ULTRASONIC SURFACE-WAVE AMPLIFICATION IN CADMIUM SULFIDE

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Observations are reported here of the amplification and attenuation of surface elastic waves in cadmium sulfide. Amplification occurred when a drift electric field was present together with a propagating surface wave. With no drift field, the attenuation of a surface wave was found to depend on the intensity of light incident upon the photoconductive CdS.

The experimental arrangement is shown in Fig. 1. We used irregularly-shaped single crystals of CdS (Eagle-Picher high purity, grade A) having one plane surface produced by sawing, lapping, mechanical polishing, and chemical cleaning. An aluminum film was vacuum-deposited on this surface then photoetched to leave two sets of interleaved comb-like electrodes. Each set acted as a surface-wave transducer at the frequency for which the surface wavelength equalled the period of the set of electrodes. A pulsed RF voltage was applied to the left-hand transducer, producing a spatially-periodic electric field and generating surface waves in the piezoelectric CdS. Waves propagating to the right coupled to the second transducer, were detected and then displayed on an oscilloscope. A drift electric field could be established between the transducers by connecting a pulsed drift supply to one comb of each transducer. Low-Q tuned air-core RF transformers isolated both transducers from ground.

The particle displacement associated with a surface elastic wave has components parallel and perpendicular to the free surface.[1] Considering the piezoelectrically-active directions appropriate to bulk plane waves in CdS,[2] one would expect that electronic interaction with a plane surface wave could occur if the c-axis were either normal to the free surface or parallel to the surface and to the direction of wave propagation. The former orientation was employed here.

In Fig. 2A are tracings from oscilloscope displays showing the effect on the received surface-wave pulse of changing the intensity of white light incident on the CdS crystal. By analogy with the behavior of bulk waves in piezoelectric semiconductors,[2] one would expect the wave amplitude to decrease initially and then to increase again as the resistivity decreases (or the illumination intensity increases). This behavior was observed as shown in Fig. 2A. Maximum attenuation at zero drift field is expected to occur when the dielectric relaxation frequency equals the signal frequency. The measured resistivity at the broad attenuation maximum was approximately 4.3×10^4 ohm-cm, as compared with a predicted value at 8 mc/s of 2.4×10^4 ohm-cm.

Figure 2B shows the effect of a drift electric field upon the amplitude of the surface-wave pulse when the illumination was adjusted for maximum zero-field attenuation. As the drift voltage increased, a slight decrease in pulse amplitude was observed, followed by a significant increase, i.e., by electronic gain. The level of the received pulse relative to the zero-field level is plotted versus drift voltage in Fig. 3. Amplification was observed above approximately 550 volts, corresponding to a drift field of about 600 volts/cm. Gain at the highest field applied was about 15 db/cm, or 0.34 db per wavelength. The amount of gain, its onset at a drift field high enough for the electron drift velocity to equal the elastic wave velocity, and the observed decrease in gain upon changing the resistivity from the optimum value, are all similar to the case of bulk wave amplification. In contrast with bulk wave results, we found no region of high attenuation at low drift fields. It should be noted that in these experiments the drift field varied somewhat with depth, owing to use of the transducer electrodes to apply the drift voltage.

Surface wave propagation has been observed in CdS crystals having their c axes either normal or parallel to the surface plane. For both orientations, a surface wave velocity of $(1.73 \pm 0.05) \times 10^5$ cm/sec was inferred from the period of the transducer electrodes $(2.20 \times 10^{-2}$ cm) and the measured frequency which maximized the received pulse amplitude. This velocity agrees well with the value 1.70×10^5 cm/sec calculated for CdS from an expression derived by Stoneley[3] which is applicable to the first-mentioned orientation.

The velocity of surface waves in CdS is only slightly smaller than the velocity of transverse bulk waves. That we have indeed dealt here with surface waves rather than bulk transverse waves is shown by the following: (a) velocity measurements in experiments with crystalline quartz (in which the velocities of bulk and surface waves are well separated) showed that the electrodes function as surface wave transducers; (b) on quartz, excellent transmission was observed from one electrode transducer to a metallic comb surface-wave transducer as described by Viktorov,[4] and Arzt and Dransfeld;[5] (c) a drop of acetone or alcohol on the CdS surface produced apparently complete absorption of the elastic pulse; (d) probing the CdS crystal with a narrow beam of light directed parallel to the plane surface produced a variable attenuation of the received pulse which showed that the wave amplitude was high near the surface and that it was negligible at large depths.

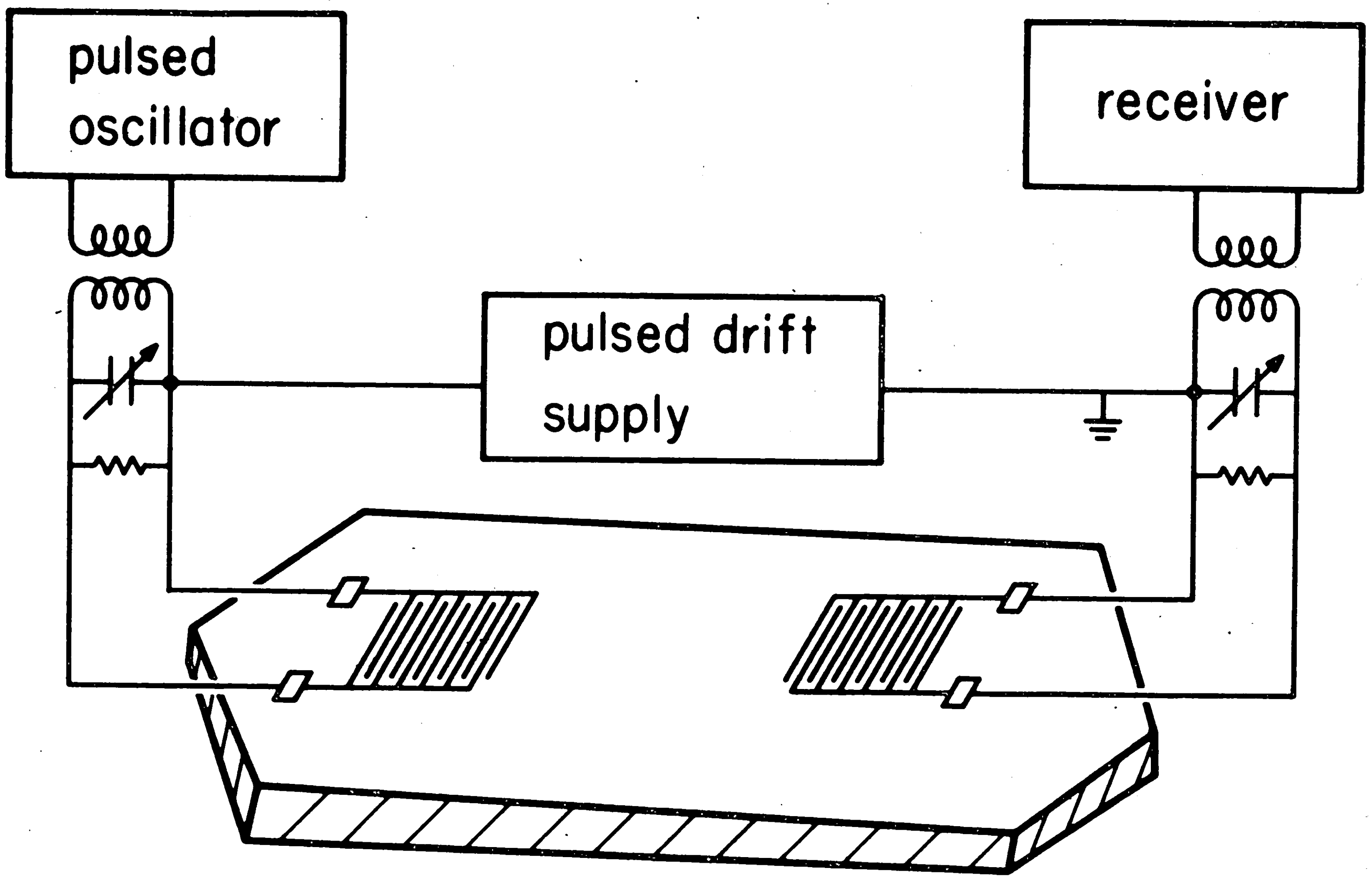

Fig. 1. Experimental arrangement. Crystal length 1.8 cm; distance between transducers 0.92 cm; oscillator frequency 8 mc/s.

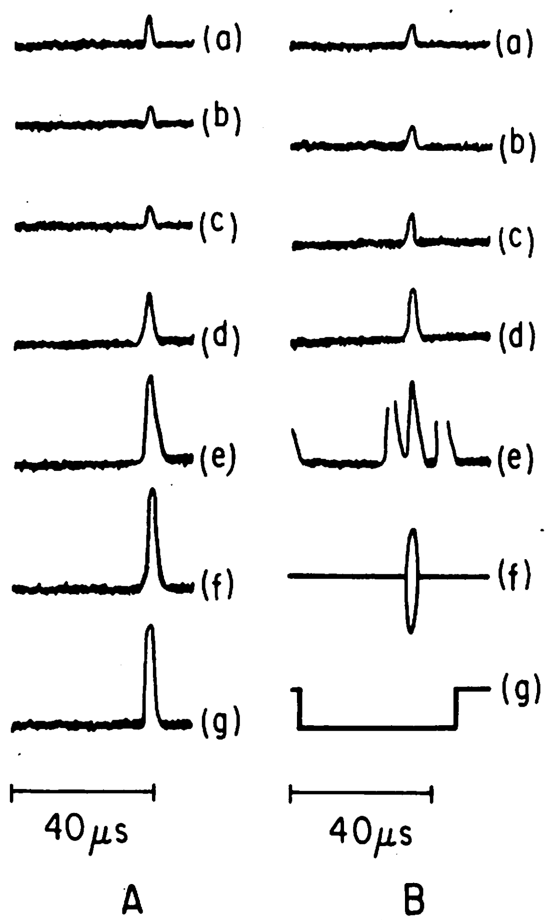

Fig. 2. Oscilloscope displays. A. Receiver output versus time, with zero drift field and light intensity increasing from top (dark) to bottom. B. Surface-wave amplification. (a) through (e) show receiver output versus time with drift voltages 0, 250, 500, 750, and 1000 volts respectively; (g) envelope and input RF pulse; (h) drift pulse. Note: direct pickup of RF and drift pulse have been deleted from all receiver traces except Fig. 2B(e).

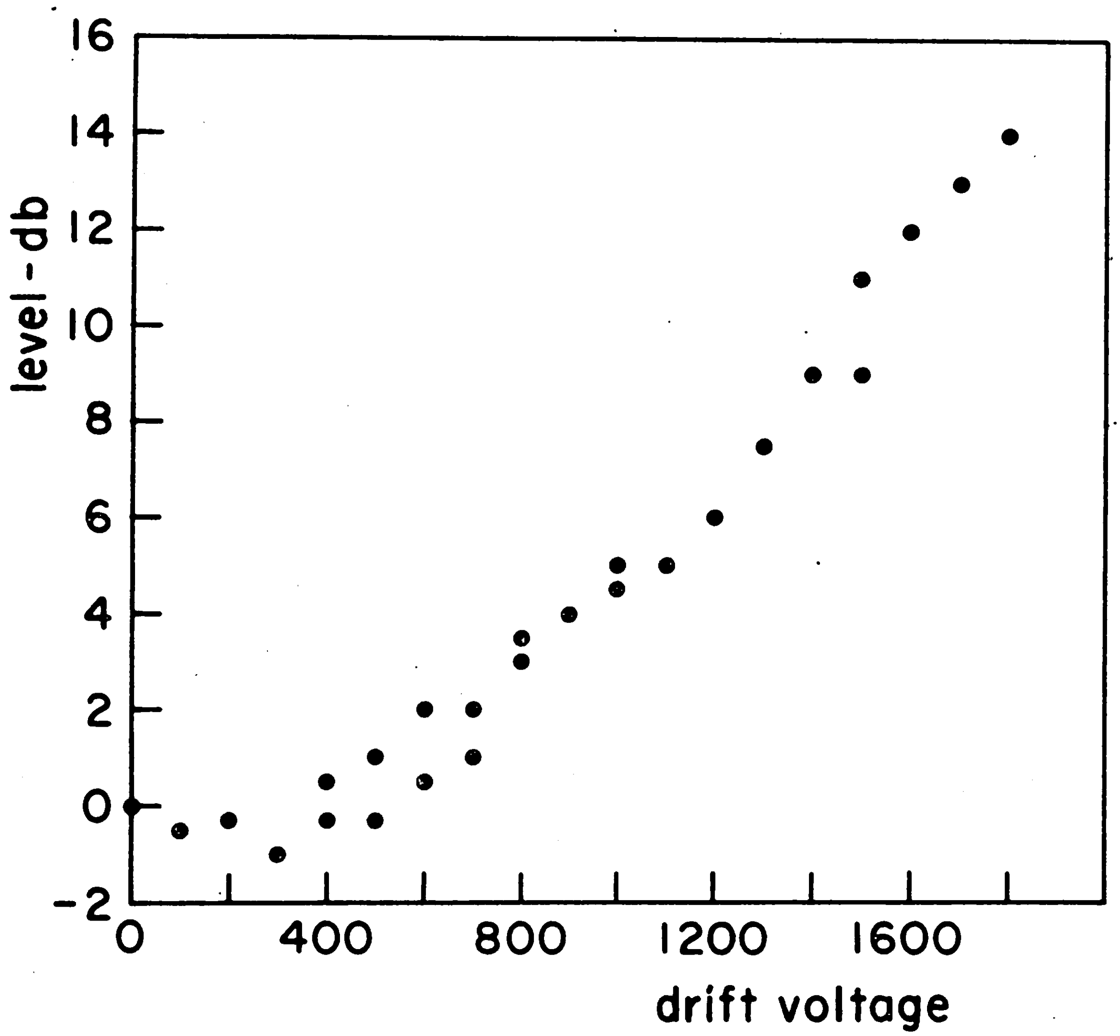

Fig. 3. Level of received pulse relative to zero-field level as a function of drift voltage, with illumination adjusted for maximum zero-field attenuation.

REFERENCES

1. H. Kolsky, "Stress Waves in Solids" (Clarendon Press, Oxford, 1953).
2. D. L. White, J. Appl. Phys. 33, 2547 (1962).
3. R. Stoneley, Geophys. Suppl. to Monthly Notes, Roy. Astron. Soc. 5, 343 (1949).
4. I. A. Viktorov, Sov.-Phys. Acoustics 7, 236 (1962).
5. R. M. Arzt, K. Dransfeld, Appl. Phys. Letters 7, 156 (15 Sept. 1965).