

A High Frequency SAW Device Transducer Structure Using Conventional Manufacturing Processes

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Abstract - This paper describes a multilevel, half-wavelength transducer structure for high frequency SAW device fabrication. This transducer configuration lacks internal reflections, has enhanced harmonic performance, and can be fabricated using only conventional SAW fabrication techniques. One version of the fabrication process presented here requires no critical alignment steps, and is inherently manufacturable. This paper describes the transducer structure, concentrating on the materials and fabrication techniques. Both theoretical and experimental results for this type of device are presented. Potential for application to high-frequency low-loss devices is discussed.

This transducer has several desirable characteristics, including the lack of reflections internal to the transducer, enhanced harmonic performance, and the ability to adjust the transducer impedance by altering the component layer characteristics. Unlike the narrow gap structure using either air gaps or anodic oxidation, production of this transducer configuration requires only conventional SAW fabrication techniques. Also, the fabrication process presented here can be done without any critical alignment steps, and is inherently more manufacturable than previously presented quasi half-wavelength structures.

INTRODUCTION

Applications requiring SAW filters at high frequencies not attainable using conventional transducer structures and lithographic techniques have sparked considerable interest in alternative methods for achieving high frequency performance. Novel substrates and non-Rayleigh waves with relatively high acoustic velocities, combined with harmonic device operation, allow for a substantial increase in the practical SAW frequency range. However, even these approaches require the use of near-half-micron lithography at frequencies of 2.5 GHz and above. Creative transducer structures which increase the linewidths to near one-half acoustic wavelength, such as the narrow gap transducer have been presented previously [1-3]. The narrow gap transducer has been shown to generate SAW responses at frequencies of up to 17 GHz [3]. Thus, the development of highly manufacturable half-wavelength transducer structures shows promise for extending the frequency range of SAW device operation. This work describes the development of a multilevel, half-wavelength transducer structure for high frequency SAW device fabrication which utilizes conventional manufacturing

TRANSDUCER STRUCTURE

Two possible implementations of the multilevel transducer structure are shown in Figure 1. In both cases, the first level metallization pattern consists of a bus bar connected to half-wavelength wide electrodes separated by half-wavelength wide spaces. On top of this first level metallization pattern is a dielectric insulating layer, such as the Si_3N_4 used in this work, which prevents shorting of the upper and lower metallization layers. The upper level consists of a metallization pattern complementary to the first level metal. As shown in Figure 1(a), the upper level metal can consist of a bus bar and connected half-wavelength electrodes, similar to the first level metal. These electrodes are horizontally aligned with the spaces between the electrodes on the first level metallization pattern. If desired, these electrodes can be slightly over-sized to reduce the requirement for precise alignment. Alternatively, these electrodes can be fabricated using backside exposure to completely eliminate the need for alignment. Another option is to use a solid metal pad as the upper electrode, as shown in Figure 1(b). Once again, this alleviates the need for precise alignment, but does result in some distortion of the passband from the interdigitated response.

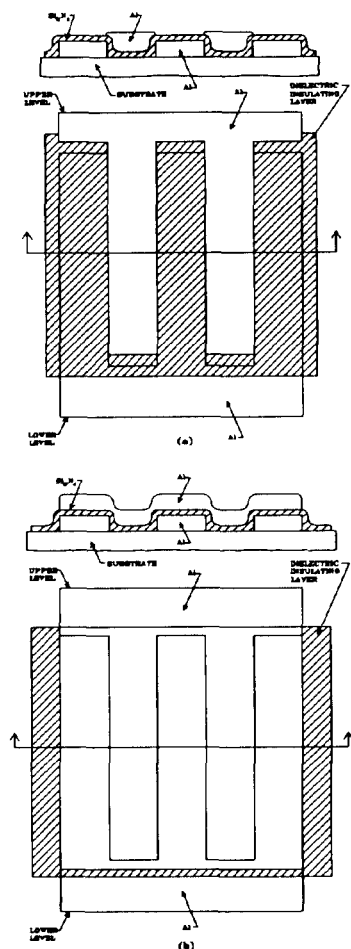


Figure 1: Two embodiments of the multilevel transducer structure. (a) Upper and lower metal electrodes are interleaved. (b) Upper electrode consists of a solid metal pad, rather than taps.

FABRICATION TECHNIQUES

YZ-LiNbO₃ wafers were coated with 1500 Å of Aluminum, then patterned using conventional photolithographic and wet etch techniques. The silicon nitride insulating films were grown in a modified Plasma Technology reactive ion etch (RIE) system (Model RIE-80), configured for plasma enhanced chemical vapor deposition (PECVD), using a combination of silane and ammonia. Details of the deposition technique can be found in [4-6]. These studies evaluated the effects of variation in deposition conditions on film quality. The

parameters which were found to be optimum for Si₃N₄ deposition for acoustic applications were used for the depositions in this work, and are summarized in Table 1. The compositions of several films deposited under these conditions were also evaluated using Auger electron spectroscopy and density comparisons, and were found to be approximately Si₃N_{3.89440.004}O_{0.005} [5]. Standard photolithographic techniques were used to define a photoresist mask for reactive ion etching (RIE) of the Si₃N₄. HMDS was used to enhance adhesion of the photoresist to the nitride film during this step. The films used in this study showed an etch rate of 14-18 Å/sec in an 8% CF₄/O₂ plasma with a gas flow rate of 100 sccm, RF power of 50 Watts, pre-plasma pressure of 250 m, and with sample temperature maintained at 25C. Following reactive ion etching of the nitride pattern, the photoresist was stripped and an O₂ plasma clean was performed to remove remaining residue. The wafers were then coated with photoresist and aligned and exposed from the top using either a coarse mask to define solid upper electrode pads or a mask with interdigitated upper electrodes requiring more careful alignment. Alternatively, the wafer could be exposed from the bottom using a coarse mask and the first level metal pattern to generate upper level electrode fingers without the need for any careful alignment, or using a coarse mask alone to define solid upper electrode pads. For either approach, following the appropriate photoresist development and bake steps the upper level metal (1500 Å of Al) was deposited using e-beam evaporation. Liftoff was then performed, using slight ultrasonic agitation in acetone. This fabrication process flow is shown schematically in Figure 2.

EXPERIMENTAL DEVICES & ANALYSIS

An array of experimental test structures was utilized in the current work. These structures included 100 MHz and 500 MHz transducers, as well as test structures for characterization of the nitride films. The electrode linewidths for the 100 MHz devices were 17.44 microns, while the linewidths for the 500 MHz devices were 3.488 microns. These values clearly demonstrate the potential benefit to developing a structure such as this, since a split finger transducer with fundamental operating frequency of 500 MHz on YZ Lithium Niobate would normally have a linewidth of less than 0.9 microns. Both unweighted and overlap apodized devices were fabricated at 500 MHz, with all 100 MHz devices being unweighted. Several configurations for the intermediate nitride layer were utilized, including pads covering the entire propagation path, pads covering just the local transducer area, groups of reflective strips, and others. Wafers were fabricated with six different nitride thickness', ranging from 400 Å to

Table 1: Si₃N₄ PECVD Deposition Parameters

RF Power = 100 Watts Power Density = 663 mW/cm²
 Pressure = 700 m Electrode Spacing = 57 mm
 Temperature = 300C Gas Flow= SiH₄/NH₃ = 0.705
 Deposition rate 110 Å/min

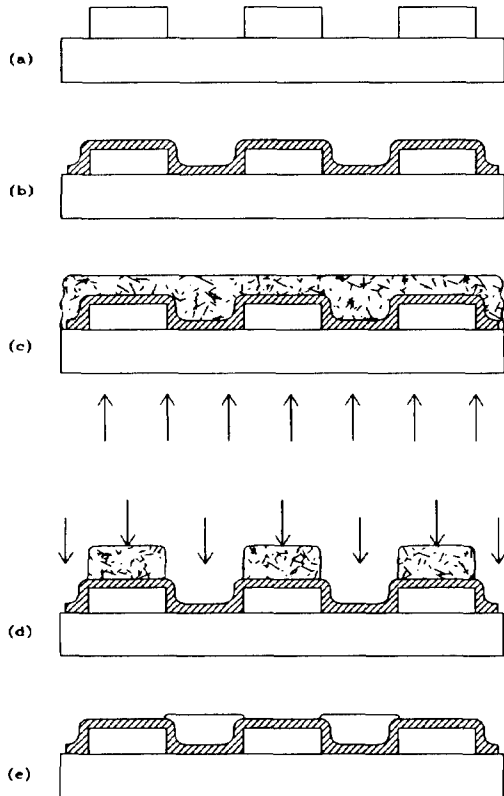


Figure 2: Fabrication process flow (a) lower metal pattern; (b) Si₃N₄ pad following PECVD film deposition, photolithography, and RIE steps; (c) Backside exposure of photoresist coated wafer; (d) Evaporation of top level metal; (e) Final device structure following liftoff process.

2900 Å. A comprehensive discussion of the variation in observed device performance with these factors is beyond the scope of the current publication, however it was noted that effective coupling decreased and device insertion loss increased substantially as the dielectric layer thickness increased. The equivalent circuit parameter extraction technique presented in a previous publication [7] was used to evaluate unknown equivalent circuit parameters for these transducer structures. Extracted values of effective

substrate capacitance were used to calculate transducer capacitance and to obtain effective coupling coefficient values. These values were then used to calculate predicted device performance and compare with experiment. The results of this data extraction process yielded equivalent circuit models which predicted experimental responses well for unapodized devices with thin (under 700 Å) intermediate dielectric layers. For devices with thick dielectric layers, and for apodized devices, this simple parameter extraction and equivalent circuit modeling process did not provide adequate correlation to observed device performance. While fundamental quantities extracted in this way may be useful, a more comprehensive transducer model must be developed, taking into account the specific transducer structure.

EXPERIMENTAL RESULTS

The response of a typical 500 MHz device fabricated with interleaved upper and lower electrode patterns is shown in Figure 3. Insertion loss for this device is approximately 31 dB, and the characteristic $\sin(x)/x$ response is evident. Figure 4 shows the device time domain response, which demonstrates the low level of reflections internal to the transducer. The identical device fabricated instead with a solid pad as an upper electrode is shown in Figure 5. Note the smearing of the response caused by the modified upper electrode. The response of a 500 MHz device consisting of one apodized and one unweighted transducer is shown in figure 6. Although the near-in sidelobes have been substantially degraded relative to the ideal device impulse response, the steep shape factor observed down to approximately 25 dB and ultimate rejection nearing 60 dB are quite encouraging for a device designed using CAD tools for conventional single level transducer structures. It should be noted that gating of RF feedthrough was required to obtain the responses shown in figures 3, 5, and 6.

POTENTIAL FOR LOW-LOSS APPLICATION

The devices demonstrated in this work all showed unmatched insertion losses in excess of 24 dB in a 50 ohm system. While losses on this order of magnitude are to be expected for this device structure based on preliminary equivalent circuit modeling, the current trend in high frequency systems is to require losses below 6 dB. This is particularly true of devices for the growing mobile communication industry. Thus it will be necessary to develop techniques to reduce the insertion loss on devices fabricated using this transducer structure. Devices demonstrating SPUDT action can potentially be achieved using dielectric overlays and other innovative approaches.

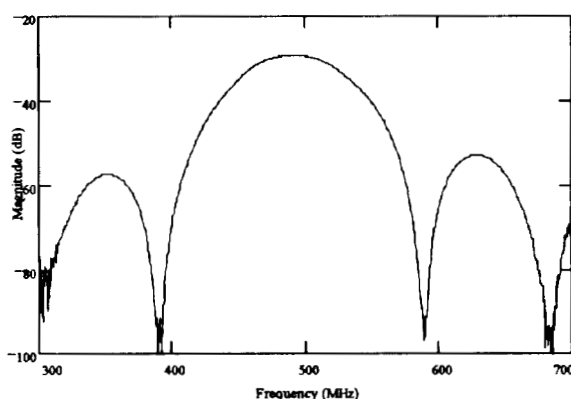


Figure 3: 500 MHz device using unweighted transducers with interdigitated electrodes, as shown in Figure 1(a).

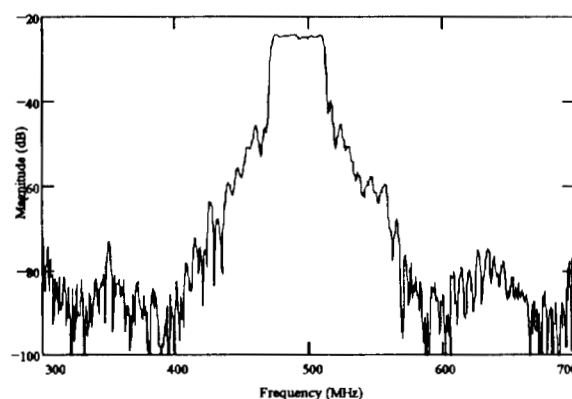


Figure 6: 500 MHz device using one apodized transducer and one unweighted transducer.

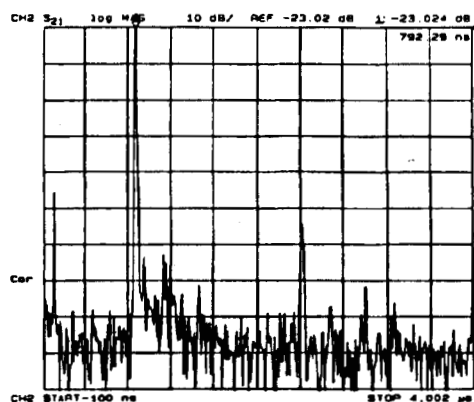


Figure 4: Time domain response demonstrating low levels of reflections internal to the transducer.

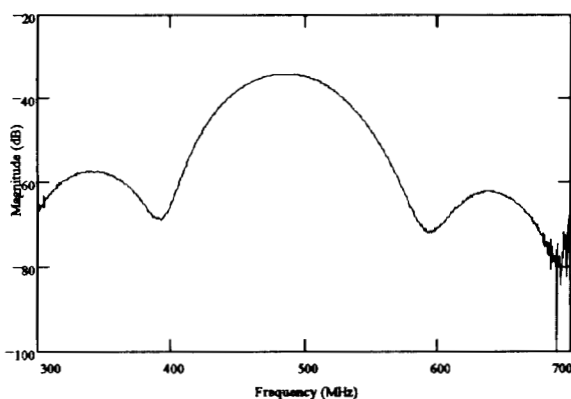


Figure 5: 500 MHz device using unweighted transducers with solid upper electrode pad, as shown in Figure 1(b).

Additionally, any device configuration commonly used to achieve low-loss performance, such as the interdigitated interdigital transducer (IIDT), can potentially be implemented using this type of transducer.

CONCLUSION

The performance demonstrated by the preliminary devices fabricated using half-wavelength multilevel transducer structures is encouraging, however a substantial amount of investigation remains to be done. The emphasis of the continuation of this work will be three-fold. First, techniques such as those mentioned above must be developed to achieve lower insertion loss. Second, a means of generating arbitrary amplitude and phase responses must be investigated. Finally, while equivalent circuit parameter extraction and modeling have proven applicable for simple multilevel transducer structures, it is clear that a more comprehensive model must be developed for this structure before it can become widely accepted for high frequency device use. The preliminary results obtained to date demonstrate the increased linewidths relative to standard split finger transducer structures. The encouraging experimental results and potential ease of manufacture of this transducer structure make this approach quite promising for future high frequency device development.

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