Topic No. 2.04, 1.05, 1.08 Abstract Reference No: 0339
Oral or Poster

Integration of GaAs-based Lateral Field Excitation (LFE) Sensor with PDMS Microfluidic Channel: Simulation and Experimental Validation

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Under lateral field excitation (LFE), gallium arsenide (GaAs) excites thickness shear mode (TSM) bulk acoustic waves (BAW) [1], suitable for biosensor application in liquid media, such as for bacteria detection [2]. GaAs-PDMS (Polydimethylsiloxane) bonding for high-pressure and leakage-free microfluidic devices is possible by depositing a thin SiO_2 layer on the GaAs substrate for plasma-assisted bonding [3]. However, the effect of PDMS viscoelastic properties on the GaAs sensor signal performance has not yet been studied. The interaction of the BAW's lateral particle displacement with the viscoelastic PDMS surrounding the suspended plate active area reduces the signal strength significantly after bonding for integration. Here we simulate and experimentally validate two different structures of GaAs-PDMS integrated microfluidic devices: device A and device B, as shown in Figure 1, where we found that the impact of viscous damping from PDMS can be reduced in device B by defining a membrane in GaAs for the confinement of the acoustic energy as well as to function as a microfluidic channel.

The results of the COMSOL Multiphysics® simulation are shown in Figure 2, where half-device structures were simulated with symmetry boundary conditions to reduce the simulation time. The simulations were performed with and without the PDMS for devices A and B, based on a standard 3-inch, 625 µm thick (100) GaAs wafer. The depth of the microfluidic channel is 300 µm. We present the impedance magnitude spectrum close to the shear mode resonance in Figures 2a and 2b for device A and B respectively (device B has a higher resonance frequency as the GaAs layer is thinner). The drop of impedance magnitude for Device B upon assembly with PDMS, is one order of magnitude smaller than for Device A. The fabrication process and the fabricated devices with measurement setup are shown in Figures 3 and 4, respectively. If additional GaAs bulk micromachining process is needed for device B, it does not require a soft lithography process using SU8 structures to create the PDMS channel as required in device A. Furthermore, alignment of electrodes and channel at the PDMS bonding step is not required for device B, thus simplifying the overall fabrication process.

Experimental results to validate the simulation are shown in Figure 5. As previously predicted in the simulation, device A presents a significant reduction in sensor impedance magnitude and phase signals upon PDMS bonding (Figure 5a). For Device B, ripples in the main signals appear before the PDMS bonding due to reflected signals interference from the edge of the GaAs etched membrane. However, the ripples disappear after PDMS bonding as the PDMS layer absorbs them. Furthermore, as shown in Figure 5b, there is only a small reduction in the acoustic signal strength due to the confinement of the main acoustic signal in the suspended plate active area. We are now pursuing further work to apply this improved GaAs-PDMS microfluidic technology to biological sensing for medical diagnosis.

Word Count: 479

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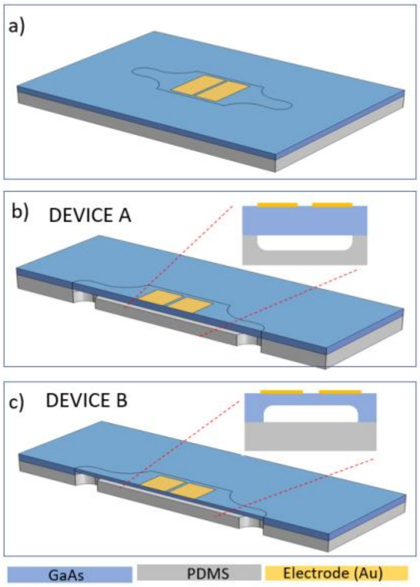

Figure 1: Sketch of the integrated GaAs-PDMS devices (a) Full device (b) Device A with PDMS microchannel and (c) Device B with GaAs etched microchannel

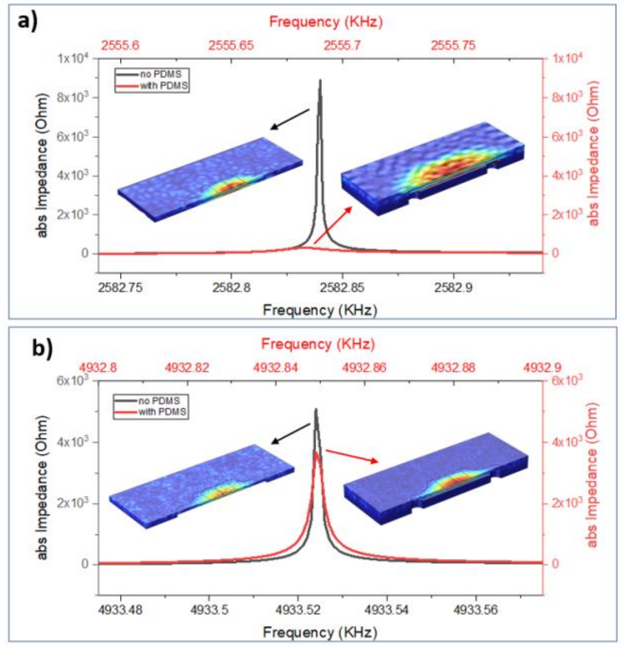

Figure 2: COMSOL simulation results: impedance magnitude of (a) device A and (b) device B, before (black) and after (red) PDMS bonding

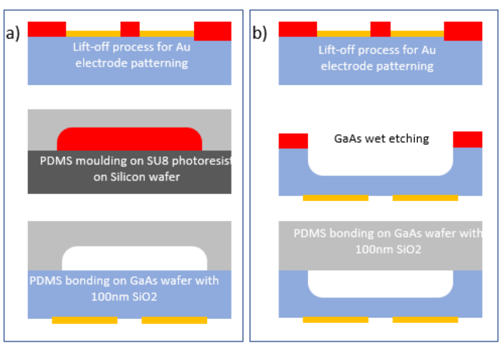

Figure 3: Fabrication process flowchart of devices (a) A and (b) B

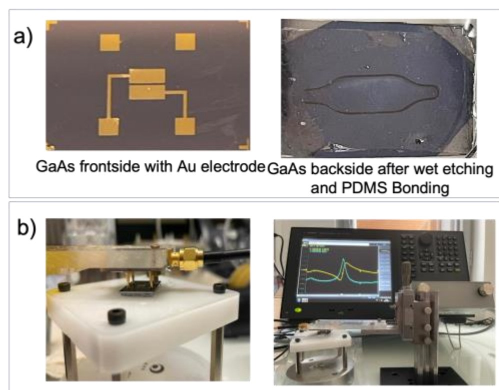

Figure 4: (a) Fabricated device and (b) measurement setup

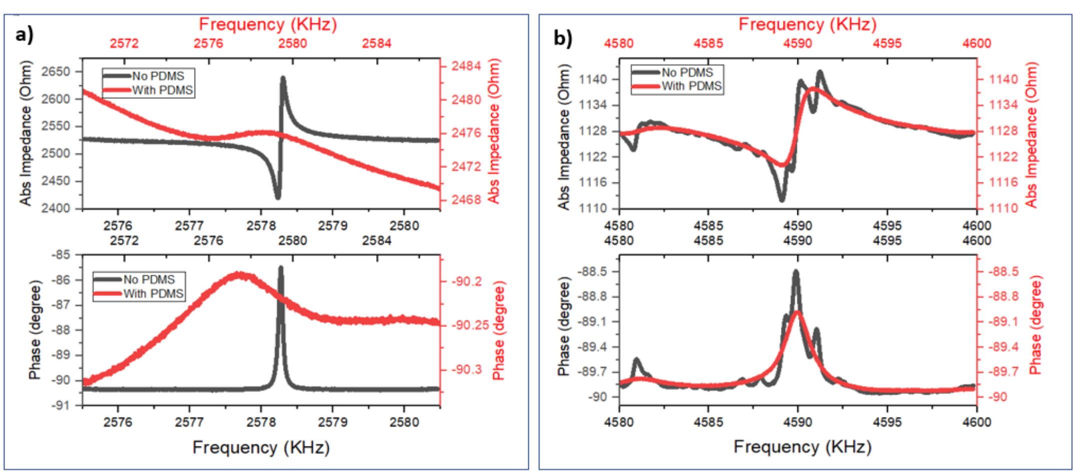

Figure 5: Impedance magnitude and phase before (black) and after (red) PDMS bonding for device (a) A and (b) B