Optimization of surface acoustic wave devices

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Surface acoustic waves (SAWs) are mechanical waves generated at the surface of an elastic material. Their amplitude decays exponentially away from the surface and their penetration depth is of the order of the acoustic wavelength. This means that SAWs have a very high energy density confined to the surface, hence the name surface acoustic waves. The excitation of SAW is achieved by the application of an oscillating potential to an interdigital transducer (IDT) that consists of periodic metal electrodes whose periodicity matches the wavelength of SAW at specific frequency. The IDT placed on piezoelectric material allows the conversion of electric signal into acoustic waves.

Surface acoustic wave (SAW) devices are currently a key enabling technology for several applications ranging from electronics and ICT (e.g. mobile phones) to sensing [1], microfluidics [2] and (recently) quantum devices [3]. Historically, SAW devices have found a wide range of applications in communication technology for their versatility and efficiency in controlling and processing electrical signals. Recently, SAWs have begun to receive significant attention for biological and chemical sensing, because they are localized in the surface region and for this reason they are very sensitive towards any change on the surface. In addition, magneto-elastic interactions were exploited to control the magnetic degree of freedom in SAW-based piezoelectric/ferromagnetic hybrid devices. In particular, surface acoustic wave were employed to drive the ferromagnetic resonance [4], trigger the magnetization dynamics [5], writing magnetic patterns and spin pumping.

For their appealing properties and for their promising perspectives, we worked on the fabrication and optimization of SAW devices such as delay lines and resonators.

A SAW delay line consists of a two-port IDT device (Figure 1a, on the left). One IDT acts as input transducer and converts signal voltage variations into a mechanical wave, the other one is employed as an output receiver to convert back mechanical deformations into an output voltage. Since the acoustic wave is much slower than an electromagnetic wave, between the emitted signal and the received one, there is a delay proportional to the IDT distance. The frequency response of the device depends on the IDT finger periodicity and on the acoustic velocity in the piezoelectric material.

We fabricated delay lines on GaAs substrates by means of optical lithography with a IDT width of 2 μm and a IDT periodicity of 8 μm resulting in a fundamental frequency of about 360 MHz (in GaAs v_{SAW}=2800 m/s). Initially, we performed a systematic study to understand the dependence of the transmitted signal on the device geometry, changing the IDT features such as shape (single, double), number of finger pairs, distance between emitter and receiver, overlap finger length. This investigation was also important to identify the geometry with less electromagnetic noise. In fact, upon applying a rf voltage to the input IDT, an electromagnetic wave (EMW) is launched since an IDT works as an antenna as well as an electromechanical transducer. The EM signal degrades the ideal device response since it is responsible of the background noise in the transmitted signal. During the characterization of different devices, we observed that the electromagnetic noise is always higher for the double geometry, regardless of the distance of IDTs or the number of pairs. Moreover, the electromagnetic noise is lower when the IDTs are placed farther away because the antenna transmitted power decreases with distance. We observed that a longer finger overlap and an increasing number of finger pairs improve the delay line transmission at the resonance frequency. A typical spectrum of an optimized SAW filter is shown in **Figure 1a**. By adjusting the delay line geometry, it was possible to enhance the SAW signal and to reduce but not to eliminate the electromagnetic noise.

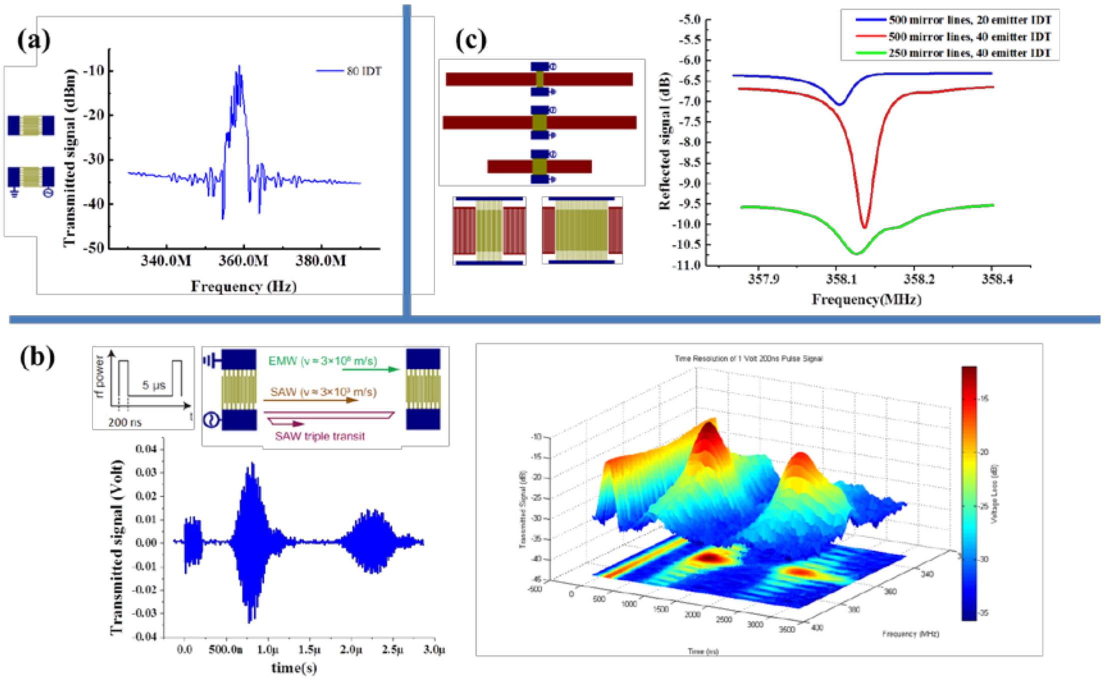

Figure 1.(a) Transmitted signal of SAW delay line with 80 IDT pairs fabricated on GaAs substrate.**(b)** Time-resolved transmitted signal response for a SAW delay line with 80 IDT pairs excited through short pulses of 200 ns at different frequencies near the resonance**.(c) on the left:** Schematic of three SAW resonators characterized by different transducer and mirror geometries fabricated on GaAs substrate; **on the right** their reflected signal response.

This contribution was removed by means of time resolved measurements that allowed to distinguish between the electromagnetic and acoustic contributions to the signal thanks to their different propagation velocity. In **Figure 1b** it is shown a time-resolved transmitted signal response for a SAW delay line with 80 IDT pairs excited through a short pulse of 200 ns at different frequencies near the resonance. Three well-distinguished impulses can be observed as a function of time. The EMW reaches the output IDT almost instantaneously and gives rise to the first pulse. The SAW travels in GaAs with speed of sound $v_{SAW} \approx 2800$ m/s and thus, with a IDT separation of 1500 μm, it can be observed in the time domain after about $t = d_{IDT} / v_{SAW} \approx 500$ ns (middle pulse). The third impulse is attributed to the SAW triple transit, i.e. the detection of a wave reflected twice at IDTs before being detected at the output IDT. It is possible to see that at resonance frequency the SAW is the dominant contribution to the whole signal.

Finally, we carried out a study on SAW resonators in order to identify the geometry with higher Q factor. A resonator is a kind of device in which an IDT is placed between two reflectors (periodic arrays of metal strips). Upon applying a rf voltage to the IDT, the waves generated at a particular frequency (determined by the period of the IDT) are constructively reflected by mirrors. In fact, the distance between the reflectors is chosen to be an integer multiple of half wavelength allowing in-phase reflections at that particular frequency. SAW resonators were fabricated by means of optical lithography with a IDT width of 1 and 2 μm, varying the number of electrodes in the reflectors and in the emitter, and distances between the reflector. We observed that an increasing number of electrodes both in the emitter than in the mirrors improves the reflected signal at the resonance frequency (**Figure 1c**). Resonators with a high quality factor ($\approx 10^5$) were obtained.

References

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