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Fabrication of conductive micro electrodes in diamond bulk using pulsed Bessel beams

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ABSTRACT

High-quality, in-bulk conductive graphitic microelectrodes are fabricated perpendicular to the surface of a 500 µm thick monocrystalline CVD diamond sample using pulsed Bessel beams. With a 12^{o} cone angle beam, different pulse parameters are explored to optimize the graphitic wires which are written without sample translation. The quality of the electrodes and their electrical and structural properties have been analysed through current-voltage characterization and micro-Raman spectroscopy. We have found that higher pulse duration favours better conductivity while pulse energy has an optimum value for the same. This trend is confirmed by the presence and the different amounts of graphitic-like sp^2 bonded carbon revealed by the micro-Raman spectra in different configurations. Using suitable writing parameters, we are able to create electrodes with the resistivity of 0.04 Ω cm, which, to the best of our knowledge, is one of the lowest values ever reported in literature in the case of graphitic-like wires fabricated through laser micromachining.

1. Introduction

Diamond is an extraordinary crystal due to its remarkable properties such as hardness (Mohs index 10), scratch resistance, biocompatibility, chemical resistivity, high thermal conductivity and low thermal expansion coefficient [1,2]. The advancements in synthetic diamond manufacturing have brought down the cost of artificial diamonds such as the ones produced through chemical vapour deposition (CVD) or high-pressure high-temperature (HPHT) techniques thus resulting in mass production of the same. This has led to an increased utilization of them for various technological applications such as photonic and microfluidic platforms [3,4], radiation detection in particle physics [5], medical dosimetry [6] and high frequency electronics [7]. Recently, the presence of optically active defects such as the nitrogen-vacancy (NV) centres has made them a special attraction in quantum optics world due to their spin dependent fluorescence which can be used for optical spin readouts. In addition, NV centres find potential applications in magnetometers due to Zeeman effect [4].

A common factor in almost all diamond–based devices is the presence of conductive graphitic microelectrodes (GMEs) which are primarily used for the application of electric fields or current transport/collection in various chips and detectors. Both surface and in-bulk electrodes are used but recently a 3-D, in-bulk orientation is widely researched due to their better performance and efficiency added with easy integration with other microstructures in diamond [8–10]. The two most prominent methods to create such electrodes in diamond are deep ion beam lithography (DIBL) and laser writing (LW). DIBL works on the fact that structural properties of the diamond undergo significant modification upon MeV ion micro-beam irradiation even creating graphitic-like structures by overcoming a critical defects density (graphite being another allotrope of carbon) both in single-crystal [11] and polycrystalline diamond [12]. In addition, ultrafast laser irradiation is also widely used for processing diamond crystals. A conventional Gaussian beam with moderately intense pulses can be used for the

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