# 3P3-2

# Evaluation wide band high frequency diamond SAW resonator using hetero-epitaxial diamond substrate

ヘテロエピタキシャルダイヤモンドを用いた広帯域・高周波 SAW デバイスの作製・評価

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## 1. Background

The demand for broadband is increasing with explosive communication market of mobile systems. In 5G communication systems, 10 to 20Gbps broadband systems with very small network delay of less than 1msec are planned, using high frequency band from 3.5 to 6GHz. Recently, five 100MHz bands from 3.6 to 4.1GHz and one 100MHz band from 4.5 to 4.6 GHz were allocated in Japan. It is an urgent challenge to realize 100MHz wideband SAW filters in the high frequency application. SAW devices using conventional materials such as LiTaO3 and LiNbO3 suffer high power durability as well as the ultra-fine lithography fabrication processing. High frequency SAW technology is receiving much attention using piezo-electric thin film on high velocity substrate. Poly-crystalline diamond has the largest elastic constant amongst all the materials, and it can be used as high velocity SAW substrates. SiO2/ZnO/Diamond narrow band SAW devices for high frequency communication system had been developed and put into practical use in early 2000s for 1.8-3.6 GHz narrowband applications [1]. Recently, high $K^2$ ScAlN piezoelectric thin film on single-crystal diamonds showed excellent SAW properties for high frequency and wideband applications [2]. In this paper, we studied SAW resonators on ScAlN on poly-crystalline diamond substrate and hetero-epitaxial diamond subsutate, evaluated the device characteristics on them.

## 2. Experimental

We prepared the high velocity diamond substrates (Single Crystalline Diamond, Poly Crystalline Diamond and Hetero-epi Diamond). Hetero-epi diamond substrate was made using micro-needle method by Namiki Precision Fewel Co., Ltd [3]. The surface roughness of Hetero-epi Diamond substrate is enough smooth for SAW device (Fig. 1). AlN buffer layer (120 nm) and ScAlN piezo-electric thin film (1000 nm, 1300 nm) were formed by magnetron sputtering method on diamond substrates. Inter Digital Transducers (IDTs) were formed by Al/Cr (90 nm/5 nm) by EB lithography and lift off methods. The IDTs were fabricated by L/S=0.5 and 0.8μm, 90 pairs with 10 reflectors (Fig. 2). Then, we evaluated the SAW resonance characteristics around 2GHz and 3 GHz. It needs to remove the roughness on the electrodes to reduce the propagation loss.

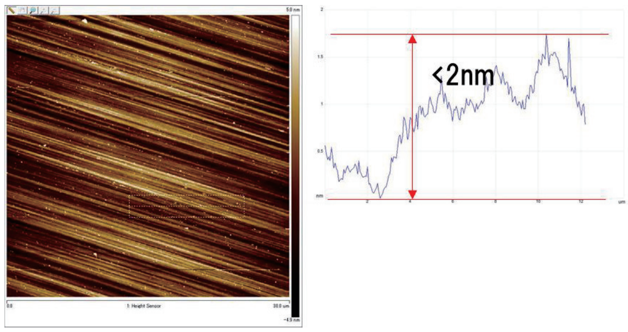



Fig. 1 Surface roughness of Hetero-epi Diamond substrate measured by AFM

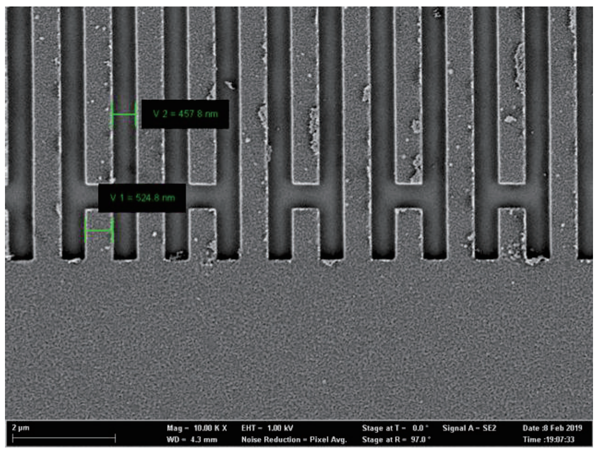
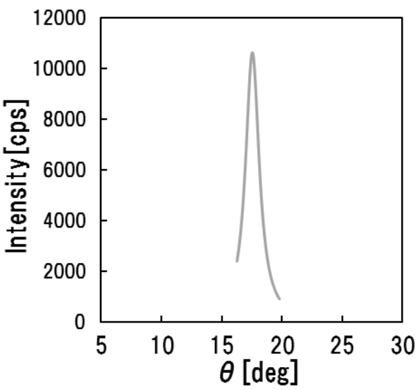



Fig. 2 SEM image of IDTs on ScAlN/Hetero-epi Diamond substrate

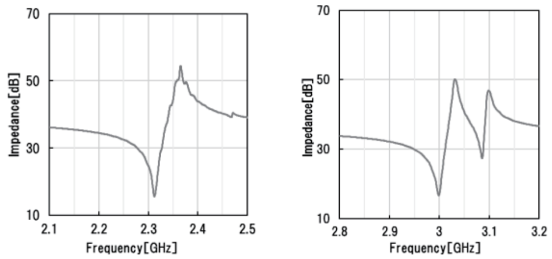
## 3. Result and Discussion

We measured the c-axis orientation of ScAlN thin film on Single Crystalline Diamond, Poly Crystalline Diamond and Hetero-epi Diamond by XRD measurement. The FWHM using XRD measurement were 1.9 deg, 2.1 deg and 1.4 deg, respectively and it means ScAlN thin films on these diamonds were showed c-axis orientation. The FWHM value of the ScAlN thin film (0002) on Hetero-epi Diamond substrate was smaller than other substrates (Fig. 3). Then we evaluated the characteristics of secondary mode of one port SAW resonator around 2GHz and 3GHz. High K2 (6.38%, 5.10%, 5.40%) resonance characteristics were showed with the all devices around 2GHz. Around 3GHz, high K2 (6.10%, 4.45%) were seen using Single Crystalline Diamond and Poly Crystalline Diamond substrates. On the other hand, Hetero-epi Diamond SAW resonator showed the lower K2 (2.26%) characteristic around 3GHz. However, this value is enough large than conventional diamond SAW devices (SiO2/ZnO/Diamond, AlN/Diamond structure) and expected as high frequency and wide band SAW devices (Fig. 5). In addition, Hetero-epi diamond can grow larger easily than Single Crystalline Diamond and has no grain boundary like Poly Crystalline Diamond. Poly Crystalline Diamond's grain boundary cause propagation loss and reduce Q value shown Fig. 5. It means Hetero-epi diamond has the enough potential as SAW device's high velocity substrates.




| θ [deg] | 17.512 |
|---|---|
| Intensity[cps] | 10625 |
| FWHM[deg] | 1.384 |

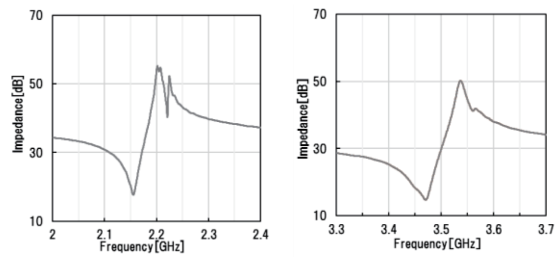
Fig. 3 FWHM using XRD measurement of ScAlN/Hetero-epi Diamond substrate




| | resonance |
|---|---|
| Frequency[GHz] | 2.31 |
| Q | 330 |
| K2[%] | 5.40 |
| V[m/s] | 7400 |

| | Resonance |
|---|---|
| Frequency[GHz] | 3.00 |
| Q | 339 |
| K2[%] | 2.26 |
| V[m/s] | 6000 |

Fig. 4 ScAlN/Hetero-epi Diamond SAW characteristics around 2GHz and 3GHz




| | resonance |
|---|---|
| Frequency[GHz] | 2.16 |
| Q | 197 |
| K2[%] | 5.10 |
| V[m/s] | 6898 |

| | resonance |
|---|---|
| Frequency[GHz] | 3.47 |
| Q | 183 |
| K2[%] | 4.45 |
| V[m/s] | 6860 |

Fig. 5 ScAlN/Poly Crystalline Diamond SAW characteristics around 2GHz and 3GHz

**Acknowledgment**
We would like to thank Murata Manuf. Co., Ltd., for their support.
This R&D was commissioned by the Ministry of Internal Affairs and Communications SCOPE (Accession No. 195007001).

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