Surface acoustic cnoidal waves and solitons in a $LiNbO_3$-(SiO film) structure

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In the particular case of the propagation of large-amplitude Rayleigh waves in a layered $LiNbO_3$-(SiO film) structure, a conversion of these waves into cnoidal waves at a sound intensity ~100 W/mm^2 has been observed experimentally for the first time. At 300 W/mm^2, the experiments reveal a conversion into a periodic train of Korteweg–de Vries solitons. There are two solitons, with different amplitudes, in each period.

The intrinsic acoustic nonlinearity of lithium niobate at a sound intensity of 100–300 W/mm^2 is quite sufficient for the formation of surface acoustic shock waves in a solid.[1,2] The fact that a nonlinear surface acoustic wave behaves in its initial stage as a simple wave suggests the possible existence in $LiNbO_3$ of surface acoustic solitons, if a dispersion is artificially arranged for surface waves in some manner. Dispersion properties of this sort can be arranged by depositing a thin insulating film on the surface of a solid, as follows from the results of Ref. 3. It is not difficult to show that in a certain interval of thicknesses of this film the dispersion law can be approximated accurately by the dispersion law in the Korteweg–de Vries equation.

In the present experiments we have developed a specific layered structure of $LiNbO_3$ and a SiO film. We have experimentally studied the conversion process during the propagation of a surface wave, which is sinusoidal at the source, into cnoidal waves or Korteweg–de Vries solitons.

The technique for the excitation of large-amplitude surface acoustic waves corresponds entirely to that described in Ref. 1. A Rayleigh wave is excited at a frequency ~114 MHz with an acoustic power flux density up to ~300 W/mm^2. An insulating film of SiO, ~500 Å thick, is deposited on the surface of a Y-cut lithium niobate

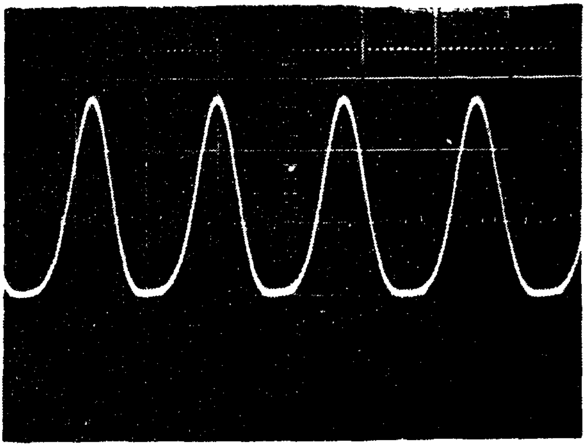

FIG. 1. Profile of a nonlinear Rayleigh wave at a sound intensity $P=100$ W/mm^2. The behavior of the longitudinal component of the vibrational velocity of the surface acoustic wave is shown here.

crystal by vacuum deposition. The profile of the nonlinear surface wave is studied by means of a moveable electrodynamic probe: a strip of copper (2 μm wide, 0.2 μm thick, and 1 mm long) deposited on a sapphire parallelepiped. The probe, oriented parallel to the front of the surface wave, in the form of a segment of an asymmetric stripline, causes an electroacoustic conversion of the test signal by virtue of the piezoelectric properties of $LiNbO_3$. The test signal is then analyzed with an S1-75 oscilloscope.

The oscilloscope trace in Fig. 1 shows the shape of the nonlinear surface acoustic wave corresponding to an acoustic power flux density ~ 100 W/mm^2. We should first point out that this shape remains essentially constant throughout the crystal, aside from a slight decrease in amplitude, because of absorption, as the wave propagates away from the transducer. With increasing intensity of the nonlinear surface acoustic wave, we then observe an increase in its period. These properties, combined with the typical shape of the observed wave, suggest that we are dealing with cnoidal waves.

With a further increase in the intensity, the surface acoustic wave, which is sinusoidal at the transducer, decays into a periodic train of short pulses (solitons); there are two solitons, with different amplitudes, in each period. Figure 2, a–c, shows oscilloscope traces illustrating the dynamics of the solitons as a function of the distance from the observation point to the transducer. The power flux density here reaches ~ 300 W/mm^2. It follows from these traces that the soliton with the lower amplitude lags behind the soliton with the larger amplitude (the wave is propagating from right to left on the oscilloscope trace). At an observation point 9.46–9.5 mm from the transducer (for example), the pattern changes sharply: Trace c is essentially replaced by trace a, and then the dynamics of the behavior of the solitons is completely repeated. The abrupt change in the positions of the solitons on the traces over a relatively small displacement of the probe (0.04 mm) demonstrates the classical picture of a collison of solitons. The dynamics of the solitons corresponds to the periodic soliton solutions of the Korteweg–de Vries equation,[4] so that the pulses observed experimentally may be interpreted as Korteweg–de Vries solitons.

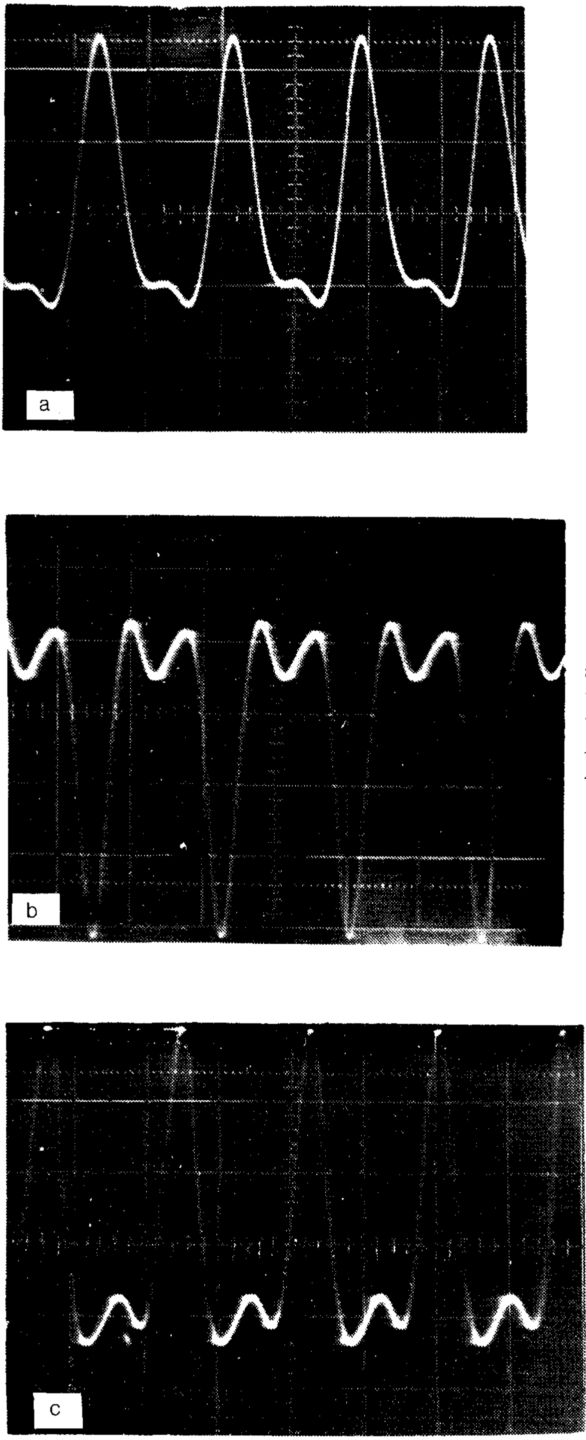

FIG. 2. a—Profile of a Rayleigh wave at a sound intensity $P = 300$ W/mm^2 (the distance form the observation point to the transducer is $l = 9.04$, 9.5 mm); b—$P = 300$ W/mm^2 ($l = 9.24$, 9.75 mm); c—$P = 300$ W/mm^2 ($l = 9.46$ mm).

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