Development of TES microcalorimeters with solar-axion converter

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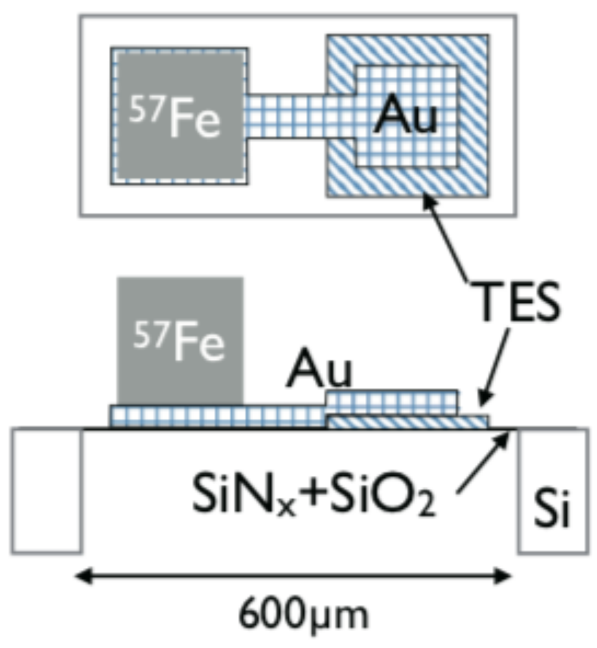
Introduction

Axion is a hypothetical elementary particle proposed to solve the strong CP problem in QCD and is one of dark-matter candidates. The sun is considered to emit axions of a continuum spectrum similar to that of blackbody emission with kT ~ 1.3 keV by the Primakoff effect. In addition, line emission is expected through M1 transitions of nuclei; an example is 14.4 keV from ^{57}Fe. [1]. The mass of an axion is constrained by several astronomical and cosmological observations. There is a narrow window in ~ 10 to ~ 20 eV in the mass constraint from the supernova 1987A[2, 3]. 14.4 keV γ-rays from a thin ^{57}Fe film were searched for by a semiconductor detector and the upper limit of 145 eV (at a 95% confidence limit) for QCD axions has been obtained so far[4, 5, 6, 7]. This is still too high compared to the axion window. The other approach to search for the monochromatic axion emission is to use magnetic field as converter such as the CERN Axion Solar Telescope (CAST). However, the search is limited to a small mass range because of the length of the magnetic field[8]. The sensitivity is expected to improve to a meaningful level by using a large-format microcalorimeter array. However, there are a few issues using Fe at a close vicinity of TES. In this paper, we focus on two possible issues in adoption a Fe membrane as the axion converter; magnetic filed from Fe, and possibly low thermal conductivity of Fe.

(1) TES-microcalorimeter design



- We need to thermally connect an Fe axion converter to a TES.
- Magnetic fields from Fe will modify the superconducting transition temperature and the temperature sensitivity of the TES [9].
- To reduce the magnetic filed on the TES, The 57Fe axion converter is placed with a distance to the TES.

Fig. 1. TES-microcalorimeter structure proposed

(2) Magnetic simulations

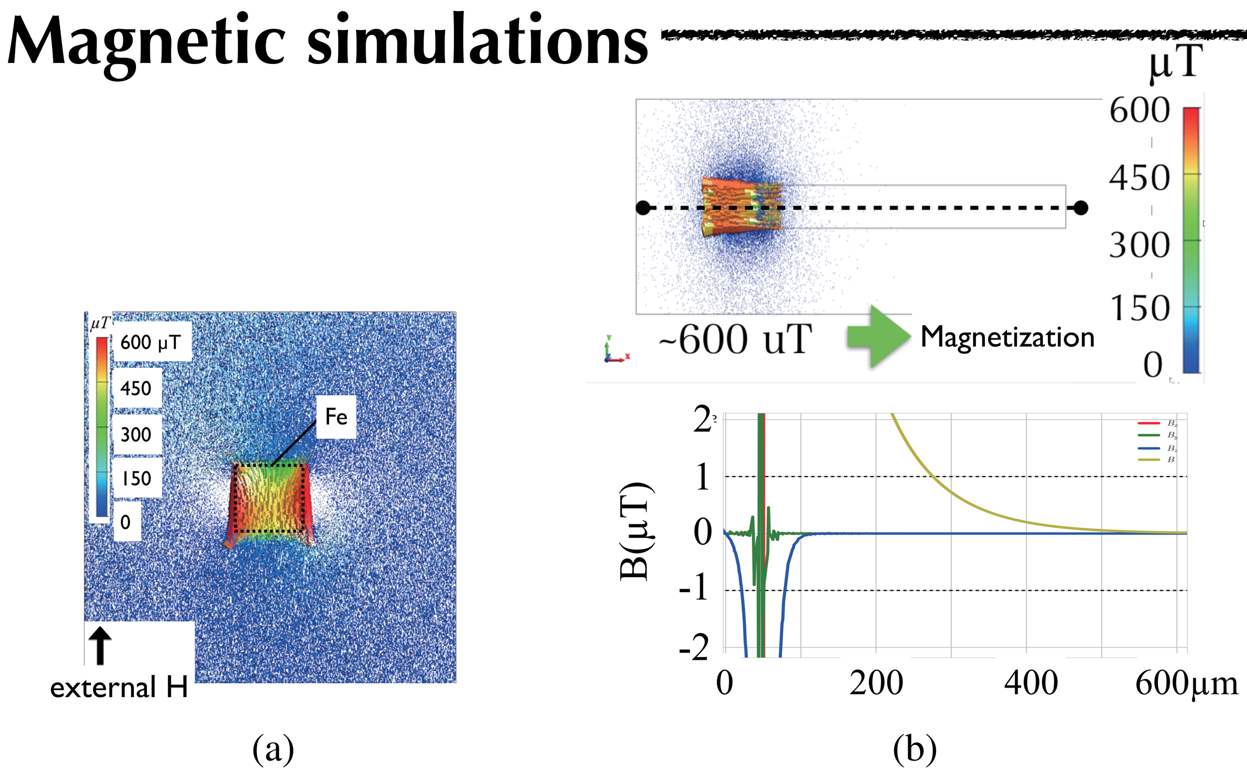


Fig. 2.(a) FEM simulations for the magnetization of Fe by the Earth's magnetic filed. The magnetic field density $B = H_E + M$, is shown with a color scale, where H_E is the Earth's magnetic field. (b) FEM simulations for B created by M when H_E is reduced to 0.

- A TES is sensitive to magnetic field, in particular its component perpendicular to the TES membrane. Our previous measurement did not detect change in the superconducting transition curve if $B_{\perp} < 1\ \mu$T [9].
- The simulations show if the distance between the edges of the TES and Fe is less than 30μm, the condition is satisfied, for the Fe membrane of 100 μm x 100 μm x 5μm size

(3) Superconducting transition of TES

- We measure the resistance-temperature (R-T) relation of the TES's (Fig3) that we have fabricated.

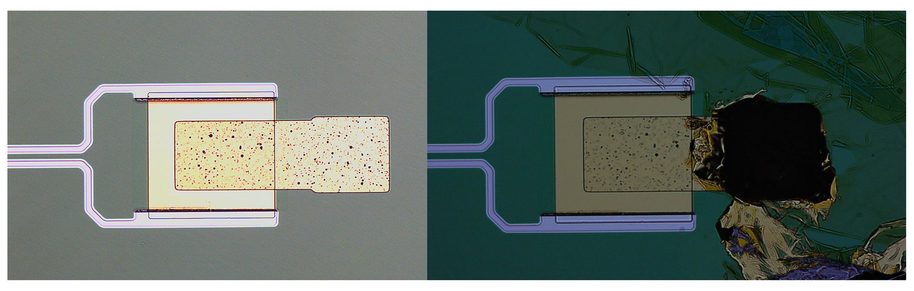


Fig .3. Photographs of TES with a Au thermal strap only (left) and TES with a thermal strap + an Fe membrane of a 20 μm thickness.

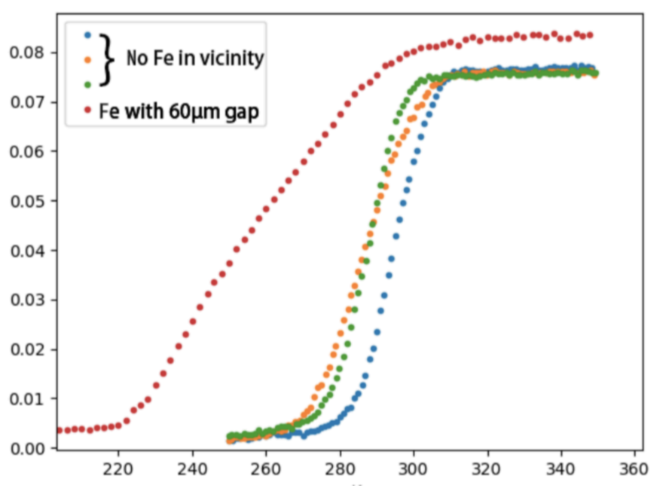
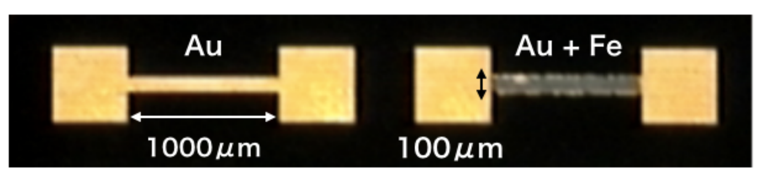


Fig. 4. Resistance-temperature relations of four TES pixels with and without Fe. The transition temperature was higher than the designed value (120 mK).

- Both the transition temperature and the normal resistance of the TES with Fe at 60 μm distance are different from those of the TES's without Fe in vicinity.
- The Fe membrane is thicker by a factor of four compared to the simulation in Fig.2. And the distance between TES and Fe was larger by a factor of 2.
- Assuming a dipole filed, the magnetic filed on the TES was expected to be smaller than simulation.
- We need more samples to compare the experimental results to simulations in order to find optimum distance.

(4) Thermal conductance of iron at low temperature



Thickness of Fe is 1.62μm.

Fig. 4.Photographs of two structures deposited on silicon substrate to measure the electrical resistance of an iron membrane.

Table1. Results of resistance measurements

T (K)	Resistance (Ω)		
	without Fe	with Fe	Fe estimated
300	3.71	0.65	0.79
4	1.25	0.20	0.24

- To estimate the thermal conductance we measured the electric resistance of Fe using the sample shown in Fig.4.
- The resistance of Fe was estimated assuming Au/Ti and Fe layers are connected in parallel to the bonding pad on the both ends (Table 1).
- Using the Wiedemann-Franz law, the thermal conductance at low temperatures was estimated from the electrical resistivity.

$$\kappa = 2.53\left(\frac{T}{4\mathrm{K}}\right)\ \mathrm{WK^{-1}m^{-1}}$$

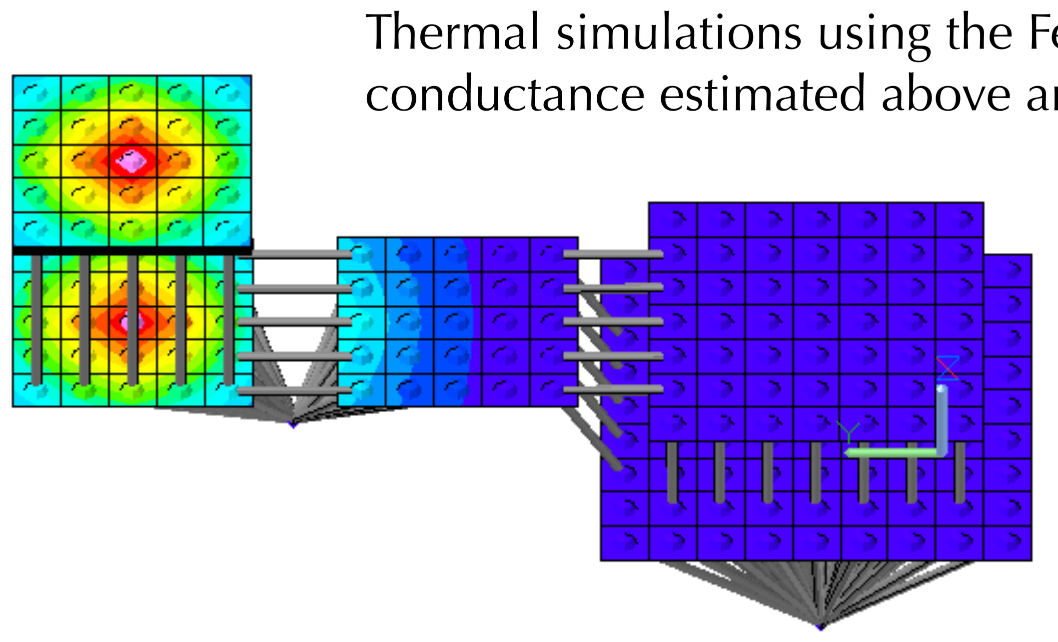
- This value is by a factor of ~ 30 smaller than the value reported for bulk iron at 4K [10], but seems reasonable considering the small RRR (Residual Resistance Ratio) of this sample (~ 3).

(5) Discussion and short-term plan

- We observed change in the R-T relation although we expect the magnetic field on the TES to be smaller than the threshold. There are two possibilities for this explanation: the magnetic filed at the TES was larger than the simulation, or the TES of this experiment was more sensitive to magnetic filed than the TES's previously tested. In the latter case, the high transition temperature of this device can be related to this. We need to test TES's with iron membrane at different distances to find the minimum distance.
- In order to verify whether the thermal conductance of Fe is enough high or not, we are working on thermal simulations.

Thermal simulations

Thermal simulations using the Fe thermal conductance estimated above are on-going.



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