Materials for printed MRI surface coils: towards better image quality and coil flexibility

Balthazar Pierre Lechene[1], Anita Flynn[1], Joseph Corea[1], Michael Lustig[1], and Ana Claudia Arias[1]
[1]*Electrical Engineering and Computer Science, University of California Berkeley, Berkeley, CA, United States*

Target Audience: RF coil designers, MR engineers

Purpose: Printed flexible MRI surface coils can conform to a patient's body better than conventional coils made of copper printed circuit boards and soldered porcelain capacitors. While incurring more electrical losses than traditional coils, printed coils can provide better signal-to-noise ratio (SNR) and patient comfort compared to conventional designs in clinical practice [1-3]. Because body-noise dominates, the losses in the coil are less impactful. Additionally, non- or semi- flexible coils tend to suffer from an offset from the body. However, when compared in a controlled environment, with identical geometry and offset from the sample, conventional coils outperform the printed coils by 20-25% SNR due to losses in the printed materials. In this work, we investigate how the choice and optimization of those materials can reduce loss and/or improve the flexibility of printed coils. We focus first on the influence of the conductor's resistivity on the coil's imaging properties and then look at the impact of the substrate on the mechanical properties of silver films.

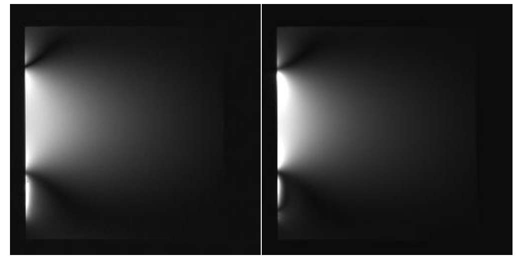

Fig 1: MRI scans of a conductive phantom with our best printed coil on PET (left) and a control coil (right), using a Siemens 3T Trio scanner.

Silver ink	MF ink	NP ink
DC resistivity Ω-cm	5.10^{-5}	3.10^{-6}
127 MHz resistance mΩ/sq	33	23
Q-factor unloaded/loaded	18.0 / 6.7	21.1 / 7.8

Table 1: Properties of silver films made from the microflake (MF) and nanoparticle (NP) inks. The 127 MHz resistance given corresponds to the minimum values obtained while varying the films thicknesses.

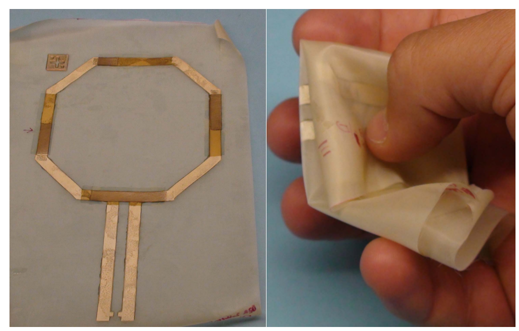

Fig 2: Printed coil on PEEK mesh, as printed (left) and crumpled (right). It is still functional after unfolding.

Methods: Our printed coils are fabricated by screen-printing three patterned layers on a flexible substrate: a bottom conductive layer of silver forms the loop of the coil, a dielectric layer forms the separator of planar capacitors and a final layer of silver serves as the top plate of those capacitors. Two silver inks are compared, a silver microflake (MF) ink (Creative Materials 118-09) which had been used in our previous studies [1-3] and a new silver nanoparticle (NP) ink (InkTec PA-010). Nanoparticles (NP) can sinter at low temperatures so the resulting films have a lower resistivity than films formed of microflakes. The resistivity of the silver films is characterized first at DC (4 point-probe), and then at 127 MHz using a micro-strip setup [4]. Complete coils are also fabricated and their quality-factor (Q) is measured, both unloaded and loaded on a conductive 0.68 S/m phantom [5]. To explore the impact of the substrate on the coil's performance, the NP silver ink is printed on many different substrates, including: polyethylene terephtalate (PET), polyether ether ketone (PEEK), ULTEM, ARAMID and Kapton sheets, NOMEX fabrics and foils, PEEK mesh, and cotton flannel. The DC resistivity of the layers is measured, and their ability to bend without breaking is compared.

Results: Once optimized, the silver layers can reach a DC resistivity of 5.10^{-5} Ω-cm for the MF ink and 3.10^{-6} Ω-cm for the NP ink. However, for micro-strips thicker than their corresponding skin-depths at 127 MHz, the two inks yield resistance values differing by only 30%. This improvement translates into a Q-factor of coils going from 18 (unloaded) and 6.7 (loaded) for the MF ink to 21.1 and 7.8 respectively for the NP ink, as compared to 250 and 11.5 for a conventional coil. When deposited on most foil substrates the silver layers tend to delaminate upon bending, while on most woven fabrics good electrical contact is hard to achieve due to inherent surface roughness. The best conductivity is achieved with our previous PET substrate. However, compromise between electrical and mechanical performance is obtained with a smooth paper-like fabric and a PEEK mesh which could be crumpled while still maintaining excellent conductivity and coil functionality (Fig.2).

Discussion and Conclusion: So far, an order of magnitude improvement in DC resistance of the new silver films leads to a 30% improvement in RF resistivity and a 16% increase in coil loaded Q-factor. Printing on the newly identified substrates, such as the PEEK mesh, significantly enhances the flexibility and robustness of the coils without sacrificing electrical performance. Our optimization of the silver layer also provides some leeway for varying coil parameters for which a trade-off with conductivity exists, such as modifying the coil size and design. Further improvements in performance could be achieved by looking into the capacitor fabrication, such as the dielectric properties or the influence of the silver surface roughness, which we leave for future work. Overall, improvements in materials contribute to the enhanced electrical performance of printed flexible coils.

[1] J. Corea et al., ISMRM 2012. [2] J. Corea et al., ISMRM 2013. [3] J. Corea et al., ISMRM 2014. [4] David Pozar, Microwave Engineering, 2nd edition, Wiley. [5] Hayes et al., Med. Phys., 12 (5) 1985, 604.