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Letter to the Editor

SURFACE ACOUSTIC WAVE PROPERTIES IN LAYERED SYSTEMS[1])

СВОЙСТВА ПОВЕРХНОСТНЫХ АКУСТИЧЕСКИХ ВОЛН В СЛОИСТЫХ СИСТЕМАХ

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As long as surface acoustic wave devices have been under discussion, layered systems have been investigated theoretically and experimentally. The simplest examples are those in metallic layers required for interdigital transducers. The surface is electrically shorted by a metallic layer, and the propagation velocity of the surface acoustic waves (SAW) becomes lower because the shorting is a partial decoupling in the case of a piezoelectric material. The velocity shift by surface metallizing is a measure for the electromechanical coupling strength, and the SAW coupling factor K^2 is defined by

$$K^2 = 2\,\frac{v_{free} - v_{met}}{v_{free}}.$$

High coupling factors are needed for constructing acoustoelectronic devices with a great bandwidth and a low insertion loss. In the past there were many efforts to find crystals and crystal cuts with high coupling factors. The coupling factors of important systems are shown in Table 1.

Decoupling can be studied in detail by observing the potential distribution normal to the surface.

Fig. 1 shows the YZ $LiNbO_3$ system for Rayleigh modes. The particle displacements u_1 and u_3 decay in a typical manner which is not influenced by surface metallizing, but the potential φ is drastically diminished due to surface shorting. It is obvious that the coupling factor will be the larger, the larger the surface potential to the particle displacement ratio is.

We will now discuss the possibility of a further enhancement of the SAW coupling factors. In principal this would be possible by shorting the whole region where the particle displacements do not wanish. That means we have to set formally $e_{ij} = 0$, e_{ij} being the piezoelectric constants. A more practicable way is to choose such positions x_3 in the substrate where a shorting plane has the maximum effect on the SAW velocity. It is obvious that this will not be possible in the case of YZ $LiNbO_3$ because the potential decays with the distance from the surface increasing.

By the help of a computer program [1] we investigated some systems with a potential maximum apart from the surface.

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The first case is PZT-4, a commercially available PZT ceramics. The position dependences of u_1, u_3 and φ are shown in Fig. 2 for a free and for a metallized surface. Placing a shorting plane in the range of the potential maximum, the electric field in the substrate is reduced to a higher extent than in the case of surface shorting. Thus we obtain a coupling factor of 26.5 % in contrast to 5.6 %. A similar behaviour can be observed in ZX $LiTaO_3$. The coupling factor by surface shorting is 1.0 %. If the electrodes are removed from the surface, the coupling factor reaches the value of 5.5 %.

Table 1
Coupling factors of important systems

Material	K^2 [%]
YZ-$LiNbO_3$	4.86
38°-ZX $LiNbO_3$	5.35
$LiTaO_3$	max. 1.52
PZT-4 ceramics	5.6
PZT ceramics ZFW	2.0
Tl_3TaSe_4	max. 4.17
Tl_3VS_4	max. 3.12
$Bi_{12}GeO_{20}$	max. 1.7
$AlPO_4$	max. 0.86
Quartz, ST cut	0.14
Z-GaAs	0.09

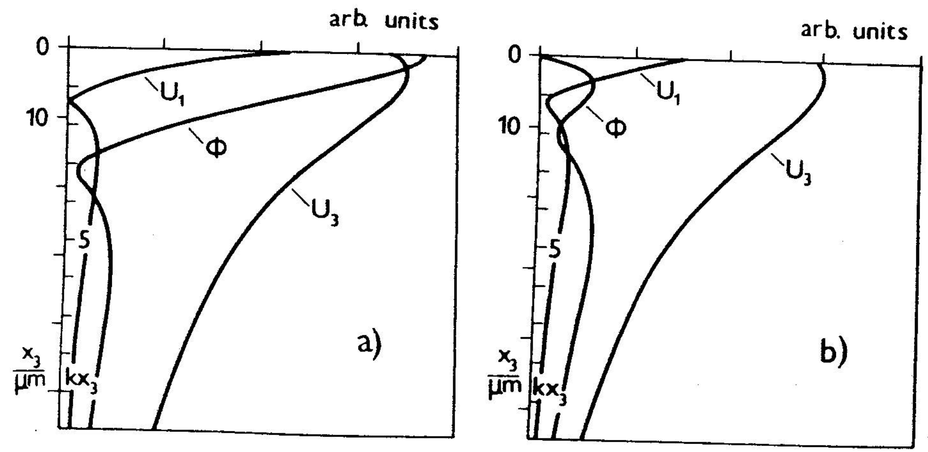

Fig. 1. Depth x_3 dependence of particle displacement u_1, u_3 and of potential φ in YZ-$LiNbO_3$ for a) free surface and b) metallized surface (k is the wave number).

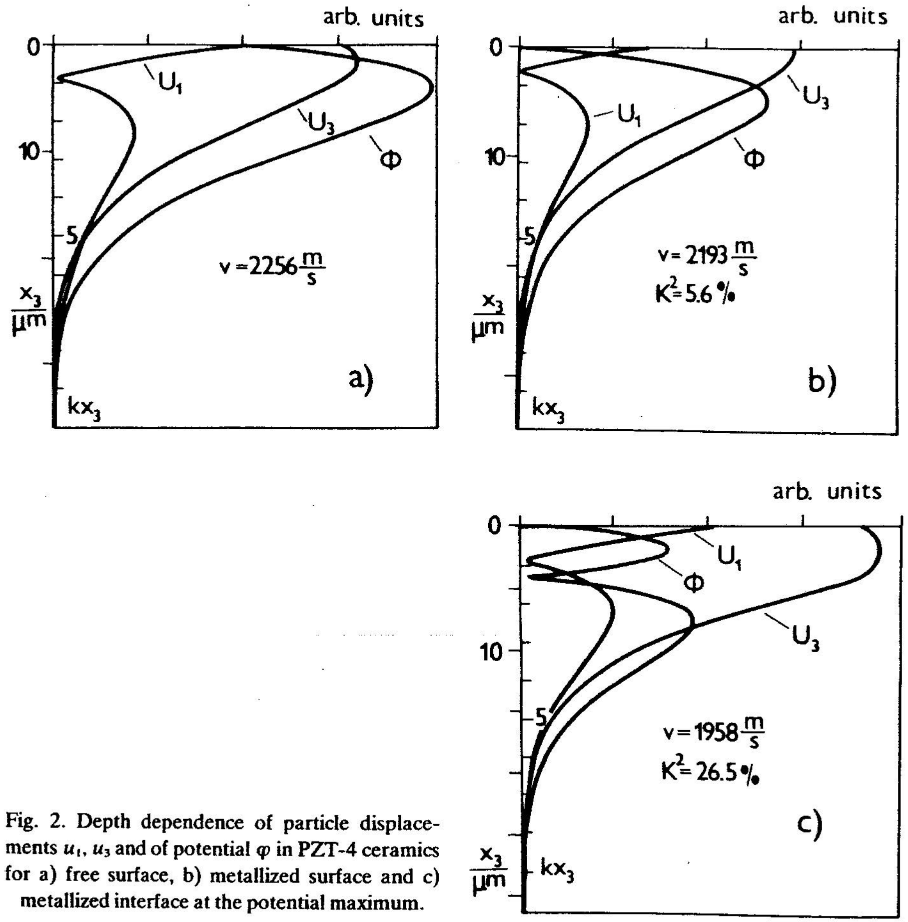

Fig. 2. Depth dependence of particle displacements u_1, u_3 and of potential φ in PZT-4 ceramics for a) free surface, b) metallized surface and c) metallized interface at the potential maximum.

In some other systems we observed a different behaviour, which corresponds to the case of 38° ZX $LiNbO_3$ with a minimum-maximum curve of the potential (Fig. 3). By surface metallization we obtain a coupling factor of 5.35 %. From the potential dependence on the coordinate x_3 we conclude that a shorting plane positioned at the maximum is less efficient than in the case of PZT-4 or ZX $LiTaO_3$ but also results in a greater coupling factor. We obtain 13 %.

Considering this phenomenon from a practical point of view we state that a coating of some substrate by the same material is possible only in few cases or requires a sophisticated technology.

This leads to the problem of finding these effects in a layered system of different materials. The phenomena in such systems are rather complicated. The layer can be assumed to be a plate coupled to the substrate. Similar to Lamb waves of different order in a plate, also modes of higher order can exist here [2]. Besides, waves with polarization in the x_2-direction are possible. Therefore we will restrict our investigations to Rayleigh modes of the first order. For changing the system as little as possible, we select a layer material having similar mechanical properties as the substrate has.

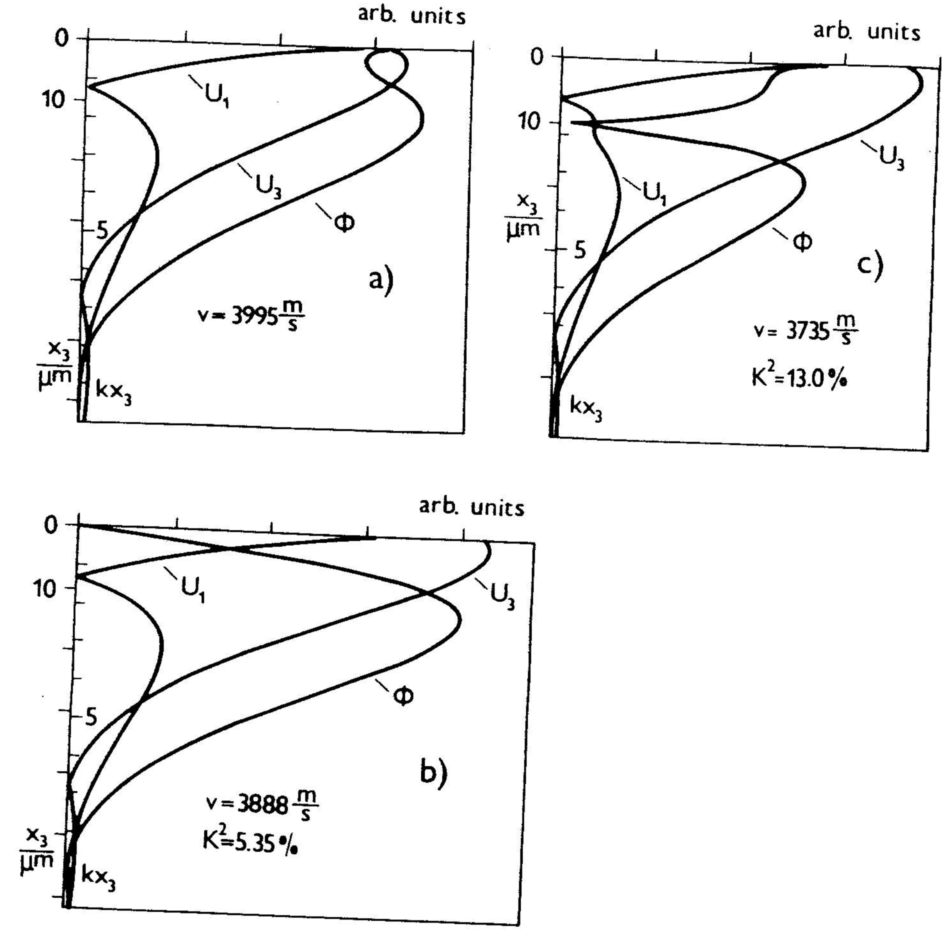

Fig. 3. Depth dependence of particle displacements u_1, u_3 and of potential φ in 38° ZX-$LiNbO_3$ for a) free surface, b) metallized surface and c) metallized interface at the potential maximum.

Such a system is a PZT-4 substrate coated by a ZnO layer which can be polycristalline, i.e. no piezoelectricity in the layer is needed. Fig. 4 shows that the potential distribution is similar to the case of a PZT layer instead of ZnO. As expected, we observe a remarkable lowering of the electric field in the substrate by metallizing the interface. Fig. 5 shows the SAW coupling factor dependent on kh (k is the wave number, h the layer thickness). A maximum value of 23.4 % is reached. The corresponding change of the propagation velocity for a free and a metallized interface is shown in Fig. 6.

A similar case is ZX $LiTaO_3$ with a polycrystalline ZnO layer. This system has a maximum coupling factor of 4.47 %.

In this way it is possible to optimize some important parameters of acoustoelectronic devices.

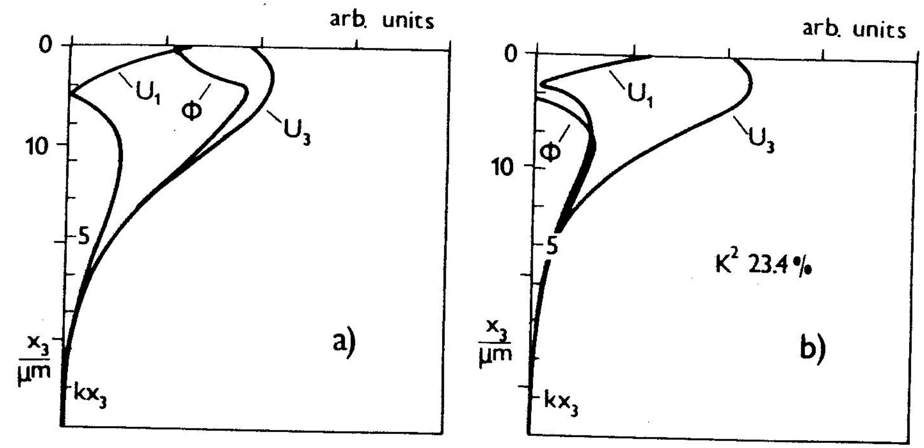

Fig. 4. Depth dependence of particle displacements u_1, u_3 and of potential φ for a) free surface and b) metallized interface between ZnO and PZT.

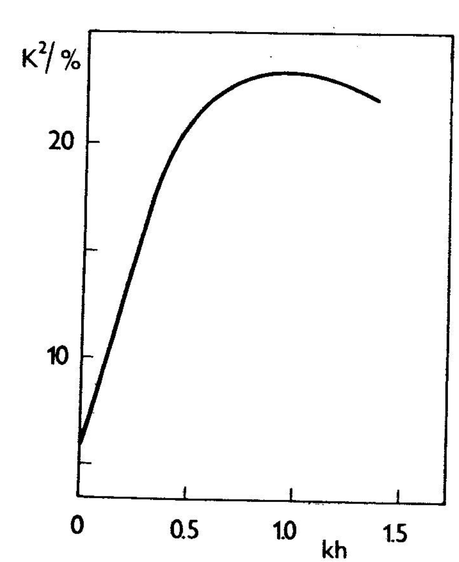

Fig. 5. Coupling efficiency K^2 as a function of kh (k is the wave number, h is the thickness) of a ZnO layer on a PZT substrate.

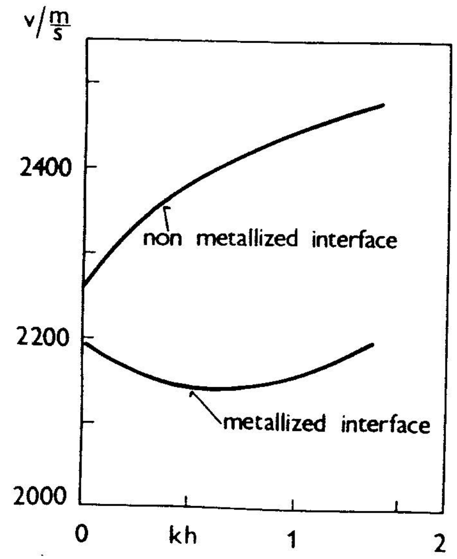

Fig. 6. Surface acoustic wave velocities for a PZT substrate with a ZnO layer of thickness h with and without metallized interface

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