Calcium titanate based ceramic resonators for high field magnetic resonance

K. Haines[1], T. Neuberger[2], M. Lanagan[3], E. Semouchkina[3], and A. Webb[4]

[1]Electrical Engineering, Penn State University, United States, [2]Huck Institute, Penn State University, United States, [3]Materials Research Laboratory, Penn State University, [4]Radiology, Leiden University Medical Center, Leiden, Netherlands

Introduction: At high magnetic fields radiation losses, wavelength effects, self-resonance and decreased Q of typical components all contribute to increased losses in conventional RF coil designs. High permittivity ceramic dielectric resonators create strong uniform magnetic fields in a compact structure at high frequencies, are extensively used in radiocommunications applications, and can potentially solve some of the challenges of high field coil design. Previously, we have shown that a specialized high permittivity barium strontium titanate ceramic can achieve excellent MR sensitivity [1]. In this study we improve upon this design by using a much more widely available high permittivity ceramic, calcium titanate ($CaTiO_3$), which is easily machined into the optimal geometry. By drilling a hole through the centre of the resonator the actual field distribution of the resonator is used more efficiently and larger samples can be investigated.

Methods: A double-stacked resonator was constructed for operation at 600 MHz with outer diameter 4.65 cm, inner hole diameter 2.38 mm, and thickness 1.2 cm for each disk. Between the disks was a 1 mm gap for the feeding loop. The $CaTiO_3$ disks were fabricated using conventional high temperature sintering methods for ceramics. The starting material was a $CaTiO_3$ powder, which was moulded into a cylindrical shape using a 2.25 inch diameter die. Forming was completed using both an axial press (15,000 psi) and a cold isostatic press (25,000 psi). The resulting green samples were then sintered in a conventional furnace at 1500°C for four hours. Once sintered, holes were created in the ceramic disks using a 3/16 inch diameter diamond corer with a drill press. A diamond surface grinding wheel was used to achieve the final thickness necessary to resonate at 600 MHz. This dimension was determined through experimental measurements with a network analyzer (HP8510C) using a standard two pickup-coil arrangement and a copper shielding tube identical to that used on the actual probe. The permittivity of the material was 156.3 (measured using the Hakki-Coleman post resonant method and network analyzer [2]), and the unloaded Q was 2081 with a corresponding loss tangent, tan δ, of -0.00048.

Results: Simulations of the B and E fields were conducted using the CST Microwave Studio analysis package with dimensions and parameters as given above, including the tan δ to account for loss, and a copper shielding tube of diameter 5.425 cm. Excitation was via a loop probe coax with a transient analysis solver. B field and E field plots are shown in Figure 1 (left), which demonstrate the positioning of the sample in the volume with high B and low E fields. A probehead was assembled in similar fashion to [1], with moveable pieces of copper used for fine tuning inside the magnet (Figure 1). Figure 1 also shows images from a high resolution three-dimensional data set from an ex-vivo zebrafish (right) and the zebrafish itself.

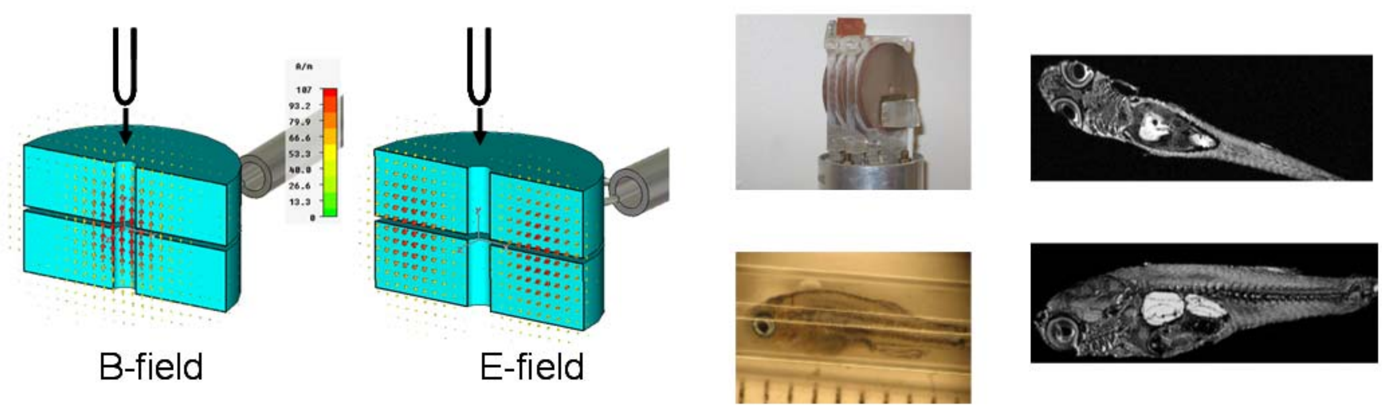

Figure 1: (left) Results from electromagnetic simulations show a strong and homogeneous B field within the sample-containing hole drilled into the ceramic resonator, with a very low electric field present. (middle) Photographs of the assembled resonator (without shield) and the zebrafish in a glass tube, (right) Images from a 3D spin-echo sequence of a zebrafish: TR/TE 250/20 ms, spatial resolution 47 x 42 x 42 µm, four signal averages, total scan time 1 hour.

Discussion: High permittivity ceramic resonators are compact, mechanically stable, high Q, low loss devices that can be designed to be high sensitivity detectors for high field magnetic resonance. Being ceramics, the magnetic susceptibility is similar to many plastics and other materials used for traditional RF coil design. The separation of electric and magnetic field components makes the design particularly suitable for lossy, biological samples.

References: 1. Neuberger T et. al. 2008. Conc.Magn.Reson.B, 33B, 109-114. 2. Hakki RW, Coleman PD. 1960. IRE Trans Microwave Theory Tech 8: 402–410.