SUPERCONDUCTING FREQUENCY TUNABLE SAW FILTER AND DISPERSION LINE

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ABSTRACT

The superconducting transition of a thin film with a high sheet resistivity can change the attenuation of surface acoustic waves (SAW) by as much as 30 dB/cm at 700 MHz. This effect could be used to produce variable bandwidth SAW filters, RAC (Reflective Array Compressors) dispersion lines, and switches in SAW delay lines.

THEORY

The acousto-electric effect(1,2) provides the coupling of surface acoustic waves (SAW), propagating on a piezoelectric substrate, to the sheet resistivity $R_\square$ ($\equiv\rho/t$, electrical resistivity / thickness) of a thin conducting film in close contact with, or deposited onto the substrate. This coupling originates from the polarization electric field, accompanying the SAW propagating at the surface of the piezoelectric substrate, inducing image charges in the conducting film. The impedance of the film produces a delay in the response to this applied electric field, and an absorption of the energy of the input signal. This delay, or phase lag, is the relaxation time τ determined by the RC value of an equivalent network $\epsilon_o (1 + \epsilon_r) / \sigma$ in which σ is the conductance of the film, where $R_\square$ may be associated with $1/\sigma$ and the capacitance may be associated with $\epsilon_o (1 + \epsilon_r)$. The absorption of energy is responsible for the ultrasonic attenuation α.

The attenuation α of a SAW in a thin superconducting film due to the acousto-electric coupling is given by:

$$\alpha = \frac{\omega \kappa^2}{2 v_o} \frac{\omega \tau}{1 + \omega^2 \tau^2} \qquad (1)$$

where

$\omega = 2\pi \nu$ is the angular frequency of the SAW,

κ^2 is the electromechanical coupling constant, 0.045 for $LiNbO_3$,

v_o is the velocity of the SAW on the substrate, 3.4 km/s for $LiNbO_3$,

τ is the relaxation time of the SAW in the film.

For a very thin film:

$$\omega \tau = v_o \epsilon_o (1 + \epsilon_r) R_\square = \beta R_\square \qquad (2)$$

in which

$\epsilon_o = 8.85\ 10^{-12}$ F/m is the dielectric permittivity of vacuum,

ϵ_r is the relative dielectric constant of the substrate, 30 to 50 for $LiNbO_3$,

$R_\square$ is the sheet resistivity (measured in Ω per $\square$) of the film in the normal (non superconducting) state, and

β is a film independent factor, $\approx 9.3\ 10^{-7}$ to $1.5\ 10^{-6}\ \Omega^{-1}$ for a $LiNbO_3$ substrate.

Equation 1 can thus be rewritten as:

$$\alpha = \frac{\omega \kappa^2}{2 v_o} \frac{\beta R_\square}{1 + \beta^2 R_\square^2} \qquad (3)$$

to better show the functionality of α in the variables ω (SAW dependent) and $R_\square$ (film dependent).

According to equation 1, the theoretical maximum in attenuation occurs when $\omega\tau = \beta R_\square = 1$, which yields $R_\square$ around $10^6\ \Omega/\square$ for $LiNbO_3$, the piezoelectric substrate of choice because of its high κ^2 and ϵ_r. This theoretical result merely aims at defining the largest attenuation for the film with highest sheet resistance. The theoretical maxima for the ultrasonic attenuation on $LiNbO_3$, referred to equation 3 with $\beta R_\square = 1$, at 0.7, 1, and 4 GHz are respectively 1260, 1800, and 7200 dB/cm. The idea suggested here is thus to search for the high Tc film with maximum sheet resistance still compatible with superconductivity. If it were possible to reach a few tens of kΩ in such a film, then α would be in excess of 100 dB/cm at 4 GHz, enough to use this attenuation effect in an effective SAW device.

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PRELIMINARY RESULTS

A sheet resistance of 32 kΩ/□ has been obtained for a NbN superconducting film in its normal state(2), and it has been demonstrated in preliminary experiments with this film that the attenuation of 700 MHz surface acoustic waves can be changed by as much as 30 dB/cm, see figure 1. This was achieved by placing the superconducting film between the transmitting and receiving interdigital electrodes of a piezoelectric SAW delay line and by heating the film above its superconducting transition temperature Tc (≈ 6 K). Higher frequencies are reached by driving the transducers at overtones of their fundamental frequency.

The recently discovered "high critical temperature", or simply "high Tc", superconductors become attractive in device design since their remarkable properties are utilizable at more tractable environmental conditions (liquid nitrogen temperature instead of liquid helium, etc) and at significantly lower cost and effort of operation.

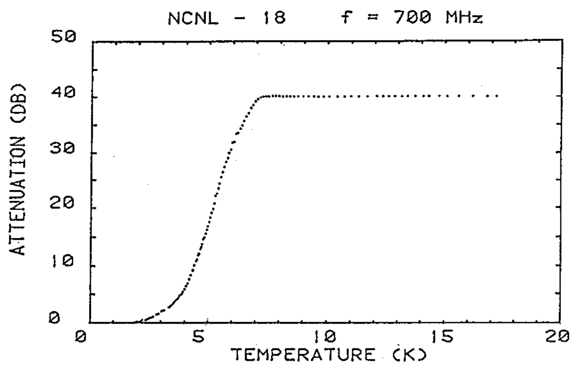

Figure 1: Attenuation data of 700 MHz SAW on superconducting NbN film.

DEVICE CONCEPTS

If it is possible to produce high Tc superconducting films with $R_{\square}(N)$ as high as, or even higher than 30kΩ, then the attenuation change due to the superconducting to normal transition in these films could be used as an on/off SAW switching mechanism in SAW delay lines. These superconducting films could also be used to produce variable bandwidth SAW filters and dispersion lines. A feasibility study of these concepts has been done at room temperature using magnetic Ni films and their associated magneto-elastic coupling(3), instead of superconducting films and acoustoelectric coupling.

Frequency Tunable SAW Filter

SAW devices have been invented to spatially separate or spread a frequency spectrum by properly designing reflective arrays, see figure 2, and slanted transducers, see figure 3, in SAW delay lines. If a superconducting film is placed in the path of the SAW on such a device, then it is possible to selectively remove or modulate parts of the device frequency spectrum by locally changing the attenuation of the corresponding parts of the film. The attenuation change could be obtained by locally heating the film with a laser beam(4), or by passing a current up to or greater than the critical current density Jc through specified portions of a properly configured film. For the latter method, in order to facilitate the control of the attenuation produced by the high Tc film, it would be desirable to produce such films with as low a critical current density Jc as possible. This points in the direction opposite to the present effort in high Tc films research, where the largest critical current densities are sought, and therefore it may be easier to accomplish.

Reflective Arrays. This device consists of broadband input and output transducers with metallic reflective arrays(5); the spatial spread of the frequency spectrum is achieved by varying the distance between the individual chevrons of the array, as depicted schematically in figure 2. In this configuration also, the time delay is the same for each frequency and the filter is therefore non-dispersive.

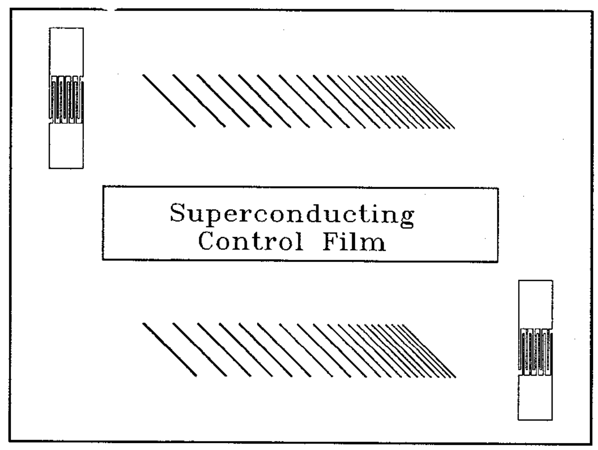

Figure 2: Frequency tunable SAW filter in the reflective array configuration.

Slanted Transducers. Another non-dispersive delay line can be designed by using two slanted dispersive transducers(6), with varying finger interspacings, to spatially separate frequency components, as schematically shown in figure 3.

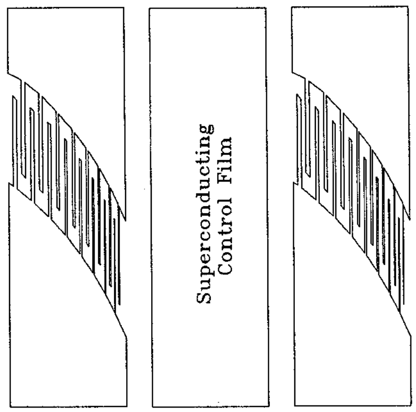

Figure 3: Frequency tunable SAW filter in the slanted transducers configuration.

Frequency Tunable SAW Dispersion Line

The principle, as above, is that the superconducting film in the delay line modulates the SAW, whose frequency is not only separated or spread in space, but also in time.

Reflective Arrays. Also called Reflective Array Compressor (RAC) configuration, depicted schematically in figure 4; the RAC is a broadband transducer and a frequency-spreading reflective array, plus their mirror image. Now the time delay increases when parts of the SAW generated at the input transducer follow a longer path as they are frequency-discriminated. The long and short wavelengths ends of the reflective array are reversed in order to undo, or decompress, a previously compressed signal.

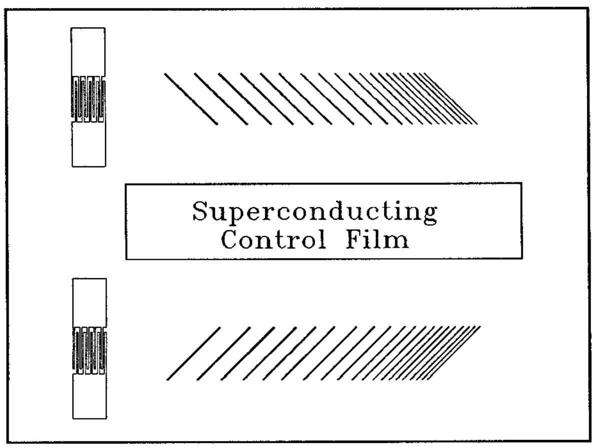

Figure 4: Frequency tunable SAW dispersion line in the RAC configuration.

Slanted Transducers. The two slanted transducers of the delay line are now in a mirror image configuration, see figure 5. The same comments as for the above reflective arrays apply here.

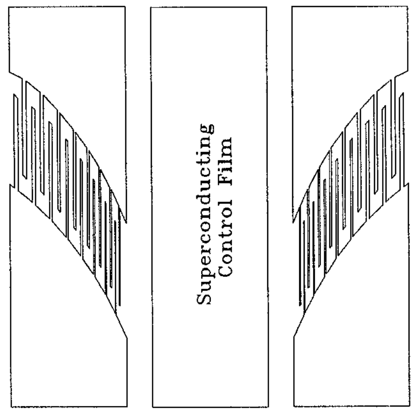

Figure 5: Frequency tunable SAW dispersion line in the slanted transducers configuration.

CONCLUSION

The high attenuation change for a high sheet resistivity change in a low Tc superconducting thin film has been demonstrated and the concepts of SAW devices utilizing this fact have been developed. The concretization of these ideas into actual devices awaits the progress of promising ongoing research in high Tc superconducting thin films.

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