Crack formation and cleaving of sapphire with ultrafast Bessel beams

L. Rapp, R. Meyer, L. Furfaro, C. Billet, R. Giust, and F. Courvoisier *
FEMTO-ST Institute, Université de Bourgogne-Franche-Comté UMR CNRS 6174,
25030 Besancon, France
(*) francois.courvoisier@femto-st.fr

Sapphire is a transparent crystalline dielectric of high hardness with many important applications, specifically to the next-generation touchscreens and to the LED growth, as substrates. However, sapphire cutting by ablative techniques is rather slow therefore fast material separation techniques are needed. Material separation by "stealth dicing" has been recently developed, it is based on material cleaving along a plane weakened by multiple ultrafast laser illuminations. This allows usually generating taper-free cutting and avoids material loss. However, the illuminated plane needs small spacing between the shot to shot (typically a few µm) and long damages inside the bulk. This requires lasers with both high repetition rate and high energy to allow high speed cutting and high aspect ratio damages.

Here we report a novel approach based on controlled crack formation in crystalline materials. We demonstrate the possibility to generate a crack in a single direction with a femtosecond pulse along one crystalline axis. The cracks can extend over more than 30 µm laterally and can be joined to form a plane of cleaving which requires much less laser pulses. We use Bessel beams to create longitudinally uniform damage [1] and we demonstrate the application to sapphire wafer cleaving.

Figure 1(a) compares the cracks formed by ultrafast Bessel beams in sapphire in single shot for the same orientation of the material and polarization, with 3ps pulses (left) and 140 fs (right). Cracks have been obtained at energies an order of magnitude higher that the energy necessary to create high aspect ratio nano-voids in sapphire [2]. The length of the cracks extends laterally up to ~ 30 µm depending on the pulse energy. Additional measurements show that the cracks longitudinally extend all along the length of the nondiffracting Bessel beam. We note on the figure that the transverse morphology is highly different between ps and fs regimes. While in the picosecond case, a 3-fold crack follows the axes of the hexagonal lattice of Oxygen in sapphire (Al_2O_3) [3], the femtosecond regime can create a crack in a single direction which is reported for the first time here.

We will report our experimental results on the dependence of crack formation on polarization, crystalline axes, translation direction and pulse duration. The parameter window that we identified allows us for creating joining lines of cracks along each of the material 3 main crystalline axes. We demonstrated successful cleaving of 150 µm thick sapphire with damages produced in single shot spaced by 20 µm and with only 20 µJ pulse energy. Optical and SEM images of a triangle separated from a sapphire wafer is shown in Fig. 1(b).

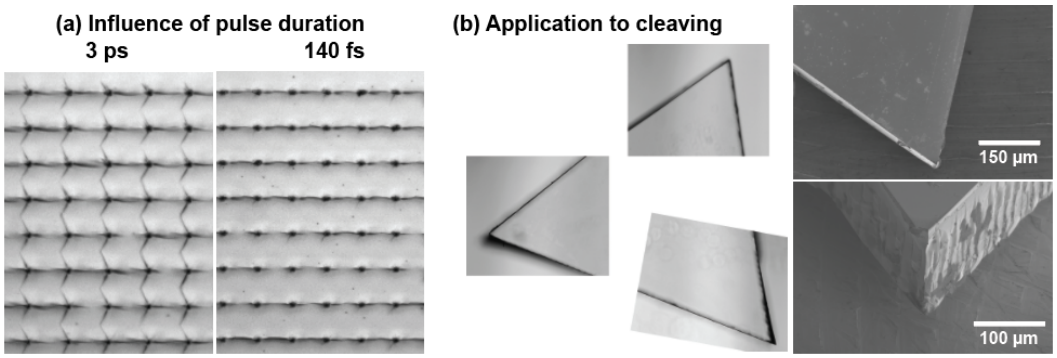

Fig. 1 (a) Comparison between picosecond (3 ps) and femtosecond (140 fs) regimes for crack generation in sapphire by single shot pulses. The cracks are produced with identical energy on horizontal direction (30 µm spacing) and the energy is increased from 20 to 30 µJ from bottom to top. (b) Application of crack formation to cleaving of sapphire along the crystalline axes with distant damages of 20 µm.

This approach therefore allows for fast and taper-free separation of sapphire without chipping and with low repetition rate femtosecond lasers. We expect this technique can be extended to other crystalline transparent materials for ultrafast laser material self-cleaving.

The research leading to these results has received funding from the European Union Seventh Framework Programme [ICT-2013.3.2- Photonics] under grant agreement No 619177 TiSa-TD. This work has been performed in cooperation with the Labex ACTION program, contract ANR-11-LABX-0001-01.

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