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Diamond-based surface acoustic wave devices

Joana Catarina Mendes[1], D. Mukherjee[1], D.M. Santos[2], M. Fernandes[2]
[1]TEMA, [2]IT

Abstract

Surface acoustic wave devices have been used since 1960's in electronics and telecommunications and have become critical components for wireless communication systems. Other applications include remote RF identification or their use as sensors.

Physical aspects such as the velocity of propagation of the acoustic waves determine the SAW's usefulness. Diamond comes as an interesting candidate for the fabrication of SAW devices since it has a large wave propagation velocity (14 mm/μs for longitudinal waves against 8.9 mm/μs in SiO_2), raising interesting possibilities in designing faster and more compact devices (both for sensing and as circuit elements).

However, diamond is not, by itself, a piezoelectric material, so it has to be used together with a proper piezoelectric substrate, such as lithium niobate, a material widely used for the fabrication of SAW devices. A thin diamond film can be deposited on the device by chemical vapour deposition, opening the door to the fabrication of diamond-based SAW devices with improved characteristics.

Introduction

The propagation of a mechanical vibration on the surface of a solid (a surface acoustic wave or SAW) was described still in the 19th century by Lord Rayleigh [1]. These waves are similar to longitudinal seismic waves, in the sense that they only penetrate solids up to a depth of the order of magnitude of the wavelength, they undergo little attenuation as they progress on the surface, and the movement of particles in the solid is elliptical. These waves can be coupled to any medium in contact with the surface. If, on the other hand, the medium where the waves propagate is piezoelectric, an electric signal can be transduced into a mechanical vibration, thus opening the possibility of a device based on SAWs to be used as an electronic component.

SAW devices have become critical components for wireless communication systems. In fact, the increasing demand for large volume data transmission requires an increasing number of devices operating at high frequencies. SAW filters can be used as reflective delay lines, resonators, impedance sensors, fixed-code ID tags and a wide variety of sensors (temperature, pressure, torque, current and even chemical sensors) [2]. They provide passive solutions that require no internal source of electrical power, and can be remotely interrogated by means of an RF beam at the appropriate frequency. With proper signal-processing hardware, SAW devices can provide for the replacement of many transducers that are at present expensive or hard to use, such as strain gages.

The operating frequency of the device is determined by (i) the propagation velocity and (ii) the wavelength of the acoustic waves. This, in turn, depends on the IDTs spacing. It becomes obvious that, in order to increase the operating frequency, either piezoelectric materials with high propagation velocities should be used, or the IDTs should be made smaller.

The minimum thickness of practical IDTs lies in the micron range, so materials with high propagation velocities are in constant demand.

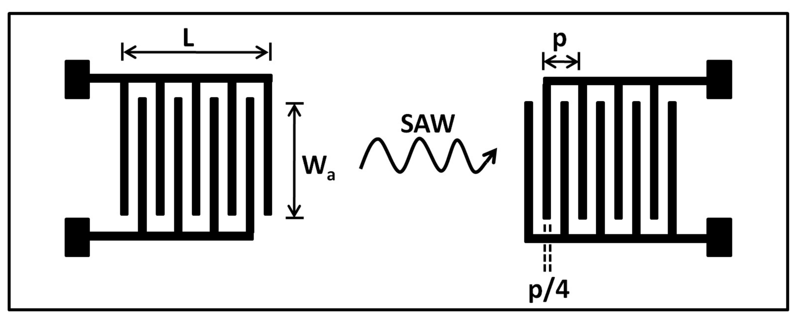

Fig.1 A SAW device in the form of a slab with an IDT at either end

Thanks to its increased resonance frequency, high values of the electromechanical coupling coefficient and a high mass sensitivity, chemical vapour deposited (CVD) diamond is one of the most attractive materials for SAW devices [3]. In addition, diamond films can be used as an effective protective layer, since CVD diamond will survive in harsh radiation environments [4].

As the SAW operation requires an electromechanical conversion, a piezoelectric layer such as ZnO or AlN is required and the metallic IDT are deposited on the diamond surface. Different SAW devices using diamond films have already been reported [3,5].

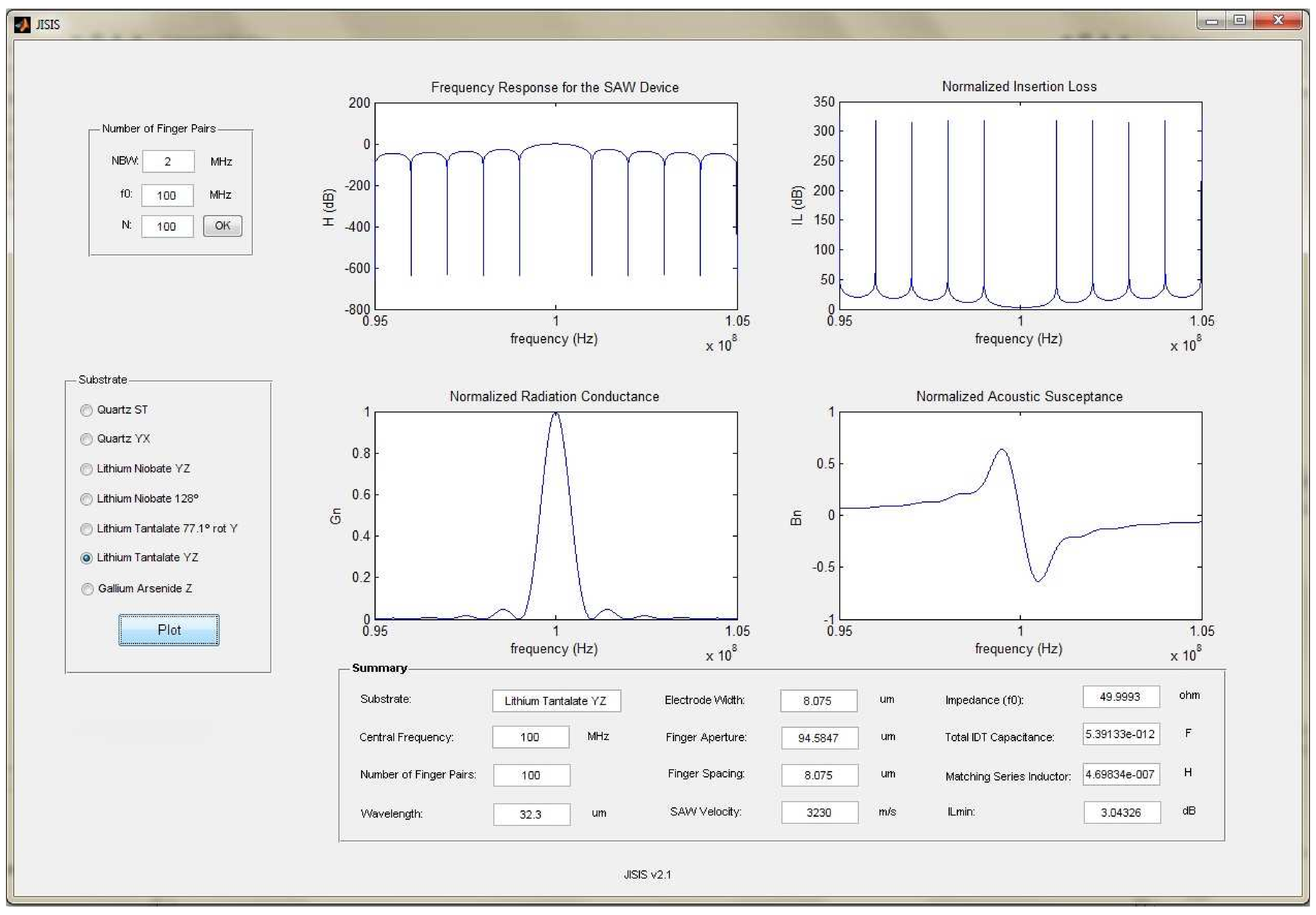

Fig.2 Simulator interface

SAW simulation

While being devices widely used in the applications listed above, the implementation of suitable and practical simulation methods for surface acoustic wave devices is still a major aim for designers, as they allow for speedy and accurate prediction of the characteristics of the devices before fabrication.

In order to predict the behavior of SAW devices, a general program was built in MATLAB to simulate the devices characteristics. The simulator is based on the impulse response method [6] and has an interface that allows the user to calculate the number of finger pairs of the IDT, in order of the bandwidth and frequency that the user chooses. Furthermore, the simulator also allows the choice of various types of substrates – Fig. 2.

The simulator was validated by comparing the simulated and measured response of commercial SAW devices. Fig. 3 presents the response of the S321273 filter, by SAWTRON.

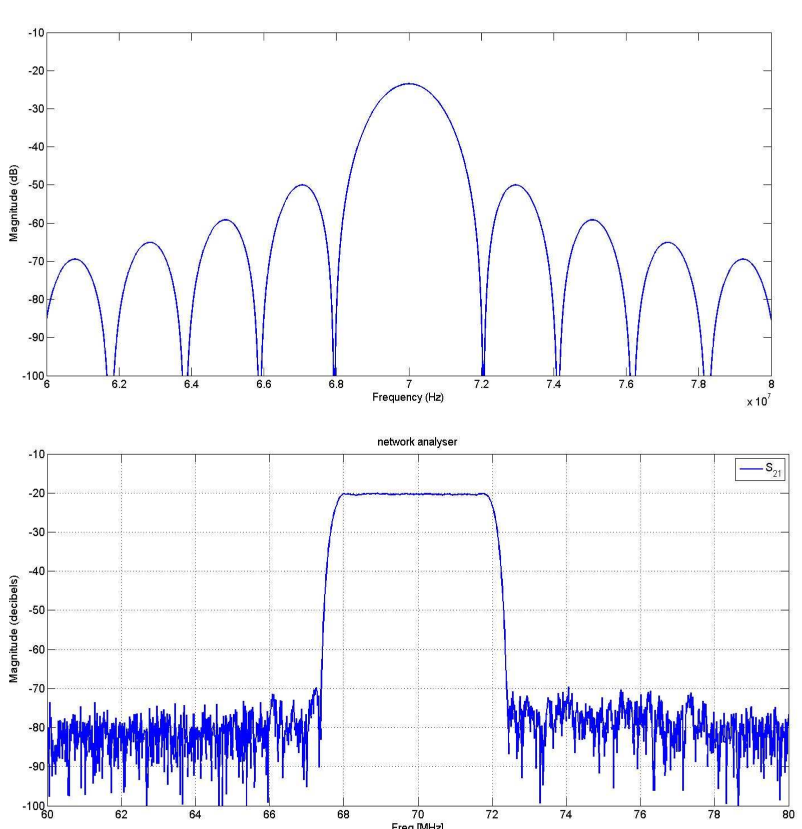

Fig.3 Response of the S321273 SAWTRON filter: simulated (top) and measured (bottom).

Diamond deposition

After the fabrication of the devices, by means of patterning proper IDTs on the piezoelectric surface, the whole set will be coated with diamond.

Diamond can be deposited by CVD on different substrates with complex shapes – Fig. 4.

However, the deposition of diamond on piezoelectric substrates is not a straightforward task, due to phase transition temperatures below the diamond deposition temperature or even to changes in the material structure.

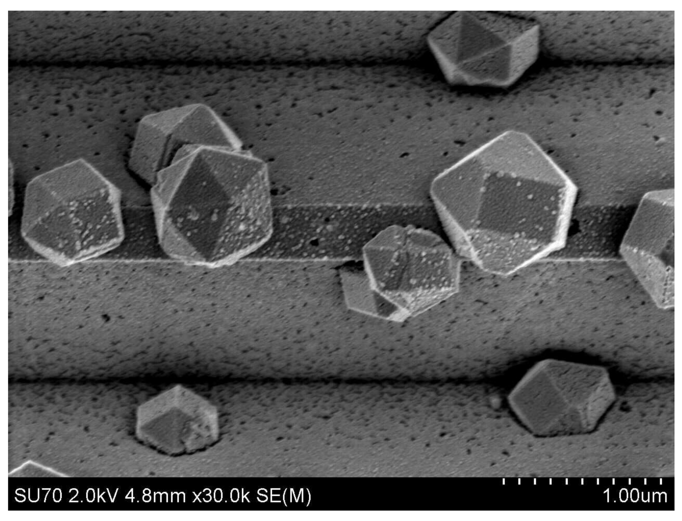

Fig.4 Diamond-coated silicon V-grooves

Conclusions

The deposition of diamond on the SAW devices will provide a simple means of increasing their operating frequency. It will also protect them against wear or corrosion, making them capable of operating under extreme hostile environments.

References

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