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Actively shielded bias magnetic field tuning coil for optically pumped atomic magnetometer toward direct MR signal detection in ultra-low field MRI

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Introduction

In recent years, sensitivity of optically pumped atomic magnetometers (OPAMs) reaches to sub-fT/Hz$^{1/2}$ [1] and ultra–low field MRIs (ULF–MRIs) with the OPAMs have attracted attentions with their low running cost, high portability and reducing the consequence to patients. In an ULF–MRI with an OPAM, although the remote MR signal detections with an flux transformer (FT) were frequently utilized, the sensitivity of MR signal detection was limited by the sensitivity of FT [2]. In this study, we propose an actively shielded bias magnetic field tuning coil to match the resonant frequencies of the OPAM and MR signals for direct MR signal detection in the ULF–MRI.

Methods

An OPAM module with diameter of 83 mm shown in Fig. 1 is planned to be used as the detector in an ULF–MRI. The actively shielded bias magnetic field tuning coil was placed around the OPAM module as shown in Fig. 2. The actively shielded bias magnetic field tuning coil with 90 mm and 110 mm in diameters of primary and shield coils was designed by the target field approach and stream function method [3, 4]. Then, to investigate the feasibility of direct MR signal detection with the OPAM module and the designed actively shielded bias magnetic field tuning coil, the magnetic field distributions generated by the proposed actively shielded bias tuning coil and the tuning coil without active shield were estimated by Biot-Savert's law when the center of a sample was at the origin and the coils were placed under the sample, whose centers were at 120 mm in the distance. In these estimations, completely homogeneous magnetic field of 23.487 μT was applied to the sample and the OPAM, while the bias magnetic field of 0.1428 μT was applied to the OPAM module to tune the potassium's resonant frequency to 1 kHz. In addition, to investigate effectiveness of the actively shielded bias magnetic field tuning coil, the means and standard deviations of magnetic fields at the sample region ($70 \times 70 \times 70$ mm^3) were evaluated as homogeneities.

Results and Discussion

The magnetic field distributions in YZ plane generated by the proposed actively shielded bias magnetic field tuning coil with 30 loops in primary coil and 18 loops in shield coil and the bias tuning coil with 30 loops without active shield were shown in Fig. 3(a) and 3(b), respectively. The analyzed mean of magnetic fields generated by the proposed coil was 23.473 μT for the resonant frequency of 0.9994 kHz for proton, which is better than that by the tuning coil without active shield in the sample region of 24.230 μT for the resonant frequency of 1.0316 kHz. In addition, the standard deviations of the magnetic fields generated by the proposed coil and the tuning coil without active shield in the sample region were 0.0526 μT and 0.2395 μT, respectively. These results suggested that the proposed bias magnetic field tuning coil designed by the target field approach and stream function method promised to tune bias magnetic field with less distortion in the sample region.

Conclusion

We proposed an actively shielded bias magnetic field tuning coil for an OPAM toward direct MR signal detection in an ULF–MRI system, which was designed by target field approach and stream function method. Results of magnetic field distribution analyses indicated that the resonant frequency of an OPAM could be matched to that of a sample with proton by the proposed coil. In addition, the active shield was effective to improve the homogeneity of magnetic field in sample region.

Reference

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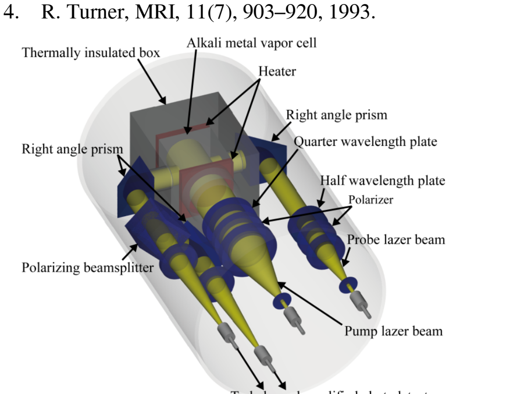

Fig. 1. Schematic of an OPAM module for direct MR signal detection.

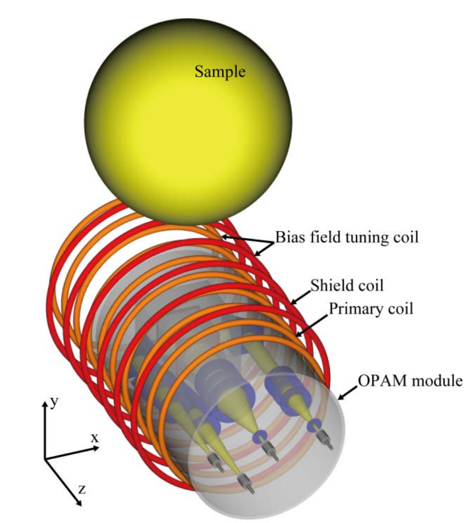

Fig.2. Schematic of an actively shielded bias magnetic field tuning coil.

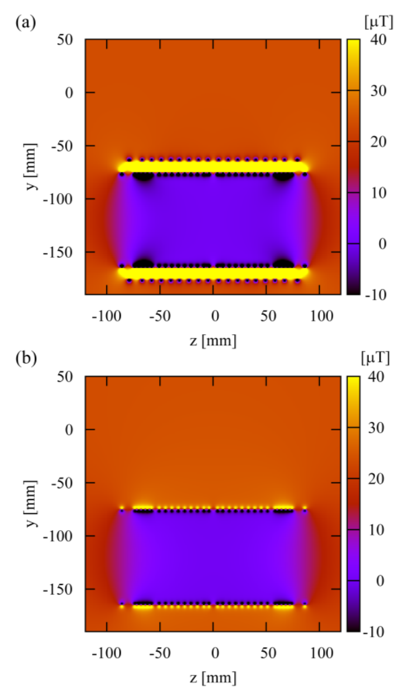

Fig. 3. The results of magnetic field distribution analyses with an actively shielded bias tuning coil (a) and a bias tuning coil alone (b).