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Experimental study of Multilayer Piezo-magnetic SAW delay line for Magnetic Sensor

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Abstract

This communication describes an experimental study of multilayer piezo-magnetic acoustic wave devices used as sensors of external magnetic fields applied in plane, parallel or perpendicular to the direction of the acoustic wave propagation direction. The considered device consists of a layered structure Mag/ZnO/IDT/LNY-128, Mag being the sensitive magnetoelastic layer. Two magnetoelastic films are investigated as sensitive layers: Ni and CoFeB. Their sensitivities to the magnetic field intensity and direction are measured and compared.

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1. Introduction

Surface acoustic wave devices (SAW) are widely used in sensor applications due to their sensitivity, small size, packageless structures [1-4]. Their use as passive and wireless sensors allows them to operate in rotating parts or in extreme conditions such as high temperatures (up to 1000°C) or radioactive environments in which no other wireless sensor can operate [2-3]. Practical SAW sensor systems have been reported such as temperature [5], chemical and pressure sensors [6]. Recently, piezo-magnetic sensors by combining magnetoelastic and piezoelectric materials have been elaborated [7-8]. Magnetic SAW devices such as a SAW delay line composed of TbCo2/

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FeCo/Y-cut LiNbO₃ [8] and a SAW resonator composed of Ni electrodes /Quartz [7] were reported. However additional efforts need to be made to enhance the sensitivity to the magnetic field of such structures. Systematic fabrication, test and extraction of SAW sensors performances are time consuming mainly when a layered structures are considered and when the sensitivity to external parameters is investigated, that is why a fully coupled physical FEM model was developed and presented in [9].

This communication describes an experimental study of a multilayer piezo-magnetic acoustic wave device with applied magnetic field either parallel or perpendicular to the direction of acoustic wave propagation. In a first step, a multilayered Ni/ZnO/IDT/LN-Y128 SAW delay line structure was made and characterized. In order to enhance the sensing properties, a CoFeB sensitive layer was used instead of Ni and the CoFeB/ZnO/IDT/LN-Y128 structure was investigated. While CoFeB keeps magnetostrictive properties, its saturation field is much lower than the one of Ni, so higher field sensitivity could be obtained. This is the scope of this paper.

This paper is organized as follows: first, we describe the micro-fabrication of the magnetic field SAW sensors (section 2), and then we give the magnetization characteristics of the sensitive magnetoeelastic layers (section 3). In section 4 and 5, the RF characteristics of the devices without and with magnetic field are depicted, as well as the relative frequency shift of the devices for both magnetic field directions.

2. Fabrication process

In a first step, Al InterDigital Transducers (IDTs) were fabricated on 128°Y-X cut LiNbO₃ substrate using photolithography and wet etching processes. The spatial period of the IDTs defining the operating wavelength was fixed to 24 μm. Then, a 250 nm thick insulator ZnO film was deposited over the IDTs by RF magnetron sputtering. The pressure in the chamber was 2×10⁻³ mbar and the power was 100 W. Finally a 200 nm thick sensitive magnetic film was deposited on the ZnO surface by magnetron sputtering (Ni or CoFeB). Depositions parameters for ZnO and Ni are described in previous work [9]. CoFeB is also deposited using RF magnetron sputtering, with Ar pressure of 5x10⁻³ mbar and a power of 90 W. Ni and CoFeB are buffered and capped using 5nm of Ta in order to protect the layer against oxidation. In short, the multilayer structures are made of a piezoelectric substrate (LiNbO₃), IDTs, an insulating layer (ZnO) and a magnetic sensitive layer (see Figure 1).

![Fig. 1: schematic view of the layered piezo-magnetic structure used in the study](image)

3. Magnetic characteristics

The magnetic responses of the Ni and CoFeB thin films have been measured with a Vibrating Sample Magnetometer (VSM) at room temperature. The response measured along the X and Y axis are displayed in Figure 2. While the nickel film is mostly isotropic in the X-Y plan, the CoFeB exhibits an easy axis along Y and an hard axis along X. According to those measurements and as expected, the saturation field of CoFeB is much lower than the one of Ni.
4. RF characterization absent of magnetic field

The S21 frequency response of the delay lines with Ni/ZnO/IDT/LiNbO₃ and CoFeB/ZnO/IDT/LiNbO₃ structures were measured with a network analyzer before and after deposition of the ZnO and Mag films depositions as shown in Figure 3. Here, only the first and the third harmonics appear clearly at 159 MHz and 460MHz.

5. RF characterization with an external magnetic field

A magnetic field parallel to the surface acoustic wave propagation direction (X) was applied to the SAW delay line. The superposition between measured dependence of frequency variation Δf/f with the applied magnetic field at the operating frequency 159 Mhz for Ni/ZnO/IDT/LN-Y128 and CoFeB/ZnO/IDT/LN-Y128 structures, in Figure 4, shows that Ni/ZnO/IDT/LN-Y128 reaches a maximum of a magnetic field sensitivity (65 ppm) at 0.15 Tesla, and 65ppm at 0.004 Tesla when CoFeB is used instead of Ni, thus the saturation magnetic field is divided by a factor 37.5.

When the magnetic field is applied perpendicular to the acoustic wave propagation (Figure 4(b)) at the same operating frequency (159MHz), the obtained results show that Δf/f linearity is improved and the sensitivity at 0.4 T is enhanced by a factor over 5 when we used the CoFeB sensitive film. The CoTeB also exhibits a strong
sensitivity and slope at low magnetic field densities (0-20mT), thus leading to a precise measurement in this range.

Fig.4: Measured relative frequency variation with (a) parallel and (b) perpendicular magnetic field intensity of layered piezo-magnetic sensors (Ni/ZnO/IDT/LiNbO₃) and (CoFeB/ZnO/IDT/LiNbO₃)

6. Conclusion

In summary, we demonstrated experimentally the use of Ni/ZnO/IDT/LiNbO₃ and CoFeB/ZnO/IDT/LiNbO₃ SAW structures as magnetic field sensors. Both devices were characterized electrically and magnetically. Devices using CoFeB, that exhibits an easy axis, show a better sensitivity that Ni devices, particularly at low magnetic field intensities.

References