The Application of Dielectric Thin Films To Enhance the Properties of SAW Devices

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Abstract: **To meet the increasing demands of personal and commercial communication systems, high performance SAW devices are required to have high frequencies, low loss, wide bandwidth, and high reliability. It was determined early in the investigation of SAWs that there were velocity, loss, coupling factor, and temperature coefficient improvements to be gained through the use of thin amorphous dielectric films on piezoelectric substrates. While this kind of film technology has been used sparingly in SAW device product development, it still represents a potential source for enhancing such products. Deposited on a bare piezoelectric wafer, amorphous films provide the functions of surface passivation, reduction of pyroelectric effects, and smoothing to reduce SAW propagation loss. Films modify the coupling factor, reduce the temperature coefficient of frequency, and permit higher order SAW modes to be propagated. As a practical manufacturing matter, thin films on electroded SAW components provide a protective coating to prevent shorting by metal particles, reduce metal migration due to electric and stress fields, protect from degradation due to chemicals and corrosive vapors, and be used very effectively for frequency trimming. For Pseudo-SAW propagation on rotated substrates, the dielectric film can reduce the leaky-wave bsses and enhance coupling factor and TCF. This paper considers the advantages of nitride and oxide films on piezo-substrates for the enhancement of SAW devices.**

I. Introduction

Surface acoustic wave (SAW) technology has been highly successful in providing practical devices for electronic systems. It was determined early in the investigation of SAWs that there were velocity, loss, coupling factor, and temperature coefficient improvements to be gained through the use of thin films on Rayleigh-wave propagating piezoelectric substrate [1]. Table 1 lists a number of the useful functions attributed to the application of dielectric films on SAW substrates. A thin amorphous dielectric film can be deposited on a bare piezoelectric wafer to provide the functions of surface passivation, chemical protection, smoothing to reduce propagation loss, and enhance the growth of other films. Thin dielectric films have been used on electroded SAW components as a protective coating to prevent shorting by metal particles, to reduce metal migration due to electric and acoustic fields, to protect environmental degradation due to chemicals and corrosive vapors, and for frequency trimming. Intermediate thickness films can be used to modify the coupling factor, reduce the temperature coefficient of frequency, and allow for higher order SAW and Pseudo-SAW modes with coupling factor and loss advantages. The higher order SAW modes increase the frequency capability of the SAW propagation for a given transducer electrode spacing and may result in the added benefits of higher coupling, lower loss, and reduced TCF. The presence of a dielectric film can reduce to essentially zero the propagation losses due to leaky waves over selected frequency regions [2]. A thick soft dielectric film is used for absorbing surface waves and helps in the identification of pseudo-SAW modes in the presence of Rayleigh-like modes. A thick solid film can support Stoneley waves and achieve a package-less SAW device. The addition of dielectric thin films to piezoelectric substrates could give the necessary edge in meeting future filter and resonator requirements. This paper looks at some examples of the application of amorphous dielectric films to piezoelectric substrates, which illustrate the benefits of thin-film technology. Considered are very thin and intermediate thickness films, and the benefits, which result from the use of some selected oxide and nitride films. Dielectric films are growing in importance in the SAW sensor area, but examples of such films will not be addressed in this paper.

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TABLE 1

Dielectric Films on Piezoelectric Substrates for SAW Device Development.

(t = film thickness, λ = acoustic wavelength)

FILM TYPE	FUNCTION	SAW DEVICE SUPPORT
I. Thin Films ($t << \lambda$)		
Uniform wafer coverage	Surface passivation	Ease processing, reduce loss
Uniform wafer coverage	Improved growth surface	Higher film quality
Patterned wafer coverage	Surface protection	Reduce assembly degradation
Patterned wafer coverage	Frequency trimming	Frequency accuracy
II. Intermediate ($0.1<t/\lambda<1$)		
Property matching film	Increased coupling factor	Low loss and wide bandwidth
Positive TCF film	Reduce TCF	Temperature stability
Customized films	Higher order GSAW-PSAW	Higher k^2, high freq., low loss
III. Thick Films ($t >> \lambda$)		
Soft elastic films	SAW absorption	Reduce reflections, reveal modes
Customized films	Stoneley wave propagation	Package-less SAW devices

II. VERY THIN FILMS

The use of a very thin dielectric film (t=20-40 nm) on a piezoelectric substrate can reduce any deleterious effects of the chemicals used in the photolithography process, eliminate surface fractures due to pyroelectric effects, reduce propagation loss, modify coupling factor, and present a more receptive surface for the growth of additional films such as piezo-films.

Lithium tetraborate (LBO), is an example of a highly desirable piezo-substrate, which has a combination of zero TCF and relatively high coupling coefficient. However it dissolves in water and other chemicals which are used in standard photolithographic processing. An investigation in the author's laboratory determined that 30 to 60 nm of sputtered glass film deposited on LBO substrates prior to depositing and etching interdigital transducer (IDT) electrodes of aluminum would permit standard wet chemical photolithographic processes to be used. The velocity, propagation loss, transducer conversion loss, and temperature coefficient of frequency were measured over a frequency range from 30 MHz to 1.0 GHz. The substrates suffered no surface damage and the change in the acoustic properties of the SAW devices was minimal. The presence of the glass actually lowered the SAW propagation loss in dB/cm by an average of 20% over a frequency range from 100 to 800 MHz and the transducer conversion loss was unchanged or slightly less.

For the deposition of the major film layer on a SAW substrate it may be advantageous to use a thin intermediary film which promotes a better growth surface for the major film layer. It was found that a thin PECVD silicon nitride layer on silicon was conducive to a higher quality sputtered aluminum nitride film [3]. The resulting fine grain polycrystalline AlN films showed acoustical properties that were very close to epitaxial AlN films.

Thin oxide films have been used for the protection of the surface of a patterned SAW device from shorting particles and to protect the electrode from chip scratches, particle adhesion, and dicing contamination [4]-[5].

There has not been a substantial amount of work done on the effects of a dielectric film over the electrode region to suppress metal migration due to high currents and high acoustic stress fields. It is anticipated that the presence of a hard metal film such as a nitride should suppress such effects.

It was realized early in the development of dielectric films for SAWs that they would be useful for frequency trimming [6]. Films can be used which either increase or decrease the frequency.

III. INTERMEDIATE THICKNESS FILMS

It is in the area of intermediate thickness dielectric films ($0.1\lambda<t<0.5\lambda$) where the most profound changes in properties of SAW substrates occur. As indicated in Table 1, control of coupling factor, propagation loss, and temperature coefficient of frequency can be substantially altered by the presence of a film layer. Table 2 shows what effects the presence of a deposited film has on the coupling factor measure, $\Delta v/v$, for dielectric films on 128° Y-X lithium niobate with the IDT pattern at the film/substrate interface. The films have different acoustic and dielectric properties as indicated. The theoretical data is given in ascending order of the increase in $\Delta v/v$ as the coupling factor measure. In the first row is given the lithium niobate without film, and in the final row is the equivalence of having a $LiNbO_3$ film, which doubles the $\Delta v/v$ value. The silicon based films all give an increase in coupling factor, which seems to grow with the growing value of the shear constant c_{44}. The dielectric constant as well as density may also play a role. The niobium pentoxide, which has a high density and dielectric constant, but low shear constant does not produce an increase in the coupling factor. The ideal film may be that which matches the properties of the substrate.

TABLE 2.
Theoretical Coupling Factor Enhancement for Deposited Thin-films on 128° Y-X $LiNbO_3$
(The interdigital electrode is at the film-substrate interface)

Film	ρ kg/m^3	c_{11} GPa	c_{44} GPa	ε (relative)	t/λ	$\Delta v/v$
None	4700	230	87	38	0	0.03
Nb_2O_5	3940	120	22	35	0.2	0.028
SiO_2	2200	78.5	31.2	3.2	0.18	0.037
SiON	2300	170	54	4.5	0.2	0.038
SiC	2100	172	53	9.7	0.1	0.0385
SiN	2650	180	80	7.5	0.1	0.046
$LiNbO_3$	4700	230	87	38	0.3	0.06

A glass film, which has a strong positive temperature coefficient of frequency (TCF = 80), when combined with a high coupling factor piezoelectric substrate with a negative TCF, can improve and even reduce to zero the first order temperature coefficient. Glass layers on PSAW cuts of niobate and tantalate have been investigated experimentally by the author [7]. Temperature coefficient of frequency vs. film-thickness to acoustic-wavelength ratio for sputtered SiO_2 on 36° $LiTaO_3$, 41° $LiNbO_3$, and 64° $LiNbO_3$, showed that the cross over points were in the range of t/λ = 0.3-0.35. Table 3 shows the trade-offs, which can be made, in preserving the advantages of high velocity and low loss while maintaining a high coupling factor and reduced TCF. Both theoretical and experimental values are shown which are in reasonable agreement. The IDT is at the interface between the substrate and the film layer and thus the aluminum electrodes are protected from mechanical and chemical effects and may also be improved in their ability to withstand high power.

TABLE 3.
Predicted and Realized Properties for Glass on Pseudo-SAW Substrates.

Substrate	t/λ	Loss (dB/λ) Theo.	Loss (dB/λ) Exp.	Velocity (m/s) Theo.	Velocity (m/s) Exp.	k^2 (%) Theo.	k^2 (%) Exp.	TCF ppm/°C no glass	TCF ppm/°C Exp.
36° $LiTaO_3$	0.13	0.02	0.023	4100	4070	7.6	6.5	-32	-32
41° $LiNbO_3$	0.12	0.18	0.08	4425	4330	18.7	15.0	-80	-42
64° $LiNbO_3$	0.19	0.20	0.18	4350	4250	10.8	7.5	-80	-38

IV. Conclusions

The new millenium will see advancements in the understanding of the acoustic properties of thin films and their application to achieve new and better SAW devices. In the communications area where integrated voice, data, and video systems will prevail, higher frequency, wider bandwidth, higher power, lower loss, and extended signal processing capabilities will be required of SAW devices. The addition of dielectric thin films to piezoelectric substrates could give the necessary edge in meeting filter and resonator requirements. Thus it is important that research and development continue in the processing, measurement, and application of thin dielectric films to SAW devices.

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