C-2-1 Variable Surface Acoustic Wave Delay Line Consisting of a Magnetic Thin Film on a $LiNbO_3$ Substrate

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A technique available for achieving a variable phase shift in the surface acoustic wave (SAW) device has been developed by A. K. Ganguly and his co-workers.[1] The SAW velocity can be continuously varied by adjusting an external magnetic field in the SAW delay line consisting of a thin film of a magnetostrictive material on a piezoelectric substrate.[2] It was reported that the variation rates of the SAW velocity in a Ni film-$LiNbO_3$ substrate configuration were 300 ppm at most.[1] However, these rates were substantially low for many expected applications. Recently, we have increased the rate to 0.27 %, which is high enough for the practical usage, by depositing the amorphous $TbFe_2$ film in place of the Ni film. In this paper, we demonstrate the dependence of the variation rate on the strength and the direction of the applied magnetic field in this configuration of the SAW delay line.

Figure 1 shows the schematic of the delay line of our $TbFe_2$-$LiNbO_3$ system. In the first place, a pair of interdigital transducers for generating and detecting SAWs of 42 MHz were prepared on the $LiNbO_3$ substrate. The magnetic film was deposited over a proper area on the SAW propagating surface between the interdigital transducers. The amorphous $TbFe_2$ film was used as the magnetic one because it exhibits a comparatively large magnetostriction and may have a large ΔE effect.[3] The film (about 2.5 μm thick) was deposited by rf co-sputtering from the composite target constructed by uniformly placing fan shaped Fe plates on a Tb disk.[4] Then, this delay line was annealed at 200 °C for one hour in a vacuum of the order of 10^{-5} Torr.

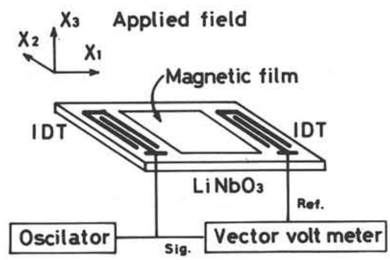

Fig.1 Schematic of the variable SAW delay line and measurement.

The external magnetic field H_e was applied parallel to the direction of SAW propagation or normal to the film, i.e., to the X_1 and X_3 direction in Fig.1. The phase shifts ($\Delta\theta$) of the SAWs were observed by the vector volt meter (YHP 8405A). The relative change in the SAW velocity ($\Delta v_s/v_s$) is determined by the following equation,

$$\frac{\Delta v_s}{v_s} = \frac{\lambda_s \Delta\theta}{2\pi L - \lambda_s \Delta\theta} \simeq \frac{\lambda_s \Delta\theta}{2\pi L} \qquad (1)$$

where λ_s and L are the wave length for H_e=0 and the length of the film in the direction of SAW propagation, respectively.

Figure 2 shows the dependence of $\Delta v_s/v_s$ on $H_e//X_1$ and $H_e//X_3$. When $H_e//X_3$ is applied, $\Delta v_s/v_s$ increases monotonically toward a saturation value. This change is very similar to the change in elastic moduli of a magnetostrictive material by Δ E effect.[3] On the other hand, when $H_e//X_1 \simeq$ 4 KOe is applied, $\Delta v_s/v_s$ attains the minimum value of about -0.27 %. The decrease of $\Delta v_s/v_s$ may be attributed to the interaction between SAWs and the magnetization within the film in addition to the Δ E effect.

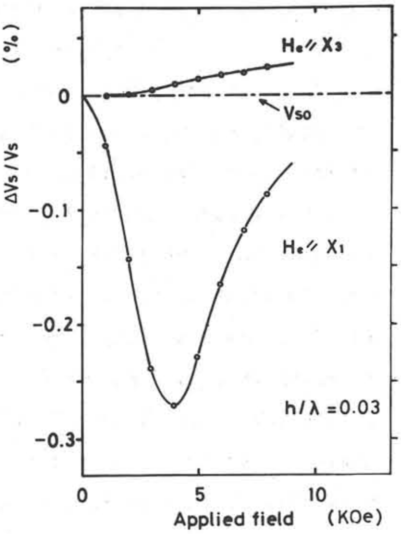

Fig. 2 Dependence of $\Delta v_s/v_s$ on the applied field H_e in $TbFe_2$-$LiNbO_3$ configuration.

In order to investigate how $\Delta v_s/v_s$ is attributed to the interaction, the SAW velocity propagating on the magnetic material is calculated by using the following magnetoelastic equations and adequete boundary conditions,

$$T = c^H S - e H , \qquad B = \mu^S H + e S . \tag{2}$$

T : the stress c : the stiffness constant
S : the strain μ : the permeability
B : the flux density H : the magnetic field
e : the piezomagnetic constant

Figure 3 shows $\Delta v_s/v_s$ calculated for a Ni-Cu-Co ferrite, of which magnetic and elastic properties are well known. Since the stiffness constant c^B is assumed to be constant (ΔE effect is ignored) for simplicity in the analysis, $v_s(H_e \neq 0)$ never exceeds $v_{so}(H_e=0)$. As can be seen from Figs. 2 & 3, the maximum $|\Delta v_s/v_s|$ for $H_e//X_1$, which is usually much larger than that for $H_e//X_3$, is mainly attributed to the interaction. The analysis also indicates that the interaction seems to depend on the electromechanical coupling factor k_{15}.

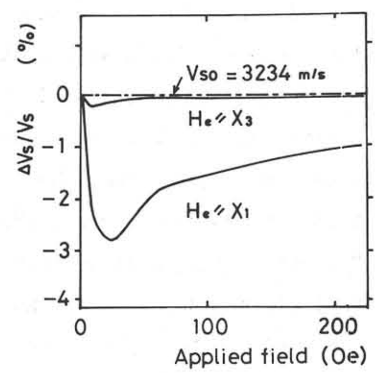

Fig. 3 Theoretical dependence of $\Delta v_s/v_s$ of a Ni-Cu-Co ferrite on the applied field.

It is concluded that the magnetic film-piezoelectric substrate configuration is usefull for realizing variable SAW delay lines. And the amorphous $TbFe_2$ film seems to show the feasibility as the material for them.

1) A.K.Ganguly et al., Electron. Lett., 11, (1975)p.610 2) M.Yamaguchi et al., Proc. Acoust. Soc. Japan Meeting, (1975) 2-2-15 3) R.M.Bozorth, "Ferromagnetism", D.Van Nostrand Co.Inc., (1951)p.684 4) H.Yamamoto et al., Trans. IEE Japan, 97-A, 11, (1977)p.17