SELF-ASSEMBLED OUT-OF-PLANE HIGH Q INDUCTORS:

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ABSTRACT

We report for the first time self-assembled out-of-plane micro inductors. The resulting Q values are among the highest reported to date.

DEVICE DESCRIPTION AND FABRICATION

Micro-machined out-of-plane inductors with coil axis parallel to the substrate plane have garnered increasing interest [1], [2] because of their fundamental advantages over conventional in-plane spiral coils. We have developed a new approach for fabricating out-of-plane coils using uncomplicated semiconductor processing technology. The process relies on stress-engineered thin films that are deposited with a built-in stress gradient so that, when patterned and released from their substrate, they curl into a designed radius of curvature. These micro-springs self assemble into three-dimensional scaffolds that we plate with copper (Cu) to form highly conductive coil windings.

It is well known that many refractory metals have a common property of acquiring tensile stress when sputtered at high pressures and compressive stress when sputtered at low pressures. A film that is compressive at the bottom and tensile on the surface can, for example, be realized by simply increasing the ambient pressure during sputtering. When patterned and released, such a stress-graded film will curl up with a radius of curvature [3] given by $r = h * Y / \Delta\sigma$, where h is the film thickness, Y the biaxial Young's modulus, and $\Delta\sigma$ the stress difference between the top and bottom of the film.

Figure 1 shows an array of molybdenum-chromium micro-springs that have been released from their substrate. The springs follow a circular trajectory with the given radius. To make out-of-plane inductors, springs are placed in opposite directions so that when released, the spring pairs curl and interlock into each other to form coil windings. Figure 2 shows scanning electron micrographs of the self-assembled springs. A magnified view of the interlocking spring tips is shown in Figure 3. The interlocking connection provides a mechanical catch that prevents paired springs from curling further after they come together. Thus, the coil diameter is determined by mask design rather than by the exact stress profile in the film. Consequently, the coil geometrical properties are largely independent of the film deposition parameters. The assembled devices can be taken in and out of a liquid without breaking apart.

RESULTS

The solenoids are designed with diameters of about 0.6 mm for operation at about 1 GHz - this frequency being chosen for its relevance to wireless communication applications. Figures 4 and 5 show Q-factor plots for coils on glass and coils on silicon, respectively. The silicon wafers have resistivities of 15 to 20 Ω -cm. We obtain quality factors of over 70 at 1 GHz for coils on glass. This value is very close to the hypothetical maximum

neglecting proximity effects and sources of losses other than skin effect current constriction in the coil winding. Coils on silicon show quality factors of 35 to 40 at 1 GHz due to substrate eddy currents. These Q values are among the highest reported to date for coils on unaltered silicon wafers.

Figure 1. SEM of an array of released micro-machined springs

Figure 2. SEM of an assembled out-of-plane coil before plating

Figure 3. Magnified image of the interlocking spring tips

REFERENCES

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3. D.L. Smith and A.S. Alimonda, "A new flip-chip technology for high-density packaging," *Proceedings of the 46th Electronic Components and Technology Conference*, Orlando, FL (1996).

Figure 4. Quality factors of out-of-plane coils on glass substrates. f_o is the parasitic resonance frequency.

Figure 5. Quality factors of out-of-plane coils on silicon substrates (resistivities = 15 to 20 Ω -cm). f_o is the parasitic resonance frequency.