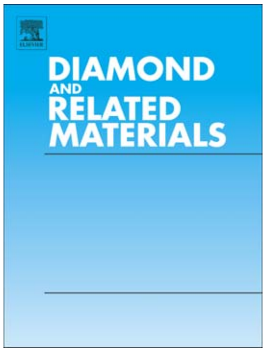

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PII: S0925-9635(17)30713-6
DOI: doi:10.1016/j.diamond.2018.02.013
Reference: DIAMAT 7039

To appear in: *Diamond & Related Materials*

Received date: 8 December 2017
Revised date: 13 February 2018
Accepted date: 18 February 2018

Please cite this article as: Samuel M. Parks, Richard R. Grote, David A. Hopper, Lee C. Bassett, Fabrication of (111)-Faced Single-Crystal Diamond Plates by Laser Nucleated Cleaving, *Diamond & Related Materials* (2018), doi:10.1016/j.diamond.2018.02.013

Fabrication of (111)-Faced Single-Crystal Diamond Plates by Laser Nucleated Cleaving

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Abstract

Single-crystal diamond plates with surfaces oriented in a (111) crystal plane are required for high-performance solid-state device platforms ranging from power electronics to quantum information processing architectures. However, producing plates with this orientation has proven challenging. In this paper, we demonstrate a method for reliably and precisely fabricating (111)-faced plates from commercially available, chemical-vapor-deposition-grown, type-IIa single-crystal diamond substrates with (100) faces. Our method uses a nanosecond-pulsed visible laser to nucleate and propagate a mechanical cleave in a chosen (111) crystal plane, resulting in faces as large as 3.0 mm × 0.3 mm with atomically flat surfaces, negligible miscut angles, and near zero kerf loss. We discuss the underlying physical mechanisms of the process along with potential improvements that will enable the production of millimeter-scale (111)-faced single-crystal diamond plates for a variety of emerging devices and applications.

Keywords: single-crystal diamond, cleaving, (111) orientation, surface roughness

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1. Introduction

Advances in homoepitaxial chemical vapor deposition (CVD) of high-purity single-crystal diamond (SCD) have made the exceptional material properties of SCD available for a variety of new and exciting applications [1–4]. In particular, the wide bandgap, high carrier mobility, large thermal conductivity, corrosion resistance, and biocompatibility of SCD have enabled new devices for high-power electronics [5], ultraviolet light sources [6] and detectors [7], nonlinear optics [8–10], quantum information processing [11], biomedical applications [12, 13], magnetometry [14], and integrated photonics [15–19].

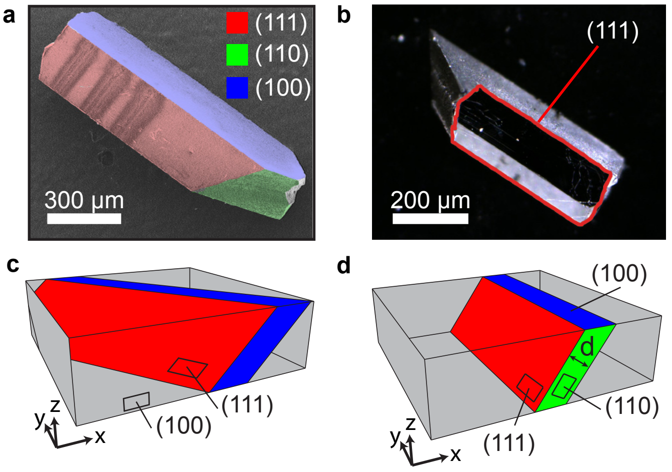

Figure 1: **Laser-nucleated cleaving of single crystal diamond.** (a) Scanning electron micrograph and (b) bright-field optical image of (111)-faced plates produced from a standard grade (SG) (100)-faced single-crystal diamond. Illustration of the orientation of a (111)-faced plate that can be produced from (c) an SG (100)-faced sample with (100) sides and (d) an electronics grade (EG) sample with (110) sides.

Many of these diverse applications benefit from the advantageous mechanical, thermal, and bond properties along $\langle 111 \rangle$. For example, the (111) crystal plane is the hardest face [20, 21], making it more resilient to damage and desirable for industrial scale diamond cutting tools [1]. Similarly, the Raman gain coefficient is strongest when the optical polarization axis is aligned along $\langle 111 \rangle$ [22, 23]. For this reason, integrating on-chip Raman lasers requires precise crystallographic orientation of the diamond layer to maximize the laser efficiency [10]. High-power electronic devices also benefit from (111) faces, which provide improved donor incorporation efficiency and correspondingly higher mobility [5, 24–28]. Finally, point defects in SCD that are used as single-photon sources and spin qubits, such as the nitrogen-vacancy and silicon-vacancy centers, have a symmetry axis aligned along $\langle 111 \rangle$ directions [29–32]. Thus, a (111) face maximizes the interaction with normally-incident light fields and optimizes the pho-

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Preprint submitted to Diamond and Related Materials *February 24, 2018*