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## Love mode layered surface acoustic wave filters

K. Kalantar-zadeh, W. Wlodarski and K. Galatsis

Novel surface acoustic wave filters have been developed by depositing SiO<sub>2</sub> and ZnO thin films onto 90° rotated ST-cut quartz crystal substrates. Up to 19dB insertion loss improvement was obtained for the filter with a ZnO film. The filters have no coupling with other wave propagating modes, exhibiting only one passband.

**Introduction:** Filters with linear-phase response are employed in communication circuits when distortion of the processed signal is to be avoided. Conventional linear phase passive L-C filters have some degree of phase nonlinearity and they are unfavourable in cost and size. By contrast, surface acoustic wave (SAW) filters with comparable performance are smaller, cheaper and have a highly linear phase response [1]. Miniaturising SAW filters is the current challenge so that they can be employed as RF bandpass filters for mobile handsets. Concerns such as low insertion loss and stability are important issues in SAW filter fabrication.

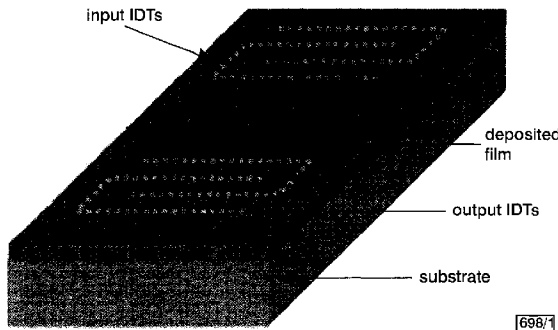


Fig. 1 Structure of layered SAW filter

Blank SAW filters have no film deposited on surface

A SAW filter generally consists of interleaved comb metal electrodes (Fig. 1) as input and output ports. In conventional structures, the inter-digital transducers (IDTs) are photo-deposited on the highly polished surface of a precisely oriented piezoelectric crystal. Signals exerted to the input port produce propagating electro-acoustic waves by means of piezoelectric coupling, which are received at the output port. The width of one IDT plus one gap between two IDTs is equal to half the wavelength of the centre frequency of the filter. With a constant wavelength, the speed of the acoustic wave propagation determines the filter centre frequency. A higher speed of acoustic wave propagation results in a higher centre frequency. Hence, to decrease the size of the filter, the speed of the acoustic wave propagation should as high as possible.

Lithium niobate and ST-cut (x-direction) quartz crystal are common materials used to fabricate SAW devices. Their main disadvantage is their low speed of acoustic wave propagation (3800m/s and 3150m/s, respectively). The low propagation speed can be improved by the deposition of piezoelectric films on non-

piezoelectric high propagating speed substrates such as Si. However, in a ZnO/SiO<sub>2</sub>(for insulation)/Si [2] structure, the ZnO film thickness must be comparable to the wavelength. This decreases the speed of propagation to magnitudes comparable to the propagation speed of ZnO (3700m/s). Piezoelectric films on diamond layer structures provide higher propagation speeds [3], but they are expensive and difficult to fabricate. All of the above structures have the disadvantage of coupling with other wave propagating modes, therefore as seen from Fig. 2a other passbands exist.

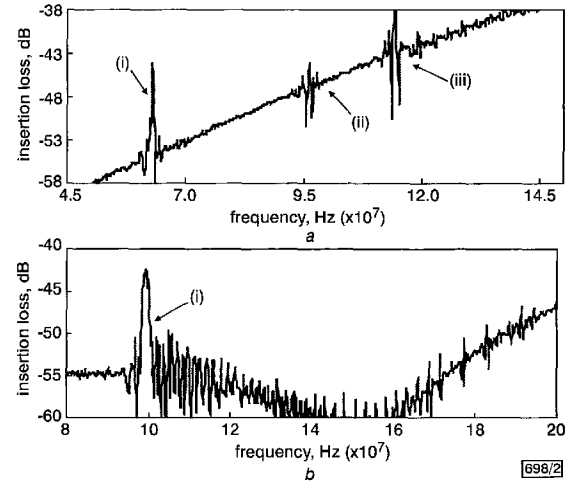


Fig. 2 Frequency response of two ST-cut quartz blank filters

- a x-direction with Rayleigh propagation mode  
 (i) Rayleigh wave (main harmonic)  
 (ii) SSBW  
 (iii) second harmonic  
 b 90° rotated with no extra coupling mode  
 (i) SSBW (main harmonic)

A suitable choice of substrate is 90° rotated ST-cut quartz crystal since the speed of propagation is 5000m/s and the dominant wave is surface skimming bulk wave (SSBW). It has zero coupling to other bulk modes. It is dominantly a shear horizontal (SH) bulk wave and has a low temperature coefficient. Its major disadvantage is its high insertion loss [1]. Depositing films of different metal oxides decreases the insertion loss as it changes the mode of operation from SSBW to Love mode [4]. If the deposited film loads the substrate, the mode of propagation changes to Love mode. This occurs when the speed of SH acoustic wave propagation in the film is less than the substrate. In this Letter, SiO<sub>2</sub> and ZnO films were deposited on 90° rotated ST-cut quartz crystal to fabricate Love mode operating filters.

Table 1: Sputtering conditions for SiO<sub>2</sub> and ZnO films

Material	Base pressure	Sputtering pressure	Power	Gas	Deposition rate
	Torr	Torr	W		μm/h
SiO <sub>2</sub>	2.5 × 10 <sup>-5</sup>	1.1 × 10 <sup>-3</sup>	140	90% Ar, 10% O <sub>2</sub>	0.9
ZnO	1.5 × 10 <sup>-5</sup>	1.1 × 10 <sup>-3</sup>	60	60% Ar, 40% O <sub>2</sub>	0.6

**Configuration of filters and fabrication process:** Love mode filters have been fabricated on 90° rotated 0.5mm thick ST-cut quartz substrates. The input and output IDTs consist of 64 and 16 IDT pairs, respectively, with 50μm periodicity and an aperture of 3mm. SiO<sub>2</sub> (with the propagation speed of 2850m/s) and crystallographically c-axis oriented [2] ZnO films were deposited using RF magnetron sputtering, with a thicknesses of 1.5μm. The sputtering conditions are shown in Table 1.

**Results and discussions:** Insertion losses were examined by measuring the transmission S parameters. S parameters were measured using a network analyser. The network analyser had a 50Ω line impedance. The measurements indicate that the operating mode of a 90° rotated ST-cut quartz crystal filter has no extra coupling modes (Fig. 2b). Fig. 3 shows the frequency response of a blank filter together with SiO<sub>2</sub> and ZnO filters on 90° rotated ST-cut quartz crystal.

The ZnO/ST-cut quartz crystal structure possesses a lower insertion loss. In this case, the insertion loss is 19dB less than the blank quartz crystal filter and 6dB better than the SiO<sub>2</sub>/ST-cut quartz crystal structure. The acoustic signals on both layered structures are dominantly SH, since an insignificant change in insertion loss occurs when the surface of the filter is loaded with a low-viscous liquid. Owing to the difference in magnitudes of propagation speeds in the deposited layers and substrate [4], the propagation mode of the filter is expected to be Love mode. The insertion loss is less in the layered structures as SSBWs change to Love waves where the waves are dominantly propagating near the surface and in the deposited layers. The ZnO based acoustic filter has a lower insertion loss compared to the blank and SiO<sub>2</sub> based filters due to the piezoelectric nature of ZnO, which increases the coupling coefficient of the structure.

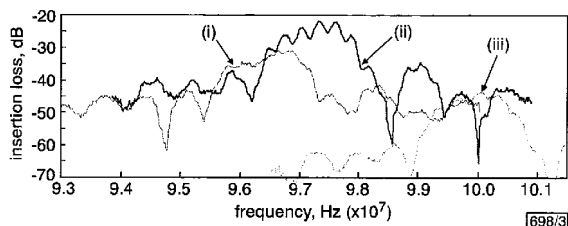


Fig. 3 Frequency response of ZnO/ST-cut quartz crystal structure, SiO<sub>2</sub>/ST-cut quartz crystal structure and blank filters

- (i) SiO<sub>2</sub> film
- (ii) ZnO film
- (iii) blank

**Conclusion:** Novel filters with SiO<sub>2</sub>/90°rotated ST-cut quartz crystal and ZnO/90°rotated ST-cut quartz crystal structures have been fabricated. They show an improved insertion loss compared to the blank quartz crystal filters. Propagation modes show no coupling with other modes and due to their high speed of propagation, they are smaller in size.

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## Errata

LIZHI CHENG, HUI XI, and YONG LUO: 'Integer discrete cosine transform and its fast algorithm', *Electron. Lett.*, 2001, **37**, (1), pp. 64–65

Author's correction

$P_N^{(2)}$ ,  $P_N^{(3)}$  and  $B_N$  should read

$$P_N^{(2)} = \text{Bdiag} \left\{ I_{\frac{N}{2}}, P_{\frac{N}{2}}^{(1)} \right\}$$

$$P_N^{(3)} = \text{Bdiag} \left\{ I_{\frac{N}{2}}, -I_{\frac{N}{4}}, \text{diag}(1, -1, \dots, 1, -1) J_{\frac{N}{4}} \right\}$$

and

$$B_N = \text{Bdiag} \left\{ I_{\frac{N}{2}}, J_{\frac{N}{2}} * \text{Bdiag} \left\{ 1, \frac{\sqrt{2}}{2} \begin{bmatrix} 1 & 1 \\ -1 & 1 \end{bmatrix}, \dots, \frac{\sqrt{2}}{2} \begin{bmatrix} 1 & 1 \\ -1 & 1 \end{bmatrix}, 1 \right\} \right\}$$

STEINLE, G., MEDERER, F., KICHERER, M., MICHALZIK, R., KRISTEN, G., EGOROV, A.Y., RIECHERT, H., WOLF, H.D., and EBELING, K.J.: 'Data transmission up to 10 Gbit/s with 1.3 μm wavelength InGaAsN VCSELs', *Electron. Lett.*, 2001, **37**, (10), pp. 632–634

Editor's correction

Fig. 2 should have appeared as follows:

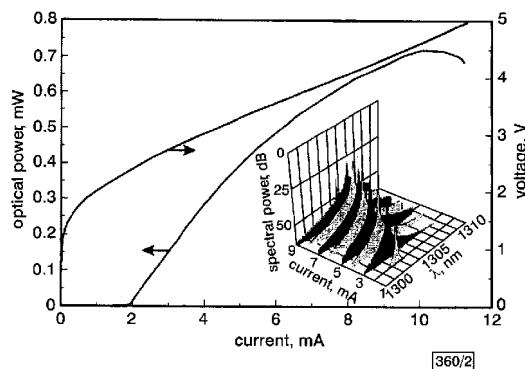


Fig. 2 CW properties and emission spectrum at various pump currents of 3 to 9 mA

Multimode operation is found for currents above 9 mA