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Micro and nano-patterning of single-crystal diamond by swift heavy ion irradiation

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ABSTRACT

This paper presents experimental data and analysis of the structural damage caused by swift-heavy ion irradiation of single-crystal diamond. The patterned buried structural damage is shown to generate, via swelling, a mirror-pattern on the sample surface, which remains largely damage-free. While extensive results are available for light ion implantations, this effect is reported here for the first time in the heavy ion regime, where a completely different range of input parameters (in terms of ion species, energy, stopping power, etc.) is available for customized irradiation. The chosen ion species are Au and Br, in the energy range 10–40 MeV. The observed patterns, as characterized by profilometry and atomic force microscopy, are reported in a series of model experiments, which show swelling patterns ranging from a few nm to above 200 nm. Moreover, a systematic phenomenological modeling is presented, in which surface swelling measurements are correlated to buried crystal damage. A comparison is made with data for light ion implantations, showing good compatibility with the proposed models. The modeling presented in this work can be useful for the design and realization of micropatterned surfaces in single crystal diamond, allowing generating highly customized structures by combining appropriately chosen irradiation parameters and masks.

1. Introduction

Structural damage induced in single-crystal diamond by ion irradiation has been studied in a variety of experimental configurations, which mostly include the use of medium/light ions at ~0.1–1 MeV energies for both fundamental studies [1–5] and device applications [6–9]. Remarkably, no systematic irradiation studies with swift heavy ion beams have been performed until very recently [10]. For all the data presented in this work, the damage generation mechanism can be attributed exclusively to nuclear stopping, since the electronic stopping force lies in the range below 14 keV/nm [2,3,10]. Due to the energy dependence of nuclear stopping, ion beams with high enough energy generate significant structural damage below the sample surface, whereas the surface layers undergo limited structural modifications. The length scales involved are typically in the micrometer range, both for the thickness of the undamaged surface layer and for that of the buried damaged one. The effect of the induced stress on the crystalline surface layer, generated by the expansion of the underlying damaged volume, gives rise to surface swelling, which has been observed and phenomenologically described in the light ion regime or at low ion energies [11–13].

The aim of this paper is twofold: firstly, to report the swelling effect in the swift heavy ion regime, comparing experimental results with the phenomenological model developed for light ions [12,13] in order to assess its validity also for swift heavy ions and, secondly, to highlight the potential exploitation of the swelling effect, with an extended range of input parameters offered by swift heavy ions of arbitrary species, to generate customized surface landscapes of lightly damaged diamond crystals with interesting aspect ratio characteristics. Phenomenological

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