakura[3], Andrea Chiappini[4], Stefano Longhi[1], Roberto Osellame[1], Gianluca Galzerano[1], Yasuhiko Shimotsuma[3], Maurizio Ferrari[4], Kiyotaka Miura[3], Roberta Ramponi[1], Paul E. Barclay[2], Shane M. Eaton[1]

E-mail: shanemichael.eaton@polimi.it

Diamond is a promising platform for sensing and quantum processing thanks to the remarkable properties of the nitrogen-vacancy (NV) impurity [1]. However, still lacking is an efficient photonic fabrication method for diamond akin to the photolithographic methods that have revolutionized silicon photonics. For the first time, we demonstrate waveguiding in diamond using femtosecond laser writing using a pulse width of 230 fs, 515 nm wavelength, focusing with a 1.25-NA lens and 50 µm below the surface of diamond (type II, optical grade, MB Optics). The inscribed Type II waveguide showed single mode behavior when scanning the input launch fiber transversely. To achieve single mode guiding, we wrote a second type II modification, consisting of two vertically offset lines (Fig. 1(b)). This supported a single mode at 635 nm with a similar transmission as the two-line modification. Fig2c is the PL spectra from the waveguide, both spectra show the first order Raman peak at 573 nm, the ZPL at 637 nm along with its broad phonon sideband from 600 to 800 nm. The spectrum in pristine diamond is the same as that in the waveguide.

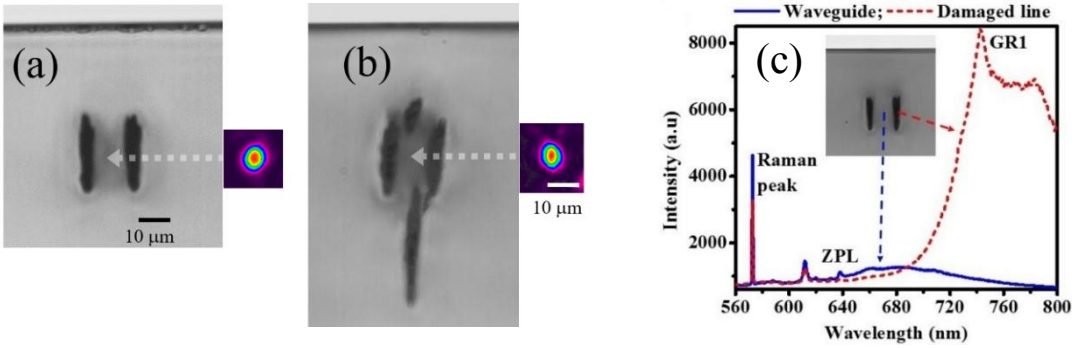

Fig. 1(a) Transverse microscope image of type II waveguide in diamond along with mode profile (λ = 635 nm) **(b)** Four-line modification to provide vertical confinement and single mode guiding. All tracks were written with 50 mW, 0.5 mm/s at 500 kHz. **(c)** PL spectra within the laser-written lines (dashed red line) and in the waveguiding region (blue solid line) for 532-nm excitation.

Characterizing the waveguides using µRaman (Fig.2), it was found that within the laser modification written at 500-kHz rep. rate, a reduction of the characteristic diamond peak at 1332 cm^{-1} is observed along with the appearance of the G-peak at 1575 cm^{-1} and the D-peak at 1360 cm^{-1}, showing a transformation of the sp^3 to sp^2 bonding. The width of D and G peaks (greater than 100 cm^{-1}) and the intensity ratio between them (I(D)/I(G) < 1) indicate that sp^2 clusters are mainly in amorphous carbon phase rather than graphite [2].

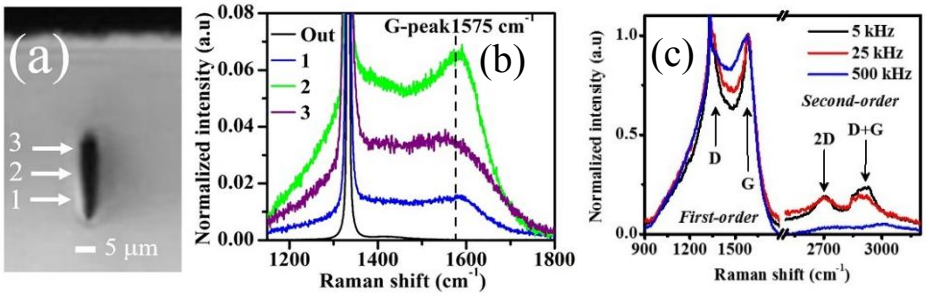

Fig. 2(a) Left panel: Single laser-induced damage track written with 500-kHz repetition rate, 50-mW average power and 0.5-mm/s scan speed showing three measurements positions for µRaman spectra in right panel with 'out' referring to the spectrum taken outside the modification. (b) µRaman spectra (normalized to the G-peak) in the center of damage tracks at repetition rates of 5 kHz, 25 kHz and 500 kHz, with pulse energy held constant (800 nJ) to produce a similar modification at each repetition rate.

As repetition rate was reduced, we observed a sharper G-peak with a slight displacement to higher wavenumber, implying a greater concentration of nanocrystalline graphite [3]. We also found that the second order peaks appear for 5 and 25 kHz, but not for 500 kHz, evidencing increased graphitization at the lower repetition rates [4].

[1] I. Aharonovich et.al "Diamond photonics," Nat. Photonics 5, 397-405 (2011)
[2] J. Schwan et.al "Raman spectroscopy on amorphous carbon films," J. Appl. Phys. 80, 440-447 (1996)
[3] A. C. Ferrari et.al "Raman spectroscopy of hydrogenated amorphous carbons," Phys. Rev. B 61, 14095 (2000).
[4] B Sotillo et.al, "Diamond photonics platform enabled by femtosecond laser writing" arXiv:1605.01854