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# Development of large size diamond wafer
# 大型ダイヤモンドウェハの開発

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## 1. Introduction

Diamond has extremely high material characteristics such as elastic constant, thermal conducivity, breakdown field, optical transparency, bandgap, mobility etc, due to its tight binding of the crystal lattice made up of sp3 bonding by carbon. Thus this material is a hopeful candidate for various kind of applications including ultimate low loss power switching device and acoustic wave devices. The application has been limited for cutting tools and heatsinks because of its small size substrates such as 8x8mm$^2$ at maximum. On the other hand, poly-crystalline diamond with the wafer size up to 3 inch has been applied for high frequency SAW devices [1-3]. However due to the micron size crystal boundaries, the propagation loss was large and further reduction in propagation loss (PL) by applying single crystalline diamond is required for lower loss devices.

There are two way to reduce PL.

(1) Fine grain diamond: This had been realized by SiO2/ZnO/small grain size poly-crystalline diamond [4] and the PL of the 2port resonator was reduced from 0.035 to 0.02dB/λ at 2.5GHz and from 0.066 to 0.042 dB/λ. This material had been applied for various kind of filters[3].

(2) Single crystal diamond: This has been studied by AlN/single crystal diamond and the PL of 1port resonator was reduced from 0.076 to0.018 dB/λ at 5GHz.[5] However, this has not been applied in real applications because the size of the limited size of single crystal diamond such as 4x4mm2 and it is too far from the conventinal wafer size.

Recently we have developed two sophisticated breakthrough techniques to enlarge the size of the diamond. The first one is the “copying technique” which we call “direct wafer fabrication technique” to fabricate diamond wafer without slicing. The second one is the “mosaic technique” to have large size substrate by connecting several “clone wafers” obtained by copied wafers. In this paper, we present the results of recent results for above techniques.

## 2. Copying technique

First, we have started the program toward large size diamond substrate by utilizing 3D growth technique that resemble “RAF method” for SiC growth to some degree, and starting from several mm square HPHT grown substrate, up to 1/2 inch size was obtained by using 2.45GHz microwave CVD. However, the slicing diamond substrate from the bulk crystal by YAG laser has large drawback of loosing diamond itself. Thus we have tried to develop “wafer copying technology”, which we call “Direct wafer fabrication method”. This fabrication process is schematically shown in Fig.1 with photographs of substrate copies.

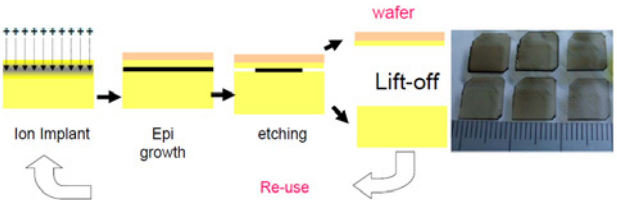


Fig.1 Fabrication process of diamond by copying which we call “Direct wafer fabrication method”

Here, we have employed ion implantation to form damaged layer in sub-surface (eg, 1.6μm underneath the surface by 3MeV impantation), which was followed by diamond epitaxial growth and lift-off [6]. By the temperature around 1000° C during the diamond epi-growth process, the highly damaged layer convert to graphitic layer and this layer is finally removed by lift-off process. The substrate lifted-off will be the wafer, which we call “clone daughter wafer”. Here, the mother substrate will be re-used to generate 2$^{nd}$ wafer, 3$^{rd}$ wafer, etc. The feature of this method is the affinity of sisters that have same crystallographic off-angle and off-direction. And even the crystal defects appear in the same place. We might add that for ion implantation process, conventional low energy ion implant such as 200keV can be used for the process, although we have started from using deep implant of 3MeV. Thick diamond growth on one of the daughter can be used as the next “mother” wafer, thus, the “grand daughters” can be obtained.

## 3. Mosaic technique

Using daughter wafers obtained by above copying technique, we have developed another technique of “Mosaic wafer” fabrication for large size wafer. Several daughter substrates are jointed by CVD growth, and applying the “Direct wafer fabrication method” to this, we can obtain large size monolithic diamond substrate[7]. The “clone daughter wafers” have same off angle and direction, thus the “step flow growth” along the step across the wafers are possible. This process is shown in Fig.2 with the photograph of nearly 1 inch wafer which consist of 4 single crystal plates. Mosaic wafer has joint area and is not a complete single crystal, however, it can be regarded as the wafer with prior dicing line. Single crystal plate area of 10x10mm2 is enough for most of the devices for power and SAW applications. The mechnical strength of the jointed line is very high and in the case of wafer breakage, this “Mozaic wafer” break along the crystal cleavage direction of <111>. Currently, we have wafers as large as 20x40mm$^2$ which is made up of 8 clone daughters. Our next target is 2inch diamond mosaic wafer, which will be realized within a year. With the high power growth CVD system, we can step up to 3, 4 inch size wafer in near future.

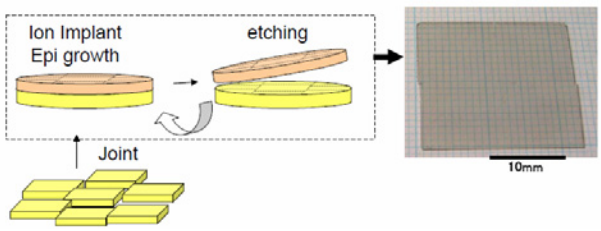


Fig.2 Fabrication process of making large size single crystal diamond which we call “Mosaic wafer”. The photo is 20x20mm2 wafer made up of 4 clone daughters.

## 4. Material candidate for sustainable frequency devices

Frequency control devices are the inevitable for all of the electronics systems adding further importance in wide spread applications in mobile. However, the bulk materials containing Li, Nb, Ta etc are still widely used in the devices. As it is well known that these elements are the “rare metals” and their “reserves” on earth is very limited. Thus, the next research topic might be in following two topics.

1) Rare metal free device by using alternate piezo-electric materials.
2) Reduction of rare metal by thin film.

In both cases, diamond will be very good substrate candidate for high frequency applications and the typical structures are shown in Table 1, which covers from narrowband to wideband applications.

Table 1. Material candidates for sustainable device

| | Phase velocity (m/s) | $K^2$ (%) | TCF (ppm/deg) |
|---|---|---|---|
| ZnO/diamond | 11600 | 1.2 | 22 |
| $SiO_2$/ZnO/diamond | 10400 | 1.4 | 0 |
| AlN/diamond | 10000 | 1.05 | 20 |
| $SiO_2$/AlN/diamond | 11120 | 0.7 | 0 |
| c-$LiNbO_3$/diamond | 11890 | 9.0 | 25 |
| $SiO_2$/ c-$LiNbO_3$/diamond | 12100 | 10.1 | 0 |
| $LiNbO_3$/diamond | 12600 | 16.0 | 25 |
| $KNbO_3$/diamond | 12600 | 38.0 | |

## 5. Conclusion

With the recent two breakthrough techniques of “Copying” and “Mozaic”, single crystal diamond will have big change in near future for large size wafer realization. It is expected as the sustainable devices with reduction of rare metals such as Li, Nb,Ta and etc.

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