Integrated UHF Magnetic Transducers

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Abstract:

Creating a surface acoustic wave (SAW) device on a silicon substrate would allow for integration leading new on-chip low-cost functionality (e.g., high-Q analog filters). Instead of using standard piezoelectric materials, our device creates SAWs using magnetostriction. In this approach, a copper wire is embedded in a magnetostrictive material, $Co_{46}Fe_{46}Ta_3Zr_5$. Current passed through the wire creates a magnetic field around the wire. The magnetic moment of the $Co_{46}Fe_{46}Ta_3Zr_5$ rotates in the presence of the magnetic field, and the material elongates along that direction. As alternating current passes through the wire, the elongation and relaxation of the magnetic material creates compression waves in the silica substrate. The compression waves traveling along the surface of the substrate are surface acoustic waves (SAWs). We detect the SAWs some distance away on the silica substrate using another SAW device.

We have fabricated two designs for the device. The first design included magnetic material only on the top and bottom of the copper wire. The insertion loss for this design has been on the order of 70 dB. The new design seen in Figure 1 has magnetic material on the sides of the wire as well as the top and bottom in order to improve magnetic response and reduce insertion loss.

Introduction:

Current passing through a wire creates a magnetic field around the wire according to the right hand rule. We take advantage of this magnetic field by filling the area closest to the wire, the area of highest magnetic field strength, with a ferromagnetic, magnetostrictive material. In a magnetostrictive material, when in a magnetic field, the magnetic moments of the material align and the atomic orbitals shift according to spin-orbit coupling, changing the shape of the material. As the magnetic field is raised and lowered, the substrate undergoes compression and relaxation, which moves across the substrate as ripples move across water. The speed that the compression wave moves across the substrate is determined by the substrate material. In our case, we have used silica and intend eventually to utilize silicon. This speed, the speed of sound in the material, is around 4000 meters per second for our substrate. By making rows of wires, we can select what frequencies we want to filter out. The compression waves created by our devices will have a natural wavelength proportional to the frequency supported by constructive interference. That frequency is equal to the velocity of the compression waves across the substrate divided by the pitch of the wires. We have made devices with pitches ranging from 20 μm to 60 μm which should operate as filters at frequencies ranging from 66 MHz to 200 MHz.

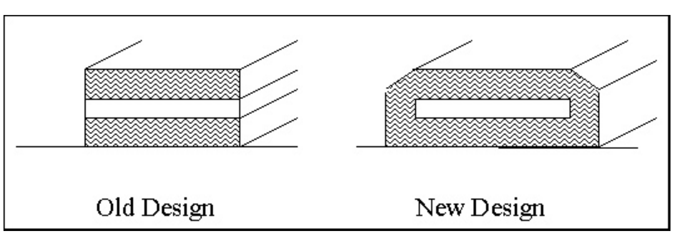

Figure 1: Cross-sectional diagram of old and new design.

Experimental Procedure:

We created alignment marks on the fused silica substrate using the Oxford 100 to etch the silica and using 1818 resist as a mask. We sputtered 350 nm of the $Co_{46}Fe_{46}Ta_3Zr_5$ material followed by 300 nm of copper. All sputtering was done without heating the substrate.

We used standard photolithographic procedures to create the inner pattern of our device. We ion-milled the exposed area leaving copper wires on a thin film of magnetic material. While ion milling, the bombardment of argon ions was limited to take place in 15 second intervals with 45 second cooling periods so that the resist would not burn. This allowed us to remove the resist by soaking in acetone. We then sputtered another 350 nm of magnetic material on top of the wires. Repeating the photolithographic procedure we exposed an outer pattern which encompasses the inner pattern, creating a copper wire embedded in magnetic material. We used the ion mill to remove the magnetic material in between the wires because no feasible chemical reaction could have removed the material in a reactive ion etcher. The removal rate for our ion mill was approximately 33 nm per minute for the magnetic material and about 65 nm per minute for the copper.

Several parameters helped us to determine the quality of the device. We initiated measurements of the scattering parameters using a network analyzer. Scattering parameters indicate the proportion of the transmitted signal that is detected or reflected.

Results and Conclusions:

The magnetically transduced surface acoustic wave device should be easily integrated in Si-based ICs. No new materials need be introduced to the processing facility as the MTSAW devices may be added in a separate facility, eliminating possibilities of contamination from bringing new substances into the front-end process area. The deposition and removal of material are both room temperature operations. There are a few concerns about how the transistors may be affected by plasma, which is used in deposition and removal of the material. The alternative lift-off method has worked for removal of material in these devices in the past [1].

Future Work:

Future work on this project includes finishing the electrical measurements stated here along with further characterization of the ferromagnetic magnetostrictive material used. We would like to understand why ion milling created CFTZ sidewalls of the shape that we observe in Figure 2. In addition, we would like to characterize the behavior of the magnetic fields in the CFTZ material over a step. Also, we plan to investigate the use of low-magnetostriction materials in similar devices for use as inductors [2].

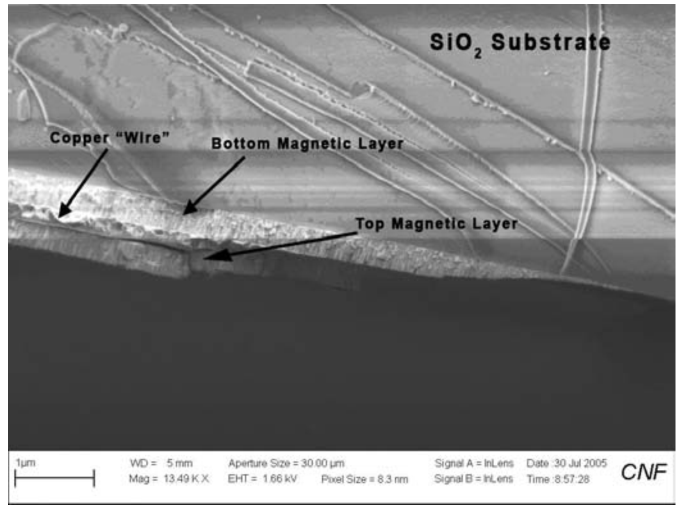

Figure 2: SEM image of cross-section of copper wire surrounded by magnetic material.

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References:

[1] K. A. Ellis, R. B. van Dover, T. J. Klemmer, and G. B. Alers, J. Appl. Phys. 87, 6304 (2000).

[2] A. Gromov, V. Korenivski, K. V. Rao, R. B. van Dover, and P. M. Mankiewich, "A model for impedance of planar RF inductors based on magnetic films," IEEE Transactions on Magnetics, vol. 34, pp. 1246-8, (1998).