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A5-2 Low-Frequency Piezoelectric-Transducer Applications of ZnO Film

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§1 Introduction*****It is revealed that a high resistivity ZnO film highly-oriented with c-axis perpendicular to a metal substrate-surface can be used as a low frequency piezoelectric transducer which generates and detects the normal strain or stress perpendicular to c-axis, i.e., perpendicular to the film thickness through the piezoelectric tensor component e_{311} or d_{311}. For example, tuning-bar filters and a flat tuning-fork filter are successfully composed of ZnO films and elinvar-alloy substrates whose resonant outputs are obtained even at frequencies lower than 100kHz, and a piezoelectric microphone is also composed of a ZnO film and a Ti membrane substrate.

§2 Resistivity of ZnO sputtered film*****The electrical resistivities of highly-oriented ZnO films prepared by sputtering of a Zn or ZnO target in Ar, O_2, or Ar + O_2 atmosphere have been reported to be 10^{1}-10^{10} $\Omega\cdot$cm at room temperature.[1-7] In our rf-diode sputtering experiment also, the films were highly-oriented with the c-axis perpendicular to substrate surfaces and the resistivities through the films were $10^{6}\Omega\cdot$cm in order of magnitude when an undoped ZnO ceramic target was used in O_2 or O_2 (50%) + Ar(50%) atmosphere. These resistivity values are not high enough to be used at frequencies below 100kHz, evaluating from the convenient and practical condition that the used angular frequency ω must be higher than the dielectric relaxation angular frequency ω_c of the piezoelectric semiconductor in case that its dielectric property is used rather than the semiconducting one. The condition $\omega \gg \omega_c$ means in ZnO film that $\rho \gg 2\times10^{7}\Omega\cdot$cm at 10kHz, $\rho \gg 2\times10^{10}\Omega\cdot$cm at 10Hz, etc., for example. So we tried to use a Li-doped ZnO ceramic target which was sintered at 1200°C from ZnO powder containing 1 weight % Li_2CO_3 powder, and could obtain ZnO films with resistivity through the film higher than 10^{10} $\sim 10^{14}$ $\Omega\cdot$cm

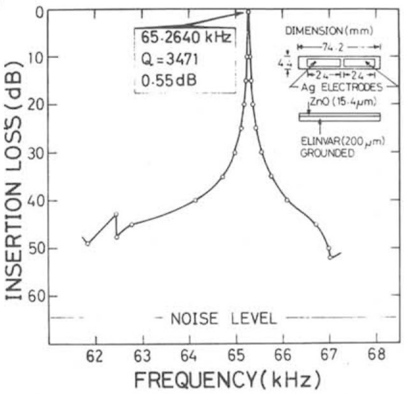

Fig.1 The insertion loss frequency characteristic of a length-expander mode filter. The source impedance is 20Ω and the load is 10kΩ.

§3 Examples of low frequency application of ZnO film*****Figure 1 shows the insertion loss frequency characteristic of a tuning-bar filter composed of an elinvar-alloy metal substrate, ZnO film and divided Ag electrodes. The mode shown in Figure 1 is the second overtone of the length expander bar, and has electrical quality factor of 3470 and insertion loss of 0.55dB at 65.2640 kHz. Figure 2 shows the insertion loss frequency characteristic of a flat tuning-fork filter at its basic mode, whose quality factor is 2360. It was easy to assemble these filters into tuning-bar or -fork oscillators.

Figure 3 shows the insertion loss frequency characteristic of another tuning-bar filter. The resonance frequency of the fundamental bending mode at 1.977kHz is approximately equal to the theoretical one, and the resonance frequency ratios of over-tones to the fundamental are well consistent with the theoretical ones. The fundamental bending mode of the sample shown in Fig.1 was observed at 176.8Hz.

A piezoelectric microphone was composed of 10-20μm ZnO film sputtered on 3-10μm Ti membrane whose tension is impressed by the method used for a standard condenser microphone. The pressure response was measured through an FET buffer and a microphone amplifier in order to compare with an electret condenser microphone. The pressure sensitivity was approximately -90dB (0dB=1V/1μbar) at frequency range lower than 10kHz where the Ti-ZnO membrane resonated, and therefore it can not afford to be used practically at present.

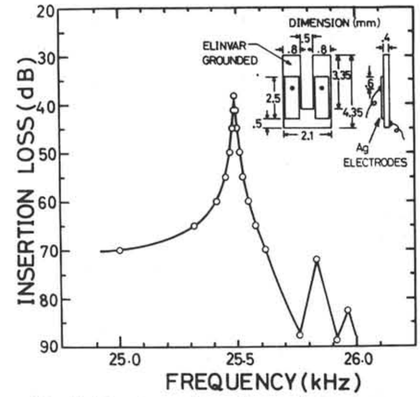

Fig.2 The insertion loss frequency characteristic of a flat tuning-fork filter. The source impedance is 90Ω and the load is 10kΩ.

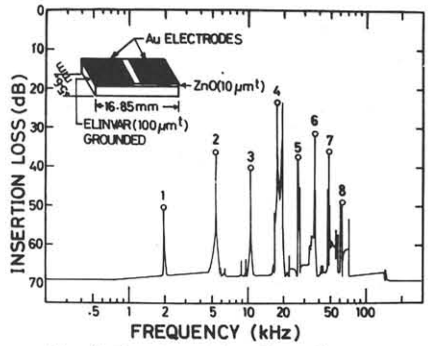

Fig.3 The insertion loss frequency characteristic of a bending mode filter. The numbers at the peaks show the overtones. The source is 90Ω and the load is 10kΩ.

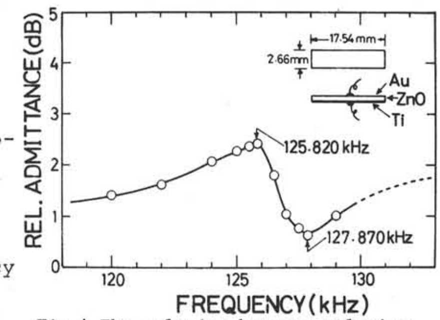

Fig.4 The relation between relative admittance and frequency near the fundamental resonance of the length-expander mode in a composite of 29μm thick ZnO and 3μm thick Ti.

§4 Electromechanical coupling coefficient k_{31} of ZnO film*****To estimate the value of the electromechanical coupling coefficient k_{31}, a 29μm thick film was grown on a 3μm Ti membrane and the electrical admittance near the resonance frequency of the length expander mode was measured (Fig.4). The resonance and antiresonance frequencies are determined by the aid of phase measurement. From these values, k_{31} ($=d_{31}/\sqrt{\varepsilon^T_{33} s^E_{11}}$) of the ZnO-Ti complex bar can be estimated as 0.19±0.01. The measured value is consistent with the value 0.182 for ZnO single crystal[8,9], and is situated between k_{31} =0.34 for PZT-5 and k_{31} =0.12 for CdS which are materials of the same symmetry.

References [1]G.A.Rozgonyi et al.: Appl.Phys.Letters,8,220(1966). [2]N.F.Foster et al.: Appl.Phys.Letters 8,221(1966). [3]N.F.Foster et al.: IEEE trans.SU-15,28(1968). [4]R.F.Belt et al.: J.Appl.Phys.39,5215 (1968). [5]G.D.Hillman et al.: J.Appl.Phys.44,5053(1973). [6]R.Inaba et al.: Japan.J.Appl.Phys.10,1493 (1971). [7]F.S.Hickernell: J.Appl.Phys.44,1061(1973). [8]H.Jaffe et al.: Proc.IEEE,53,1372(1965). [9]D.F.Crisler et al.: Proc.IEEE 56,225(1968).