HIGH FREQUENCY SAW FILTER ON DIAMOND

K. Higaki, H. Nakahata, H. Kitabayashi, S. Fujii, K. Tanabe,
Y. Seki and S. Shikata
Itami Research Laboratories, Sumitomo Electric Industries, Ltd.
1-1-1, Koya-kita, Itami, 664 Japan

ABSTRACT

Surface acoustic wave (SAW) filters based on diamond which has very high SAW velocity have been investigated. 2.5 GHz low loss narrow-band filter and 1.5 GHz IF filter were demonstrated by the SiO2/ZnO/diamond structure with zero temperature coefficient of frequency and the ZnO/diamond structure, respectively. The super-high power durability of the ZnO/diamond structure was also confirmed at 2.9 GHz. Diamond SAW filters having high velocity and high power durability, can be expected for broad applications on future high frequency communication systems.

INTRODUCTION

For the increasing demands for large data volume transmissions and mobile communications, several digital communication systems with high frequency bands ranging from 1.5 GHz to 2.5 GHz are in course of realization, such as Personal Communication Systems (PCS) and Future Public Land Mobile Telecommunication Systems (FPLMTS). For optical fiber communication systems, high bit rate data transfer such as 2.488 Gbps is already used for public communication network. For these communication systems, the high frequency SAW filters are used as band pass filter or retiming filter of radio frequency (rf). But, for conventional SAW devices which are composed of piezoelectric bulk crystals such as quartz, LiNbO3 and LiTaO3, the fine pattern lithography is necessary to obtain these high frequency devices due to their low SAW velocities from 2,500 to 4,500 m/s. Reduction of the electrode size is suffered from the problems such as reliability, power durability and fabrication margin in manufacturing process. Thus, the high velocity materials are required for SAW filters operating at high frequency. For these four years, we have been developing the diamond/Si wafer and studying characteristics of SAW filters based on diamond which has very high SAW velocity. For the diamond/Si wafer, the 3 inch wafer have been developed so far, as shown in Fig. 1, which is applicable to the conventional photolithography process. We have fabricated various SAW filters on these diamond/Si wafers with the aluminum inter digital transducers (IDTs) and the piezoelectric ZnO film, and found that this material is practical for high frequency SAW filters[1-5]. In this paper, the characteristics of the diamond SAW filters are summarized including late results on some practical high frequency SAW filters.

DIAMOND SAW STRUCTURES AND THEIR CHARACTERISTICS

The structures of diamond SAW filters including schematic diagrams and their SAW characteristics were summarized in Table 1. IDT/ZnO/diamond structure have the velocity of more than 10,000 m/s and coupling coefficient (K2) value of more than 1 %. Utilizing the

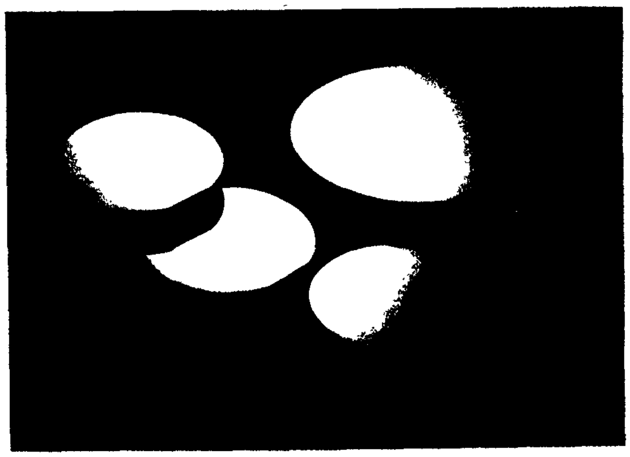
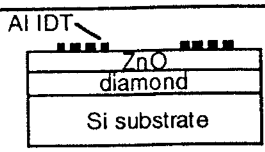
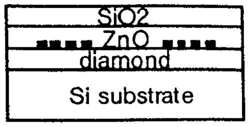
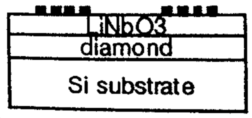


Fig. 1. Photograph of 2 inch and 3 inch diamond wafers.

Structure	IDT/ZnO/diamond	SiO2/ZnO/IDT/diamond	IDT/LiNbO3/diamond
Cross-section			
Velocity (m/s)	11,600	9,000	11,900 (calc.)
Coupling coefficient (%)	1.1	0.4	9.0 (calc.)
Temperature coefficient of frequency (ppm/°C)	-28	~0	-25 (calc.)
Application	power durable RF	narrow band (retiming, resonator)	wide band

high velocity, a 2.5 GHz filter was fabricated with almost 1 μm line-and-space (L&S) IDTs. The SAW filters with the center frequency of 3.4 GHz and 4.7 GHz were also successfully fabricated with almost 0.8 μm and 0.6 μm L&S IDTs, respectively. This results suggests the great advantage of the diamond SAW filter in manufacturing and the reliability of high frequency devices compared with the conventional materials, as shown in Fig. 2. The SiO2/ZnO/IDT/diamond structure can provide zero temperature coefficient of frequency (TCF) as well as high velocity of 9,000 m/s and relatively high K2, which indicates that this structure is suitable for narrow band filters in high frequencies such as a resonator and a retiming filter in optical communication systems. It was also found by theoretical calculations using Campbell's method that IDT/LiNbO3/diamond structure have potential of high K2 of 9 % with high SAW velocity of 11,900 m/s, as can be seen Table 1. Thus, this structure is expected to be used for wide band filters in GHz range systems. As shown in Table 1, the SAW filters based on diamond with varieties of structures have high potential for various types of high frequency applications.

POWER DURABILITY

We have also investigated the power durability of the ZnO/diamond SAW filter with the IDT electrode width of 1.0 μm, and compared with the LiTaO3 SAW filter with the same IDT pattern[6]. The ZnO/diamond SAW filter maintained the linearity of input-output relation up to the input power of 35 dBm at 2.9 GHz, whereas the LiTaO3 SAW filter which operated at 822 MHz lost the linearity above the input power of 25 dBm and finally degraded at the input power of 28 dBm. Fig. 3 shows SEM photographs of these filters after the high power application. There was no change on the IDT of the ZnO/diamond SAW filter. But for the LiTaO3 SAW filter, melting of the electrodes and cracks on a surface of the LiTaO3 substrate were observed mainly at the edge of the IDT. It was also found by measuring the time of failure of these filters, that the ZnO/diamond SAW filter was durable for almost 8 dB higher input power than that of the LiTaO3 SAW filter even at the 3.6 times higher frequency, as shown in Fig. 3. Thus, it is expected that the ZnO/ diamond SAW filter, which operates at the same

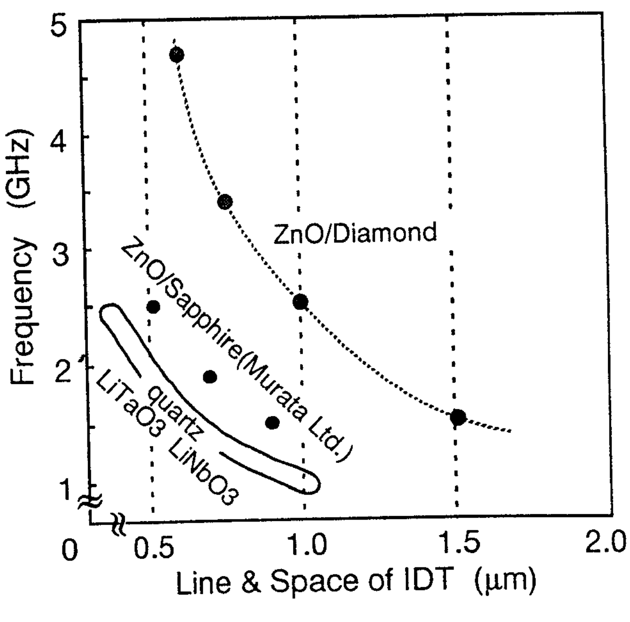
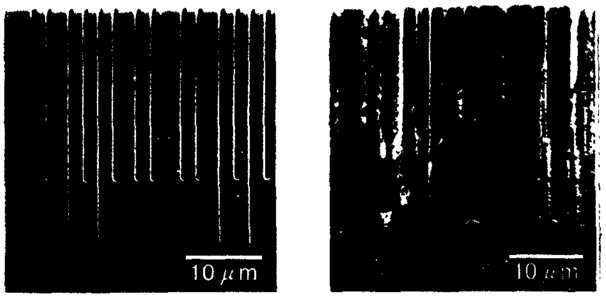


Fig. 2. IDT size dependence of frequency for various kinds of SAW materials



(a) ZnO/diamond (b) LiTaO3

Fig. 3. SEM images of IDTs of (a)ZnO/diamond and (b)LiTaO3 SAW filters after high power measurements, with the applied powers of 36dBm and 28dBm, respectively. (IDT size is 1.0μm.)

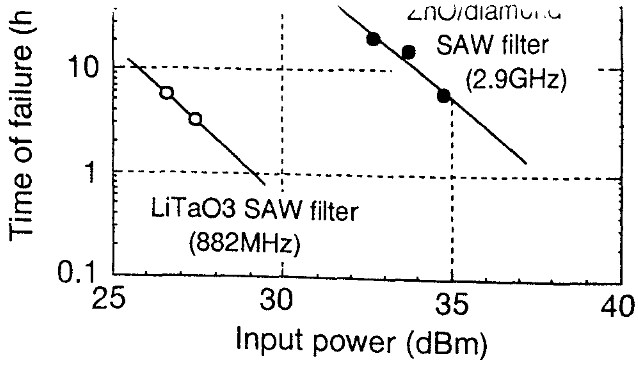


Fig. 4. Input power dependence of time of failure of ZnO/diamond and LiTaO3 SAW filters. These measurements were carried out at 120°C, with the testing devices in ceramic packages. (IDT size is 1μm)

frequency as the LiTaO3 SAW filter, has much higher power durability, because of the 3 times larger scale IDT associated with material characteristics. These results indicate that the ZnO/diamond SAW filter has the super-high power durability. The degradation of SAW devices with the high power input is induced by stress migration of Al electrodes, which is accelerated by the temperature rise and the large displacement of the substrate surface which occurs with SAW propagation. The result on power durability of the ZnO/diamond SAW filter is presumably due to both small temperature rise and small displacement of surface, which come from the high thermal conductivity and high elastic constant of diamond, respectively. Thus, it is considered that the ZnO/diamond SAW filter which has the super-high power durability, can be expected as transmission RF filters and duplexers operating at high frequency and high power.

FABRICATION OF HIGH FREQUENCY FILTER

For the demonstration of the diamond SAW filters, 2.5 GHz narrow-band filter[7] and 1.5 GHz IF filter[8] have been designed and fabricated. 2.5 GHz narrow-band filter was fabricated with SiO2/ZnO/IDT/diamond structure with IDTs of 0.9 μm L&S. As shown in Fig. 5, its typical Q value was 660 that is large enough to be used for retiming in optical communication system, and the insertion loss was as small as 10 dB which is 5 to 10 dB smaller than those reported with ST quartz substrate. The measured temperature dependence of the shift of the center frequency is shown in Fig.6. It gives small temperature dependence comparable to that of ST quartz whose characteristic is also shown in Fig. 6 as a reference. The frequency shift in the range from 20 to 80 °C was no more than 70 ppm. Considering the application for the retiming of the 2.488 Gbps system, the center frequency of the filter should be tuned exactly to 2.488 GHz, and this can be achieved by surface etching treatment using plasma process. These results indicate that this filter has practical and superior characteristics for the 2.5 GHz retiming filter in optical communication systems. The high frequency IF filter was also fabricated with ZnO/IDT/diamond structure with apodized double type IDTs of 0.75 μm L&S. Fig.

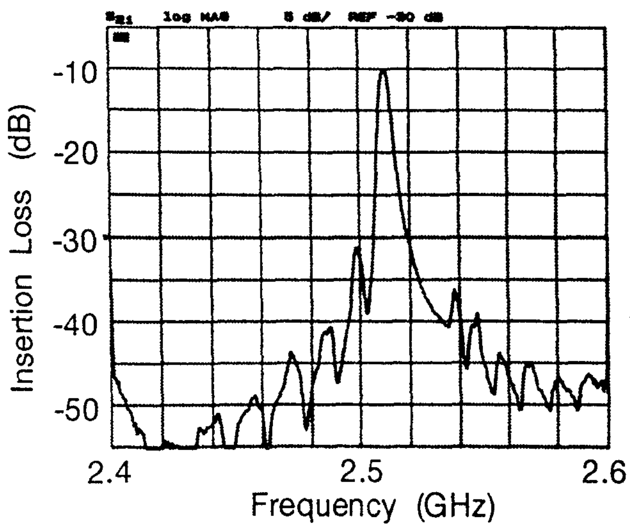


Fig. 5. S_{21} characteristics of narrow band SAW filter of SiO_2/ZnO/IDT/diamond structure. Line and spaces of IDT are 0.9 μm.

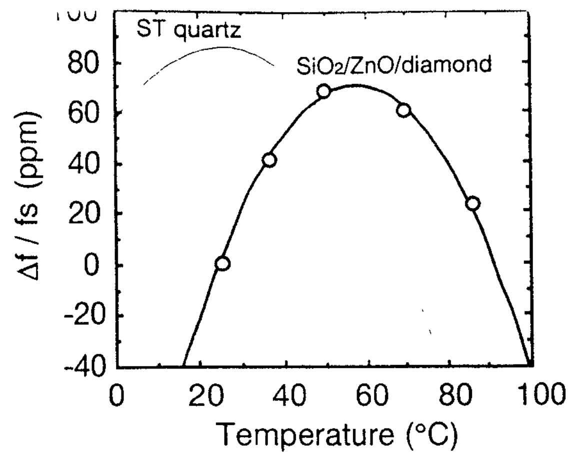


Fig. 6. Temperature dependence of frequency shift measured for SiO_2/ZnO/IDT/diamond SAW filter. ($\Delta f = f - fs$, f : frequency at measured temperature. fs : frequency at 25°C for SiO_2/ZnO/diamondand at 70°C for quartz.)

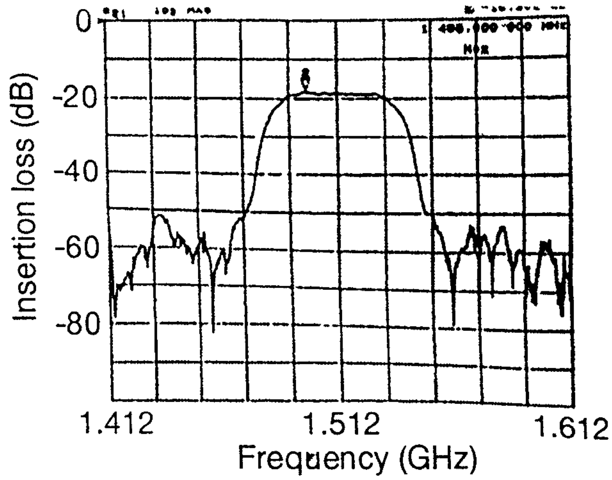


Fig. 7. S21 characteristics of 1.5GHz IF filter of ZnO/IDT/diamond stracture[7]. Line and spaces of double type IDT are 0.75 μm

7 shows the frequency response of the IF filter. Its bandwidth was 45 MHz and insertion loss was 18.3 dB, which indicates that this SAW filter is expected to be the first IF filter of the microwave and millimeter-wave communication system.

CONCLUSION

SAW characteristics of the diamond SAW filters were summarized, which indicates that the high velocity of more than 10,000 m/s and coupling coefficient value of more than 1 % can be provided by IDT/ZnO/diamond structure and zero temperature coefficient of frequency as well as high velocity of 9,000 m/s can be provided by the SiO2/ZnO/IDT/diamond structure. The power durability of the ZnO/diamond SAW filter was also investigated. It was found that the ZnO/diamond SAW filter is durable for the high input power; 8 dB higher than that of the LiTaO3 SAW filter even at 3.6 times higher frequency. For the demonstration of the diamond SAW filters, 2.5 GHz narrow-band filter and 1.5 GHz IF filter were fabricated. It was found that these filters had practical and superior characteristics and were expected to be the 2.5 GHz retiming filter in optical communication systems and the first IF filter of the microwave and millimeter-wave communication system, respectively. As shown above, the varieties of material systems of the diamond SAW filters associated with high velocity and high power durability, will find broad applications in high frequency SAW devices.

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