Mold metallization process for the batch fabrication of high-resolution MRI solenoidal micro-coils enabling low loss integration of electronic devices

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Introduction

This paper presents a general metallization process for the fabrication of solenoidal micro-coils for high resolution MRI of small volume samples integrated within a planar wafer geometry. The advantage of micro-coils over conventional size coils is their potential to achieve a higher signal-to-noise ratio (SNR_{MRI})[1]. It can be shown that the coil sensitivity, expressed in terms of the transverse magnetic field induced per unit current B_{xy}/i, is inversely proportional to the coil diameter d_{coil}[2~4]. Further, solenoidal coils have a superior magnetic field homogeneity and yield a higher filling factor as compared to spiral (surface) coils. The proposed process allows for the simultaneous and MEMS-compatible fabrication of identical coils integrated within a planar wafer geometry. A low-loss connection to external tuning/matching devices can be established via standardized wafer bonding techniques. This is not possible in the case of cylindrical substrate based fabrication[5~7].

Fabrication process

We demonstrate the metallization process using a hollow borosilicate glass mold. The fabrication of the mold structure is based on reactive ion etching and anodic bonding has been reported elsewhere[8]. Figure 1 shows a schematic of the starting structure. Despite a more complicated fabrication process, glass was chosen as a substrate material for its superior dielectric properties as compared to silicon, and its optical transparency for MRI sample inspection. Figure 2 shows the metallization process of the glass mold for a cross-section along the line A-B (Fig. 2 a). The conformal metallization with a 200 nm thick copper layer by means of metal organic chemical vapor deposition (MOCVD) is shown in figure 2 (b). $C_{10}H_{13}CuF_6O_2Si$ (Schumacher CupraSelect®CuTMVS) was used as vapor precursor with Ar as a carrier gas. The Cu deposition rate was ~30 nm/min at a substrate temperature of 200°C and a pressure of 500 Pa. As the bottom side of the wafer is in contact with the substrate holder, the deposition was performed on both sides of the bonded wafers. In figure 2 (c), the conformal metal layer is patterned by UV photolithography and briefly dipped into an acidic palladium solution. The Pd treatment ensures a good start of the Cu electroless galvanization (Fig. 2 d), which was done using a commercially available solution (Printoganth V Copper by ATOTECH GmbH). A homogeneous, 8 µm thick Cu layer was deposited at a rate of ~1 µm/30 min at 34°C and pH 12 under slight agitation with a magnetic stirrer and periodic replenishing of the bath. Due to the skin effect, this thickness is well sufficient for coil operation around 300 MHz. To prevent the Cu from further oxidation and to ensure good electrical contact, a 200 nm gold surface finish in a cyanide based gold electrolyte concludes the fabrication process.

Results

Figure 3 contains SEM images showing the cross-section (a) and top-view (b) of the realized 10-turn micro-coil. To obtain the cross-sectional image, the wafer was embedded in an epoxy-resin and material removed by polishing until the plane of interest was reached. Both images show that Cu layer is homogeneously deposited within the mold structure, forming a continuous connection from the top to the bottom side of the wafer. Electrical measurements verified the integrity of the devices, proving that the metallization process reliably works over a larger wafer area.

Conclusions

We present a versatile and parallel metallization process suitable for the fabrication of solenoidal micro-coils based on planar substrates and therefore easy to integrate with external tuning/matching devices without severe signal loss and additional noise generation by un-shielded connectors. The main fabrication steps are the conformal wafer metallization by means of Cu MOCVD, patterned by standard UV photolithography, and the electroless galvanization forming the coil conductor. On substrates of 20×20 mm^2 size, already 64 coils can be fabricated simultaneously. The process can be easily adapted for the metallization of different geometries or the use of other materials, such as silicon.

References

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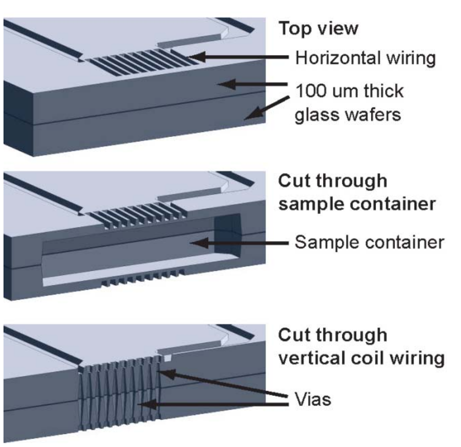

Figure 1: Schematic of the initial mold structure.

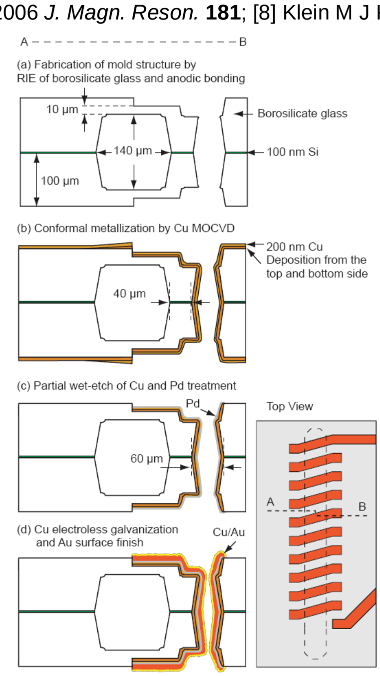

Figure 2: Metallization process based on Cu MOCVD and electroless galvanization.

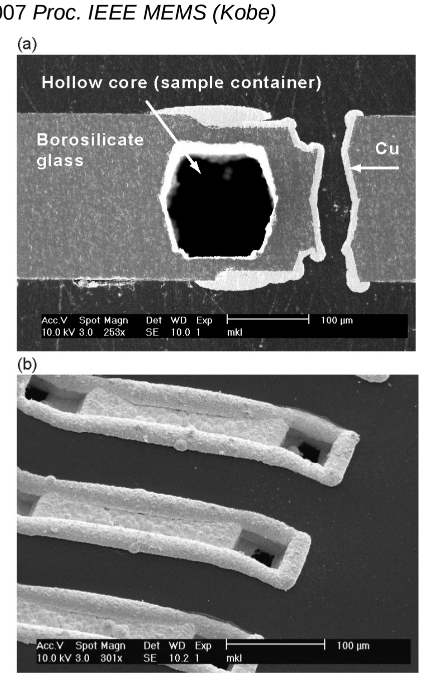

Figure 3: SEM images of the final coil structure. (a) Cross-sectional view, and (b) top view.