Ultrasonic attenuation of surface acoustic waves in superconducting zinc

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The attenuation of 90-MHz elastic surface waves propagating in both 3 000 and 10 000 Å films of zinc has been measured as a function of temperature from 3 to 0.38 K. The surface acoustic waves were generated and detected by using a surface-acoustic-wave device with interdigital transducers plated onto a *Y-Z* cut lithium-niobate substrate. Utilizing the experimental results, in the BCS theory, energy gaps of $2\Delta(0)$ equal to 4.17 ± 0.20 and 3.81 ± 0.20 in units of $k_B T_c$ were calculated for the 3 000 and 10 000 Å films, respectively. The transition temperatures for the 3 000 and 10 000 Å films were 1.5 ± 0.01 and 1.31 ± 0.01 K, respectively.

In previous studies, both longitudinal[1] and transverse[2] waves have been utilized to measure the anisotropic superconducting energy gap in bulk single crystals of zinc.

The present investigation utilizes surface acoustic waves to extend these superconducting-energy-gap studies into thin films of zinc. The conventional ultrasonic methods, as utilized in the previous experiments,[1,2] are not applicable for investigating thin films. In order to make accurate ultrasonic measurements in thin films at low temperatures it is desirable to use high-efficiency electromechanical-coupling interdigital-transducer surface-acoustic-wave (SAW) devices. These devices generate SAW's which propagate on the surface of a piezoelectric substrate. Recent advances in microelectronic photolithography and also in thin-film technology have resulted in relatively simple procedures for fabricating these SAW devices with fundamental frequencies ranging up to 10^9 Hz.

The SAW devices utilized in this investigation were fabricated on *Y-Z* lithium-niobate ($LiNbO_3$) substrates. The $LiNbO_3$ was decided to be the best-suited substrate material for this experiment primarily due to its high coupling coefficient and also to the fact that the phonon scattering losses are small for frequencies of 90 MHz. Figure 1 shows the type of SAW device used in this study. The beam width was chosen to be 5 mm so as to reduce the requirements on transducer alignment and to avoid beam steering losses. The interdigital fingers were chosen to be five periods in length with a synchronous frequency of 90 MHz. The distance between each of the fingers was chosen to be equal to the finger width to allow for the generation of higher-frequency odd harmonics for future experiments.

The electronics system, liquid-^{3}He refrigerator and thermometry system utilized in these measurements have been described in previous publications.[1,2] The cryostat was modified to contain two rf transmission lines, since this experiment employed the transmission method as opposed to the pulse-echo method used in previous investigations. All of the ultrasonic attenuation measurements were taken on the triple transit pulse which had made three trips through the thin zinc film being studied.

The zinc films were plated in a vacuum of 1×10^{-6} Torr using a VB-4 electron beam gun system manufactured by Veeco Instruments Inc. The film thicknesses were monitored with a Sloan digital thickness monitor DTM-200. A shutter system[3] was used to open and expose the substrate at some preselected thickness set point and close it at another. This al-

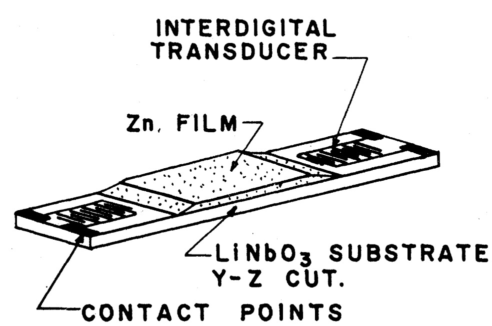

FIG. 1. Surface-acoustic-wave device showing the interdigital electrodes at each end of the $LiNbO_3$ substrate with the zinc film plated between them.

lowed for a clean, steady state evaporation condition to exist before exposing the substrate to the evaporant. The zinc films were plated from a 99.9999% pure zinc ingot. An Auger profile analysis[4] was conducted on the films by using a system manufactured by Physical Electronics, Inc. containing an ion gun (Model 20-045) and an Auger analyzer (Model 10-155). The only elements found to be present in the films (within the limits of the equipment) were zinc and oxygen. The small oxygen contents should have minimal, if any, effect on the superconducting properties of the films.

An x-ray study was undertaken to determine if the zinc films had established a preferred crystallite orientation upon being plated onto the substrate surface. In this study the intensity of the Bragg peaks for $K\alpha$ radiation were recorded as a function of 2θ, where θ represents the angle formed by the surface of the specimen and the incoming x-ray beam. These measurements were made with a Norelco diffractometer manufactured by the North American Phillips Co. It was found that most of the unit cells were oriented with their $\{000l\}$ planes parallel to the lithium-niobate substrate.

For surface acoustic waves, the ratio of the ultrasonic attenuation in the superconducting state to that in the normal state (α_s/α_N) has been shown theoretically[5] to be equal to the same ratio for longitudinal bulk waves. This relationship has been experimentally confirmed by Krätzig[6] in films of Sn and Pb and also by Robinson, Maki, and Levy[7,8] for Al films. Thus, in analyzing our data we have utilized the same procedure used earlier for longitudinal waves.

The transition temperature was determined in each film studied by observing the temperature at which the echo voltage abruptly changed when passing from the normal state to the superconducting state and vice versa. The transition temperatures for 3 000 Å and 10 000 Å zinc films were found to be 1.50 ± 0.01 and 1.31 ± 0.01 K, respectively.

The energy gaps $2\Delta(0)$ obtained from the experimental data for the reduced temperature range of $1.0 > t > 0.40$ were 4.17 ± 0.20 and 3.81 ± 0.20 in units of $k_B T_c$ for the 3 000 Å and 10 000 Å films, respectively.

These results give a thickness dependence for both the transition temperature and the superconducting energy gap for superconducting thin films. Both properties are enhanced above the appropriate values for bulk zinc single crystals, and the thicker the film the more nearly it exhibits the properties of the bulk form.

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[1]C. R. Cleavelin and B. J. Marshall, Phys. Rev. B 10, No. 5, 1902 (1974).

[2]E. H. Breashears, C. R. Cleavelin, and B. J. Marshall, Phys. Rev. B 13, No. 11, 4801 (1976).

[3]W. E. Bailey, L. L. Hatfield, and B. J. Marshall, Rev. Sci. Instrum. 49(4), 546 (1978).

[4]Thomas A. Carlson, *Photoelectrons and Auger Spectroscopy* (Plenum, New York, 1975).

[5]F. Press and J. Healy, J. Appl. Phys. 28, 1323 (1957).

[6]E. Kratzig, K. Walther, and W. Schilz, Phys. Lett. 30A, 411 (1969).

[7]D. A. Robinson, K. Maki and M. Levy, Phys. Rev. Lett. 32, 709 (1974).

[8]D. A. Robinson, H. Salvo, Jr., K. Maki, and M. Levy, J. Low Temp. Phys. 17, 121 (1974).