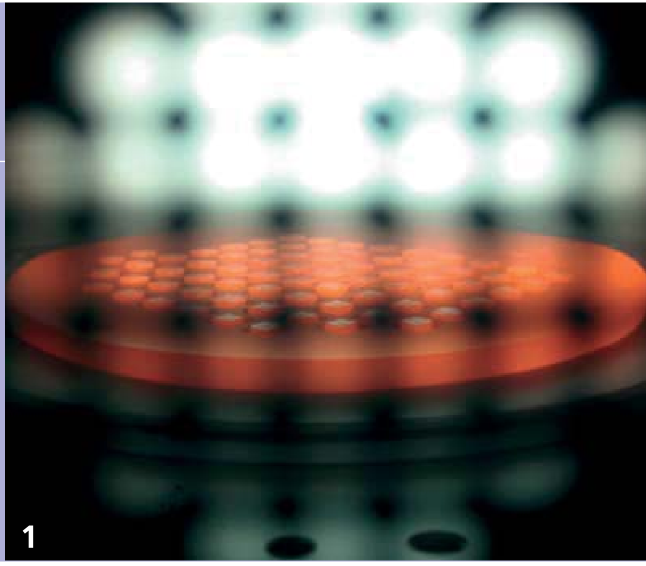


1

SEPARATION OF SINGLE-CRYSTALLINE DIAMOND PLATES BY MEANS OF ION IMPLANTATION

THE TASK

Large single-crystalline diamond plates, SCD for short, (<40 µm to 500 µm thick) are of considerable interest for applications in optical and X-ray optical components, radiation detectors and electronic devices. Currently, high quality diamond plates are available up to only about 10 mm edge length, since they are cut and polished from grown diamond crystals. Diameters of at least 50 mm are in particular demand for the production of diamond wafers for the semiconductor industry.

Natural jewelry diamonds are traditionally cut with rotating copper blades. This is a comparably imprecise process and not suited for high-tech applications. Increasingly, laser cutting is being used with good results for smaller cut depths (<10 mm), but there are also disadvantages. For one, the laser cutting profile is V-shaped, which causes considerable material losses at large cut depths. For another, the laser cutting creates a defect zone of several tens of micrometers, which must be removed by polishing after the cutting.

With respect to future developments of diamond plates with significantly larger dimensions, current separation technology is insufficient. The task therefore lies in the development of processes that allow the separation of large surface plates of diamond crystals without much loss of material and with minimum defect zones.

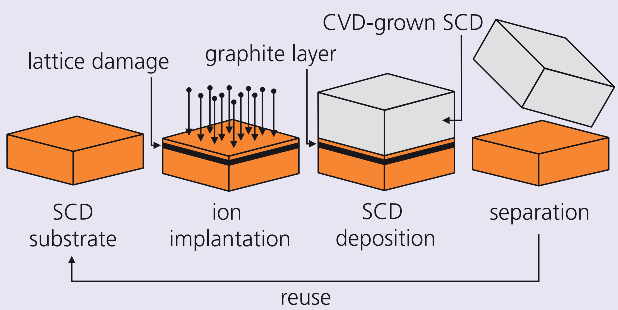
OUR SOLUTION

At the Fraunhofer Center for Coatings and Diamond Technologies CCD (see also p. 128), in close collaboration with Michigan State University and Western Michigan University, technologies are being developed that exploit ion implantation for the separation of diamond plates (Fig. 2).

The initial diamond substrate is first irradiated with highly energetic ions in order to produce a thin damage zone located a few micrometers underneath the crystal surface. This process is scalable to substrate sizes typical of the semiconductor industry. The crystal surface remains intact in the process, so that the following plasma CVD process can grow new diamond homoepitaxially.

Due to the high process temperature (900 °C) during CVD the damage zone inside the crystal graphitizes. After the growth process, the graphitized layer is removed through chemical etching in order to separate the newly grown diamond crystal from the substrate. The substrate is polished and used again for the next cycle.

Process schematic to separate diamond plates by means of ion implantation



2

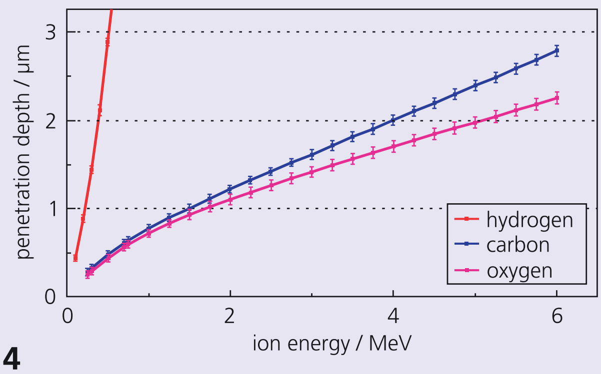
3

RESULTS

In preparation for the experiments, Monte Carlo simulations were carried out first, in order to find suitable ion energies. The energy must be sufficient to achieve a damage zone in the desired depth within the substrate crystal. The desired penetration depths are a few micrometers.

For the experiments, ion energies of 500 keV for protons, 3 MeV for carbon ions and 3.25 MeV for oxygen ions were chosen. The use of carbon ions has the advantage that no additional chemical elements are introduced into the diamond crystal. Oxygen ions, on the other hand, assist and accelerate the subsequent etching process. Protons have an essentially higher penetration depth in comparison to the heavier ions of comparable energy. This is of interest for further applications of the implantation technology.

Penetration depths of hydrogen, carbon and oxygen ions in diamond crystals as a function of the ion energy (SRIM Monte Carlo Simulations, Stopping Range of Ions in Matter)

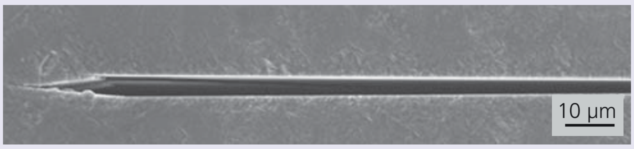


4

The ion implantation experiments were carried out with a 6 MeV Van de Graaff tandem accelerator at Western Michigan University. A special sample holder allows the stepwise irradiation of substrates with dimensions up to 75 mm x 75 mm (Fig. 3).

Immediately after the ion implantation process, the irradiated substrates appear dark. If the substrate remains dark after the CVD diamond growth, the experiment was successful and the damage zone could be removed. This happens, for example, through thermal oxidation at temperatures of 550 – 580 °C. In this temperature range, the graphitic carbon phase oxidizes to CO and CO_2 while the diamond phase does not oxidize. Figure 4 shows an SEM picture of the etched damage zone after the oxidation process. Figure 3 shows CVD diamonds of various shapes and sizes that are separated through the described process.

SEM image of a diamond substrate crystal. The dark horizontal line is the area of the damage zone, which was removed by chemical etching.



5

1 *Fabrication of 70 diamond crystals in plasma CVD process*

3 *CVD Diamonds of different sizes and shapes, separated by ion implantation and thermal oxidation*

CONTACT

M.Sc. Michael Becker

☎ *+1 517 353 8181*

✉ *mbecker@fraunhofer.org*