# Conductive Microelectrode Generation in Diamond Using Pulsed Bessel Beams

**Akhil Kuriakose[1,2], Andrea Chiappini[3], Belen Sotillo[4], Adam Britel[5], Pietro Apra[5], Federico Picollo[5], Ottavia Jedrkiewicz[1]**

*1. IFN-CNR, Udr di Como, Via Valleggio 11, 22100 Como, Italy; akhilk478@gmail.com, ottavia.jedrkiewicz@unisubria.it*

*2. Dipartimento di Scienza e Alta Tecnologia, Università dell'Insubria, Via Valleggio 11, 22100 Como, Italy*

*3. Istituto di Fotonica e Nanotecnologie (IFN)-CNR, CSMFO and FBK-CMM, Trento, Italy; andrea.chiappini@unitn.it*

*4. Department of Materials Physics, Faculty of Physics, Complutense University of Madrid, Plaza de Ciencias 1, 28040, Madrid; bsotillo@gmail.com*

*5. Department of Physics and "NIS" Inter-departmental Centre, University of Torino, Via Pietro Giuria 1, 10125, Torino, Italy;a.britel@unito.it, pietro.apra@unito.it, federico.picollo@unito.it*

Ultrafast laser micromachining has emerged as an excellent tool for fabrication of microstructures in different dielectrics and crystals using pico and femtosecond pulses thanks to the non-linear absorption processes involved in the radiation-matter interaction, such as multiphoton absorption and avalanche ionisation [1]. Recently, non-conventional beams such as Bessel beams, which are characterised by an elongated focal region as opposed to the Gaussian beams with short focus, have been used for in-bulk modification of different transparent materials without the need for sample translation [2]. Diamond is widely used in high energy particle detectors, integrated photonic chips and microfluidic systems due to extreme hardness, high thermal conductivity, biocompatibility and top-notch chemical resistivity [3].

The microfabrication of 3D conductive/graphitic electrodes in diamond are crucial since these structures act as an electric field source in all the applications mentioned above. In this work, in-bulk conductive microelectrodes have been fabricated perpendicular to a monocrystalline CVD (5 × 5 × 0.5 mm) diamond sample surface using pulsed Bessel beams and without any sample translation. The microfabrication studies were performed by means of a 20-Hz Ti:Sapphire amplified laser system delivering 40-fs transform-limited pulses at 790 nm wavelength in the mJ pulse energy range, and tunable in duration up to the ps regime. An axicon was used to reshape the Gaussian beam into a finite energy Bessel beam. The current-voltage characterization was conducted with a 2-probe configuration in an IVT chamber. Raman spectra were acquired using a LabRAM Aramis (Horiba Jobin-Yvon) instrument with a spectral resolution of ~1 $cm^{-1}$. Different electrodes have been fabricated for different laser parameters such as pulse duration, energy etc. Figure 1 shows the electrode structure, the corresponding I-V graph and the microRaman spectra of the same.

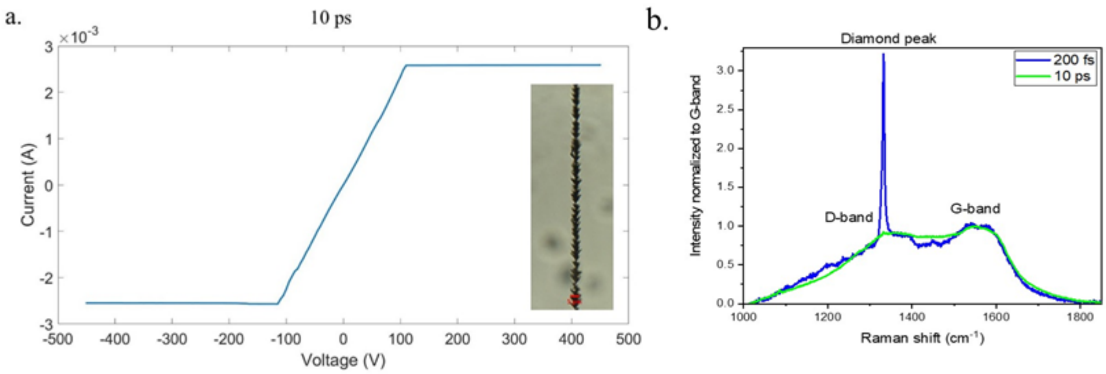


**Fig. 1.** I-V graph at a.)10 ps (inset – optical microscope image of the electrode structure) and b.) microRaman spectra of the electrodes fabricated at 200 fs and 10 ps pulse durations.

We found that the conductivity value increases with the pulse duration. This is confirmed by the microRaman spectra showing the diamond peak highly suppressed for the 10 ps fabrication regime compared to the 200 fs one. Furthermore, increasing the pulse energy leads to an increase in the conductivity only up to an optimal point after which it starts to decrease. Using pulsed Bessel beams, we have fabricated high quality in-bulk conductive electrodes with a resistivity of 0.04 Ω cm which, to the best of our knowledge, is one of the lowest values compared to the literature results using laser micromachining and the lowest using Bessel beams. These results shine light into various potential applications such as incorporating conductive electrodes in diamond based detectors, microfluidic chips and integrated photonic circuits.

[1] R. R. Gattass, E. Mazur, "Femtosecond Laser Micromachining in Transparent Materials", Nature Photonics, Vol. **2**, pp. 219-225 (2008).
[2] M. Duocastella, C.B. Arnold, "Bessel and annular beams for materials processing", Laser and Photonics Reviews **6**, pp. 607-621 (2012) .
[3] V. Bharadwaj, O. Jedrkiewicz, J. P. Hadden, B. Sotillo, M. R. Vázquez, P. Dentella, T. T. Fernandez, A. Chiappini, A. N. Giakoumaki, T. L. Phu, M. Bollani, M. Ferrari, R. Ramponi, P. E. Barclay, S. M. Eaton, "Femtosecond laser written photonic and microfluidic circuits in diamond", Journal of Physics: Photonics **1**, 022001 (2019).