Catheters for Interventional MR: LaserLathe Fabrication of Micro-Coils for Remote Catheter Tip Deflection

Prasheel Lillaney[1], Vincent Malba[1], Leland Evans[1], Anthony Bernhardt[1], Mark Wilson[1], Timothy Roberts[2], Alastair Martin[1], Maythem Saeed[1], Ronald Arenson[1], and Steven Hetts[1]
[1]Radiology and Biomedical Imaging, University of California San Francisco, San Francisco, California, United States, [2]Radiology Department, University of Pennsylvania, Philadelphia, PA, United States

Target Audience: Interventional MRI community

Purpose: Remote MR guidance of catheters for endovascular interventions has been the object of considerable research and development over the past ten years [1]. The purpose of this work was to develop a microfabrication technique for catheter tips that could be utilized to deflect a catheter into targeted small vessels. The approach utilizes the static magnetic field of an MR system to interact with a magnetic moment created by passing an electric current through coils placed at the catheter tip [2]. To create sufficient magnetic moment the coil designs at the tip require several turns and hence very fine feature sizes.

Methods: We propose a lithographic technique to manufacture the coils, which we call LaserLathe [3]. This method allows non-planar surfaces such as cylinders to be patterned with feature sizes as small as 5 um. A conductive coating (a "seed layer") consisting of a copper layer (~200 nm) over a titanium layer (~50 nm) was deposited on the non-planar surface with a sputtering system fitted with a rotary fixture for uniform deposition on a cylinder. The purpose of the Ti/Cu seed layer is to create a conductive layer onto which a positive electrodeposited photoresist can be electroplated. In addition, the photoresist coating provides a uniform photoactive layer on the surface that can be patterned with a laser. Figure 1a shows a schematic of the LaserLathe apparatus. It consists of three high-precision translation stages (x, y, and z), and one high-precision rotary stage. The axis of the rotary stage is parallel to the translation of the x-stage. The "cutting tool" for the LaserLathe is a 405-nm, 50 mW diode laser. It doesn't actually cut; it is used to expose the positive photoresist. The z-stage is used to focus the beam by moving a microscope objective through which the beam is passing. With precision motion control of the stages provided by a Delta Tau PMAC card, any design can be patterned on the surface of the cylinder.

Results: The typical designs are shown in figures 1b and 1c, which illustrate the solenoid and racetrack coil designs. By encapsulating one of these cylinders within the other it is possible to create two-axis coil, which allows for magnetic moments to be created in two orthogonal directions at the tip of the catheter making the device more versatile. The deflections using the two-axis system were measured from the MR images and ranged from 17 to 42 degrees depending on the orientation of the coil, and the polarity of current in the coils. The single axis racetrack coil was tested in a water bath bifurcation phantom (figure 1 d-f) using a balanced SSFP MR imaging sequence (TR = 5.5 ms TE = 1.6 ms, 30º flip angle, 128 x 128 matrix, 5-6 mm slice thickness) to demonstrate navigation capabilities. Studies related to the heating issue of the activated catheter are underway.

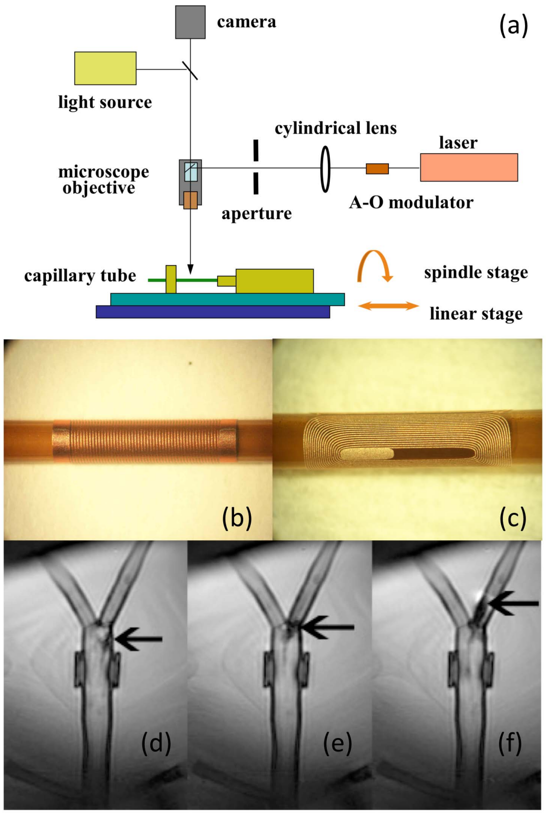

Fig. 1 (a) The LaserLathe apparatus. (b) 50-turn helical coil patterned on a 1.37 mm OD polyimide cylinder. 0.5 mm collars at each end are solder attachment pads. (c) 40-turn racetrack coil. There is a solder attachment pad at the center of the racetrack. (d-f) Frames from bSSFP imaging to test catheter navigation capabilities. A racetrack coil was used and the catheter was deflected towards the right bifurcation. The orientation of the static field vector is inferior to superior.

Discussion/Conclusions: We have demonstrated proof of concept of a remote controlled deflectable catheter design that utilizes laser lithography to fabricate the catheter tips. To improve the two-axis coil design we propose having one coil pattern, a layer of dielectric, and the other coil pattern all on one cylinder. The heat produced by the activated coil is also a concern, and current work focuses on safety issues related to measuring and reducing the heat generated to insure that there are no damaging effects in vivo.

References:

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3. Malba, V., et al., *Laser-Lathe Lithography--a Novel Method for Manufacturing Nuclear Magnetic Resonance Microcoils.* Biomedical Microdevices, 2003. **5**(1): p. 21-27.