Micro-scale inductively coupled radiofrequency resonators on fluidic platforms for wireless nuclear magnetic resonance spectroscopy

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Introduction

Micro-scale inductively coupled rf resonators enable wireless investigation of small sample volumes in a conventional NMR spectrometer. The inductively coupled approach has the advantage of focussing the sensitivity and rf power on the small sample volume, without the need for any connections to the spectrometer. Preceding research demonstrated that inductively coupled coils can indeed rival the performance of directly connected ones [1]. The achieved resolution is currently about 2Hz, limited by B_0 inhomogeneity. The hitherto fabricated microcoils were composed of a planar inductor coil and an integrated tuning capacitor, which required an out-of-plane connection (wire bonding). We also present planar resonators that are tuned to self-resonate at the rf frequency of 600MHz and thus spare the out-of-plane connection. That can be accomplished by adapting the resonator geometry (spacing and number of turns) respectively. Their B_0 homogeneity can be improved by filling the coil area homogenously with metal tracks, thus avoiding susceptibility mismatches at the coil surface. We investigated the influence of Eddy currents on the performance of those filled coils.

Fabrication

Conveniently, the fabrication includes mainly standard MEMS processes. The microfluidic sample chambers are produced by conventional lithography and glass etch. A second glass substrate covers the fluidic network, assembled by thermal fusion bonding (see Fig. 1). The spiral gold tracks are patterned on the sample chamber side of the glass sandwich. Subsequently, the resonators are covered by a dielectric SU-8 layer. The spiral gold tracks are patterned via lithography and electroplating and finally covered by a dielectric SU-8 layer. Fig. 2 shows a completed resonator with integrated capacitor, whereas the microcoil in Fig. 3 is self-resonant at 600MHz without the need of bond wires.

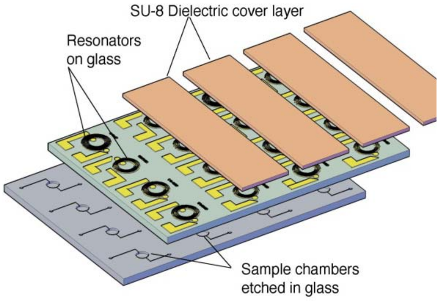

Fig. 1: Assembly of a microcoil array on the microfluidic platform

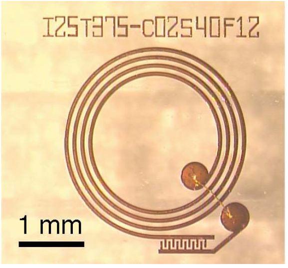

Fig. 2: 3-turn microcoil with integrated capacitor, tuned to 600MHz

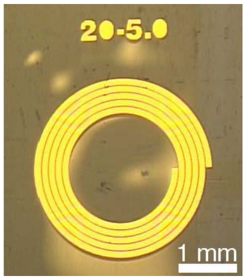

Fig. 3: 5-turn microcoil with 20µm spacing, self-resonant at 600MHz

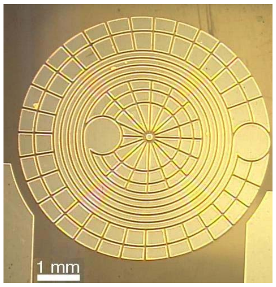

Fig. 4 Self-resonant coil with fine segmented filling

Testing and Results

The resonator chips are immersed in doped water and magnetic resonance image slices are taken perpendicular to the resonator plane at varying excitation power settings. When accurately tuned, the volume close to the resonator coil should provide a very strong signal, whereas the surrounding water should be all but invisible. In Fig. 5 the absolute values of the signal intensity in the coupling region (black data points and blue line) and of the background intensity way outside the coupling region (white data points and orange line) are plotted against the applied excitation power. The ratio of the signal intensity maximum to the background intensity at that excitation power indicates the quality of the tuning. The first bond wire-free coil designs proofed to be promising, with signal-to-background ratios of up to 12. Fig. 5 shows an ethanol spectrum recorded with the coil from Fig. 2, aligned over the microfluidic sample chamber. As can be seen, the resolution is good enough to resolve the J-splitting in the –CH3 group.

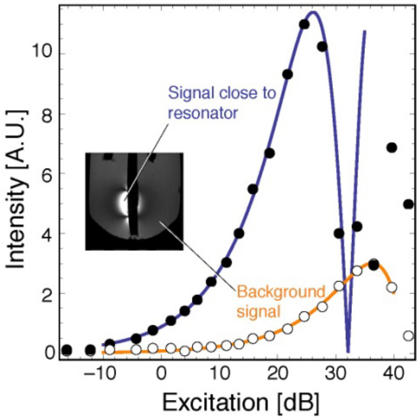

Fig. 5: Signal and background intensities plotted against excitation power

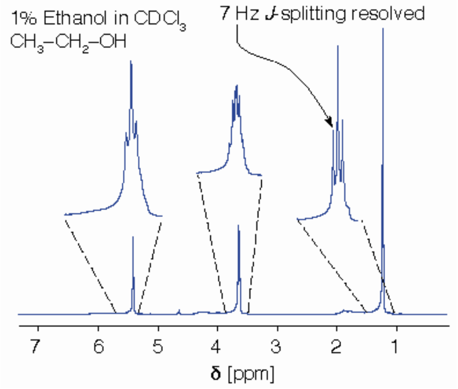

Fig. 6: Ethanol spectrum recorded with inductively coupled microcoil on microfluidic sample chamber

Filled Microcoils

The first filled microcoils were fabricated with varying filling designs from numerous fine segments (as shown in Fig. 4) to one full segment. The spacings between the segments shall disturb the eddy current paths. First tests showed a clear dependency of the coupling quality on the segment size, increasing with decreasing size, from about 3 for the on big segment to over 7 with fine segments.

Conclusions and Outlook

Inductively coupled, self-resonant planar microcoils have successfully been fabricated and tested. Spectra could be recorded in a promising quality and first NMR images of self-resonant coils show reasonable signal-to-background ratios, even when the coils are filled with metal segments. The next steps are to further improve the tuning and test the sensitivity and resolution of the coils in detail and to proof that the coil filling indeed improves the sensitivity. A Helmholtz coil arrangement with the sample chamber in between 2 resonators facing each other is in fabrication, which will increase the homogeneity of the rf-field and thus further improve the sensitivity.

References

[1] Utz M, Monazami R. “Nuclear magnetic resonance in microfluidic environments using inductively coupled radiofrequency resonators.” J Magn Reson. 2009 May