Resonant conditions for Love wave guiding layer thickness

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In this work, we report an investigation of polymer overlayer thickness in a Love wave device working at a fundamental frequency of 110 MHz and at the 330 MHz harmonic. At both frequencies, we observe the initial reduction in insertion loss associated with a Love wave device. Significantly, we also observe a series of resonant conditions as the layer thickness is further increased. The separation of these resonances is attributed to an increase in thickness of half of the acoustic wavelength in the polymer.
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A Love wave is a type of shear horizontally polarized surface acoustic wave that can be produced in a surface skimming bulk wave (SSBW) device when an overlayer with an acoustic shear velocity less than that in the bulk is deposited over the propagation path.[1] The overlayer has the effect of confining energy to the surface and hence acting as a guiding layer producing a reduction in the insertion loss compared to that of an uncoated SSBW device. The use of Love wave devices for biosensing applications was reported in 1992[2] and has since attracted much attention.[3–7] Several reports have focused on establishing the optimum guiding layer thickness for sensing applications[7,8] and have therefore concentrated on determining the change in insertion loss and frequency as an overlayer is built up. The maximum sensitivity has been reported as occurring for a thickness slightly greater than that required for the minimum insertion loss. There have been no reports of the basic properties for devices with substantially thicker guiding layers. In this work, we report an investigation of the effect of overlayer thickness on the insertion loss and shift in resonant frequency for a Love wave device operated at a 110 MHz fundamental frequency and at the 330 MHz harmonic.

The SSBW devices used in our experiments consisted of a split-finger (double–double) interdigital transducer (IDT) design. Devices were fabricated on ST-cut quartz with propagation orthogonal to the crystalline *X* direction, which is known to support a SSBW, and designed for operation at a fundamental frequency of 110 MHz. With an appropriate IDT metalization thickness, this split-finger design also resonates at the third harmonic. Coating the SSBW device with a suitable overlayer allows a Love wave to be excited at either the fundamental or third-harmonic frequency.[9] Each IDT was of length 40λ and aperture 65λ where the wavelength λ was 45 μm, the finger widths were 6.75 μm and spacings were 4.5 μm. The path length was 7 mm and the guiding layer, deposited directly onto the quartz surface, consisted of spin-coated Shipley S1813 photoresist. After deposition the resist films were soft baked at 110 °C for 10 min; film thickness for the layers were confirmed by measurements using a Veeco Dektak 3 Surface Analysis System. The insertion loss and resonant frequency of the devices were measured using an Agilent 8712ET network analyzer.

In Fig. 1 we show the insertion loss (squares) and resonant frequency (triangles) as a function of overlayer thickness for operation at the fundamental frequency of 100 MHz. The Love wave guiding effect can clearly be seen with an initially improving insertion loss and a reducing frequency of operation with increasing overlayer thickness. The lowest insertion loss, due to the guiding effect, occurs at around 1.5 μm. Beyond this overlayer thickness, the insertion loss increases as previously reported in the literature. However, the frequency also continues to decrease with increasing overlayer thickness until at around 2.5 μm a clear resonance is observed corresponding to both a large frequency decrease and a substantial insertion loss. This pattern is further repeated in a periodic manner and we were able to observe four clear minima in the insertion loss and frequency before the noise level became too large. The average overlayer thickness between two successive minima was (5.2

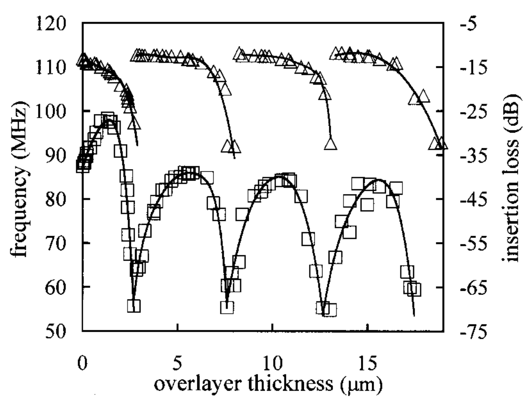

FIG. 1. Insertion loss (squares) and resonant frequency (triangle) for a device operated at the fundamental frequency as a function of overlayer thickness.

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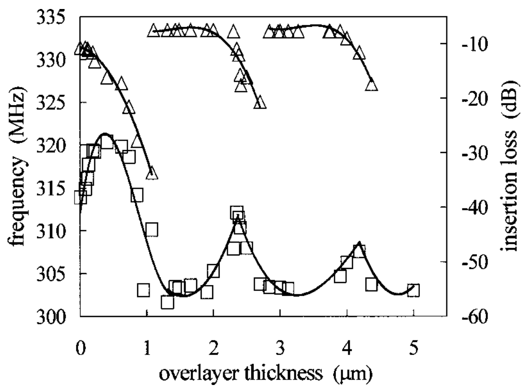

FIG. 2. Insertion loss (squares) and resonant frequency (triangle) for a device operated at the third harmonic as a function of overlayer thickness.

± 0.1) μm and the thickness for the first minima was (2.7 ± 0.1) μm.

In Fig. 2, we show the insertion loss (squares) and frequency (triangles) as a function of overlayer thickness for the harmonic of the same device operated at 330 MHz. As the device is operating at three times the fundamental frequency, the SSBW wavelength is one third that of the fundamental. Thus, assuming the acoustic speed in the overlayer is independent of frequency, the acoustic wavelength in the overlayer will also be one third that occurring when the device is operated at the fundamental frequency. This is reflected in Fig. 2 in the positions of the resonances and the initial Love peak, which now occurs for an overlayer thickness of 0.5 μm. The periodic pattern in the frequency shift is clearly observable with a period in the overlayer thickness of (1.7 ± 0.1) μm compared to that of (5.2 ± 0.1) μm at the fundamental frequency. A series of related maxima and minima can also be observed in the insertion loss although the exact shape is different to that observed at the fundamental.

The solution of the dispersion equation from Love wave theory[10] predicts a series of modes with the first Love wave mode corresponding to a displacement with an antinode at the top surface of the layer and a single node located in the substrate close to the interface with the overlayer. The next higher order mode also has an antinode at the overlayer surface, but two nodes with one located within the layer and one located in the substrate close to the interface with the overlayer. Subsequent higher order modes introduce additional nodes within the overlayer. Equating the period in our overlayer thickness to one half of an acoustic wavelength gives an estimated acoustic speed in the overlayer of (1120 ± 60) m/s and this is consistent with expectations from Love wave theory.

In conclusion, we have studied the effect of increasing the overlayer thickness on a SSBW device. A series of resonance patterns have been observed in the insertion loss separated by a thickness consistent with a change of half an acoustic wavelength in the overlayer. This was observed for operation at both the fundamental frequency and harmonic for the same device.

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