Nuclear Instruments and Methods in Physics Research B 348 (2015) 199–202

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Realization of a diamond based high density multi electrode array by means of Deep Ion Beam Lithography

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ARTICLE INFO

Article history:
Received 10 July 2014
Accepted 6 November 2014
Available online 2 January 2015

Keywords:
Deep Ion Beam Lithography
Diamond
Biosensors
Multi electrode array

ABSTRACT

In the present work we report about a parallel-processing ion beam fabrication technique whereby high-density sub-superficial graphitic microstructures can be created in diamond. Ion beam implantation is an effective tool for the structural modification of diamond: in particular ion-damaged diamond can be converted into graphite, therefore obtaining an electrically conductive phase embedded in an optically transparent and highly insulating matrix.

The proposed fabrication process consists in the combination of Deep Ion Beam Lithography (DIBL) and Focused Ion Beam (FIB) milling. FIB micromachining is employed to define micro-apertures in the contact masks consisting of thin (<10 μm) deposited metal layers through which ions are implanted in the sample. A prototypical single-cell biosensor was realized with the above described technique. The biosensor has 16 independent electrodes converging inside a circular area of 20 μm diameter (typical neuroendocrine cells size) for the simultaneous recording of amperometric signals.

1. Introduction

In the last decade diamond has attracted interest for the development of electronic devices with promising performances [1] owing to its extreme electrical properties. Significant effort has been made to optimize the interfacing of diamond with conventional electronics, resulting in the development of techniques for the fabrication of electrical contacts and electrodes in this material. Different approaches have been adopted, ranging from surface processing such as metallization [2] or hydrogen termination [3,4], to bulk doping achieved by ion implantation [5]. Moreover, high power pulsed laser was employed to promote the diamond graphitization both on the surface and in the bulk [6].

Besides the above-mentioned techniques, ion-beam-induced graphitization of diamond has been extensively investigated with Deep Ion Beam Lithography (DIBL) [7,8]. This approach takes advantage of the metastable nature of diamond, which can be converted into the stable allotropic form of carbon in ambient temperature and pressure conditions (i.e., graphite) by inducing high defect concentration in the lattice and by subsequently processing the material via thermal annealing [9]. The damaging with energetic ions in matter occurs mainly at the end of ion range, where the cross section for nuclear collisions is strongly enhanced [10], while the effects of electronic energy loss can be neglected in this material. In order to connect the buried implanted structures to the sample surface, a three-dimensional masking technique was developed to modulate the penetration depth of the ions from their range in the unmasked material up to the sample surface with increasing thickness of stopping material [7,8]. The permanent conversion of ion-implanted diamond to a graphite-like phase upon thermal annealing at high temperature (>900 °C) occurs when a critical damage density (usually referred to as "graphitization threshold") is overcome. Such threshold value has been estimated as 9×10^{22} vacancies cm^{-3} [11]. MeV ion beams focused to micrometric spot sizes have been employed in DIBL and opened the way to the fabrication of micro-structures in diamond.

Ion beam lithography in diamond was extensively applied for the fabrication of a broad range of devices: waveguides [12–14], photonic structures [15–17], micromechanical resonators [18–20]. The possibility of creating graphitic conductive regions allowed the fabrication of infrared radiation emitters [21], field emitters

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http://dx.doi.org/10.1016/j.nimb.2014.11.119
0168-583X/