PVF2 Transducers for NDE

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Abstract
We report on recent calculations and experiments on the broadband properties and impulse characteristics of PVF2 transducers and arrays. Experimental wedge transducers show bandwidths of approximately 100% in the excitation of surface acoustic waves at 7 MHz on nonpiezoelectric silicon nitride ceramic substrates. Computer calculations predict similar bandwidths for interdigital transducer arrays on PVF2 films for surface acoustic wave excitation on similar substrates. Insertion loss versus frequency measurements on bulk longitudinal wave transducers in water at frequencies in the 1 to 30 MHz range show good agreement with theory. A computer program for multilayer piezoelectric films predicts included angles of acceptance exceeding 60°, and control of acceptance angle profiles, in face plates using multilayer PVF2 films.

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ABSTRACT

We report on recent calculations and experiments on the broadband properties and impulse characteristics of PVF₂ transducers and arrays. Experimental wedge transducers show bandwidths of approximately 100% in the excitation of surface acoustic waves at 7 MHz on nonpiezoelectric silicon nitride ceramic substrates. Computer calculations predict similar bandwidths for interdigital transducer arrays on PVF₂ films for surface acoustic wave excitation on similar substrates. Insertion loss versus frequency measurements on bulk longitudinal wave transducers in water at frequencies in the 1 to 30 MHz range show good agreement with theory. A computer program for multilayer piezoelectric films predicts included angles of acceptance exceeding 60°, and control of acceptance angle profiles, in face plates using multilayer PVF₂ films.

PVF₂ bulk wave transducers are made by bonding 25 μm PVF₂ film (≈ 1/2° × 1/2°) onto brass backing rods with V-6 epoxy. The PVF₂ film is obtained from Kureha Corporation in stretched, poled and electroded form. We etch off the aluminum electrodes, which erode quickly when placed in water, and put down a thin layer of chrome followed by a layer of gold (≈ 1000 Å).

These bulk wave transducers have a very flat frequency spectrum up to 20 MHz when radiating into water. This is expected, since the acoustic impedance and velocity of longitudinal waves in PVF₂ (3.83 × 10⁹ gm/cm²sec and 2.15 × 10⁵ cm/sec, respectively) match relatively well to the impedance and velocity of water (1.48 × 10⁹ gm/cm²sec and 1.48 × 10⁵ cm/sec). As the impedance mismatch at the brass/PVF₂ interface is large, little energy is radiated into the brass. These characteristics of PVF₂ result in a clean, nearly bipolar impulse response (Fig. 1). PVF₂ transducers have shown a 60 dB two-way insertion loss at their resonance frequency (λ = 4 × film thickness).

We are currently examining the possibility of a PVF₂ face plate which could receive acoustic radiation at angles other than normal incidence. For a face plate used as a receiver, broadband frequency response leads to broad angular response. Therefore a PVF₂ face plate should have a very broad angular response. Just as a wide aperture optical lens has better resolution than a narrow aperture lens, a broad angular response transducer will lead to better resolution than a transducer with a relatively narrow angular response. Thus, a PVF₂ face plate promises good resolution. Photolithography would be used to produce periodic electrode patterns on the PVF₂ surface which could then be electronically scanned to achieve imaging. At present, theoretical studies on the angular response of brass backed PVF₂ face plates are underway using a computer program developed by Auld and Roberts. Figure 4 shows the voltage response as a function of angle of a PVF₂ brass backed film. The three curves show the effect of the value of the piezoelectric coupling coefficient eₜₙₚₙ transducer response. (Shear wave effects have been suppressed in order to simplify understanding of the result.) As eₓₓ and eₜₜ have opposite signs, it is seen that eₓₓ detracts from the uniform character of the voltage response from 0° to 30°.
Calculations have also been made which involve both shear and longitudinal waves. These show a large shear wave resonance near a 55° angle of incidence. The tail of these resonances contributes to the uniform character of the response from 0° to 30°.

![Multilayer transducer structure.](image1)

**Fig. 2.** Multilayer transducer structure.

We have devised a scheme that involves stacking three layers of PVF₂ in such a way that the resulting $e_{xz}$ and $e_{zz}$ of the stacked films have the same sign. By rotating a film 90° about an axis perpendicular to the plane of the film we can interchange $e_{xz}$ and $e_{zy}$, which differ by a factor $\approx 5$. By inverting a film we change the sign of $e_{xz}$ and $e_{zy}$. Using these changes, we theoretically construct a three-layer stack with the properties shown on Fig. 5. This figure also shows the voltage response of such a stack. The theoretical response of such a stack is more favorable (out to 45°) than a single film.

Wedge transducers have been constructed for the excitation of surface acoustic waves on high velocity nonpiezoelectric substrates. These could be used to perform NDE on surface flaws. In this case, a PVF₂ transducer irradiates the substrate at an angle such as to phase match with a surface acoustic wave propagating on the substrate. The experimental wedge transducers have a resilient RTV wedge between the PVF₂ transducer and the surface wave substrate allowing experimental variation of the wedge angle by distorting the RTV, this being a critical parameter. (See Fig. 6). As PVF₂ can be used at frequencies near 20 MHz, the wavelength of such a surface wave will be small, and resolution will be good. Using 30 μ PVF₂ films, a bandwidth of approximately 100% has been observed at 7 MHz in initial measurements using two identical wedge transducers on a silicon nitride substrate.

![Theoretical PVF₂ face plate response.](image2)

**Fig. 4.** Theoretical PVF₂ face plate response.

Interdigital surface wave transducers in which PVF₂ film provides coupling between the interdigital array (deposited on the PVF₂) and a nonpiezoelectric substrate are being studied. The effective coupling is determined by evaluating the fractional difference in velocity ($\Delta v/v$) of a surface wave propagating in the film substrate combination under two conditions: (1) no electrodes are present at the surface which is to contain the interdigital array, and (2) a uniform conductor is placed at that surface. The surface wave velocities have been calculated using a computer program.
developed by Kino and Wagers, are shown in Fig. 7. Focusing on the curve label 10-00, we see that this curve rises to a reasonably high value (0.8%) and is also fairly broad. This implies that an IDT with the 10-00 structure would be capable of a broad frequency response. The resulting transducer will be flexible and mechanically conformable for use on curved surfaces (see Fig. 8).

Fig. 6. Wedge transducer schematic.

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Fig. 7. $\Delta v/v$ versus film thickness.

Cases

01-00 - IDT on top of PVF$_2$
short at sub-PVF$_2$ interface

10-00 - IDT at PVF$_2$ sub-interface
short on top of PVF$_2$

11-01 - IDT at sub-PVF$_2$ interface
short on top of PVF$_2$

11-10 - IDT on top of PVF$_2$

(H = film thickness, K = propagation constant)

Fig. 8. IDT schematic.

The PVF$_2$ program at Stanford also includes a material synthesis group. C. Frank and S. Bowker of the Chemical Engineering Department are studying the chemistry and synthesis of PVF$_2$, aimed at improving the piezoelectric properties of PVF$_2$.

R. Reigelson, R. Route, and R. DeMattei are involved in melt press production of PVF$_2$ films at the Stanford Center for Materials Research.

References

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