Chapter 5 : In Conclusion

An eddy-current proximity sensor is a device that measures the distance between the transducer and target using eddy-current sensing techniques. The transducer used to generate the high frequency fields required to produce the eddy-currents is usually an inductor or coil.

5.1.0 Summary

Single coil designs use the change in inductance of the system (coil plus target) due to the presence of the target as a measure of the distance between the coil and the target. As the target moves closer, the mutual inductance between the target and the coil increases causing the inductance of the system, which is the inductance of the coil minus the mutual inductance between the coil and the target, to decrease. Single coil transducers are usually used in self excited oscillators as part of the tank circuit or as one of the arms in an AC bridge. In self excited oscillators, the change in coil inductance with distance causes a shift in the resonant frequency of the tank circuit. In the AC bridge, the change in coil inductance produces an unbalanced bridge. However, as single coil designs are scaled down to microelectronic dimensions, the resistance of the coil increases dramatically. In the self excited oscillator case this causes the peak of the magnitude of the impedance of the tank circuit versus frequency to decrease in amplitude and to spread out making frequency measurement difficult. In the case of the AC bridge, this requires the bridge oscillator to be operated at very high frequencies for the inductance of the coil to dominate it’s resistance.

Two coil transformer designs circumvent the problem of change in response with increase in coil resistance. In the two coil design, the phase difference between the input voltage applied to the primary coil and the output voltage across the secondary coil changes with change in distance between the coils and the target. A distinct dip is seen in the phase difference versus frequency plot. This dip increases as the target is brought closer to the coils. The dip occurs at a lower frequencies than that needed to operate the single coil design. Also this dip is relatively insensitive to the increase in resistance with scaling making the two coil transformer design superior to the single coil design.

Due to it’s application in the Smart Bearings project, the coils were to be fabricated at the bottom of an etched hole in a silicon wafer, on the back of a dielectric membrane. This kind of fabrication produced some very interesting fabrication issues. In order to etch the silicon to form a hole with a membrane at the bottom it was determined that a square mask hole was needed to dry etch the masking dielectric. This mask hole needed to be aligned to the <111> planes of the <100> wafer to prevent overhangs of the dielectric from forming. To perform photolithography along the walls of the hole (for the interconnects) and at the bottom of the hole (for the coil), a very conformal coating of photoresist was needed. A sample which had four holes placed symmetrically to the photoresist spin axis produced the most conformal coating. In order to expose the coil pattern in the photoresist, the RDI Pattern Generator was used as a direct write tool. Conventional exposure techniques produced photoresist profiles that were not very conducive to using lift-off as the metallization technique. Thus the pattern was exposed through the front of the membrane with the photoresist coated on the back. This produced the ‘overhang’ type of photoresist profile needed for metal lift-off. The ‘auto-focus’ function of the pattern generator was investigated as a tool to perform photolithography along the walls of the hole.

5.2.0 Work to be done

The formulae used to calculate the inductance and resistance of the coils ignore the redistribution of current at higher frequencies due to the skin effect and the ‘proximity' effect. These effects need to be incorporated into the inductance and resistance calculation in order to obtain more accurate simulation results in the single coil design case. If incorporated into the calculation, this would also result in a more accurate prediction of the component values needed in the PSpice® model of the two coil transducer. The model used to calculate the R_{plate} in the PSpice®model also needs to be refined.

Using a planar spiral coil as the transducer means that a center tap or bridge is need to make a contact between the center of the coil to the interconnect. In order to fabricate the coil, a two level metallization process is needed. The inter-metal dielectric (polyimide, photosensitive polyimide, spin-on-glass) to be used needs to be studied in detail. A process recipe to spin the inter-metal dielectric, to cure it, to pattern the vias for contacts and to perform the second level metallization is needed. Finally the 'autofocus' function of the RDI Pattern Generator needs to studied in more detail and the patterning of the walls, for the interconnects, needs to be done.

A very important aspect that needs to be addressed is the circuit design of the circuit needed to drive the primary coil of the transformer and the phase detector needed to measure the change in the phase difference with gap. This circuit needs to be monolithically integrated with the transducer to eliminate the effects of parasitic inductance, resistances and capacitances. This places some additional constraints on the components and the component values to be used.

In Chapter 4 some novel applications of the eddy-current sensor have been discussed. The accelerometer conventionally uses capacitive sensing techniques while the bearing wear sensor uses ultrasonic sensing techniques. More detailed investigations need to be performed into the potential advantages of the eddy-current sensing techniques over these techniques.