Ultrasensitive microsusceptometer for magnetic AC measurements at very low temperatures and high frequencies

M.J. Martínez-Pérez[a], *J. Sesé*[b], *F. Luis*[a], *D. Drung*[c] *C. Assman*[c], *and T. Schurig*[c]

[a]*Instituto de Ciencia de Materiales de Aragón and Dep. de Física de la Materia Condensada. Zaragoza, Spain*

[b]*Instituto de Nanociencia de Aragón and Dep. de Física de la Materia Condensada. Zaragoza, Spain*

[c]*Physikalisch Technische Bundesanstlalt (PTB) Berlin, Germany*

pepam@unizar.es

The aim of this work is the fabrication of an ultra sensitive SQUID susceptometer capable of operation under extreme conditions of high frequency and low temperatures. A huge bandwidth of about 1 MHz is expected and the sensor will be placed inside the mixing chamber of a dilution refrigerator ($T \approx 13$ mK). With this instrument, measurements of AC susceptibility will be done to search for quantum phenomena at very low temperatures.

For this pourpose 2-stage SQUIDs sensors frabricated at PTB-Berlin will be used [1]. These are 3 mm×3 mm sized chips consisting of an ultra low noise single SQUID read out by a 16-SQUID array (Fig. 1). At $f = 100$ kHz and $T = 4.2$ K, the typical flux noise is about $S_\Phi^{1/2} \approx 800$ nΦ_0/Hz$^{1/2}$. It turns out that doing one simple modification in the wire scheme of the chip, a susceptometer directly coupled to the SQUID is obtained. This implies an enhancement of the sensitivity since the sample is placed over the sensor and no extra connections or inductive couplings are needed.

Two kinds of sensors can be produced. For the first type, the estimated sensitivity is $s_\mu \approx 10^4$ μ_B/Hz$^{1/2}$ and the pick-up coil is big enough (1mm×360micron) to enable an easy deposition of samples i.e. gluing crystals with vacuum grease. For the second type, the sensitivity is enhanced since there is no inductive coupling between the pick-up coil and the SQUID ($s_\mu \approx 10^3$ μ_B/Hz$^{1/2}$) and the sample area is much smaller (≈60×180micron) so they are ideal for deposition of small magnetic particles using the dip-pen lithography technique.

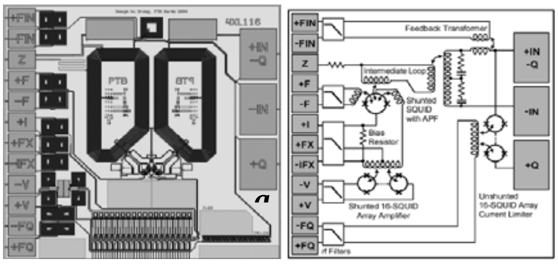
The modification of the chips is carried out at the Instituto de Nanociencia de Aragón (INA, Zaragoza) by Focused Ion Beam etching and deposition. In both cases, the modification consists in the inversion of the current sense of one of the coils coupled to the SQUID. That turns out to be simple because of the existence of wire crossovers between the washers (Fig. 2).

The sensors have been already tested inside the mixing chamber of a dilution refrigerator (Leiden Cryogenics) down to 15 mK. The base temperature is not significantly altered by the presence of the devices and the thermalization of samples is ensured since they are immersed in the ^{3}He-^{4}He mixture. In this experiment, a crystal of molecular magnets (ErW_{10}) was used for ac-susceptibility measurements up to 1 MHz applying an ac-field of 5 mOe (Fig. 3). For low frequencies, the resolution is limited by the $1/f$ noise of the SQUID. As follows from the fluctuation-dissipation theorem, measurements of the noise curves also enable us to see the peak associated with the superparamagnetic blocking of the susceptibility (Fig. 4).

References:

[1] D. Drung, C. Aßmann, J. Beyer, A. Kirste, M. Peters, F. Ruede, and Th. Schurig, IEEE Transactions on Applied Superconductivity, **17**, 699-704 (2007).
[2] E. S. Sadki, S. Ooi and K. Hirata, Applied Physic Letters, **85**, 6206 (2004).

Figures:



(a) **(b)**

Fig. 1: **(a)** Chip layout **(b)** Simplified scheme of the circuit [1]. Modifications in order to obtain the susceptometer are carried out within the Intermediate loop.

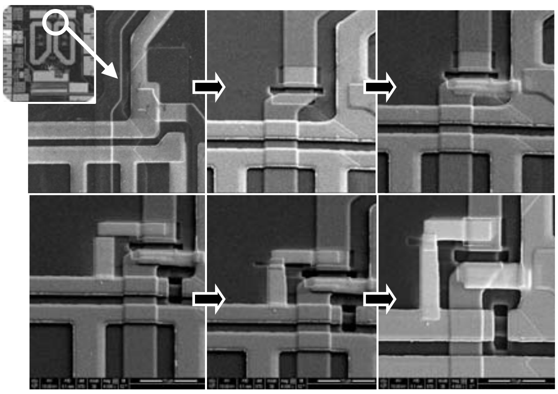


Fig. 2: SEM images of the modification process. The crossover between the two transformer coils is inverted by FIB etching and deposition of W. The material deposited is actually a composite material of W, C and Ga, and it is superconducting below 5.2 K [2].

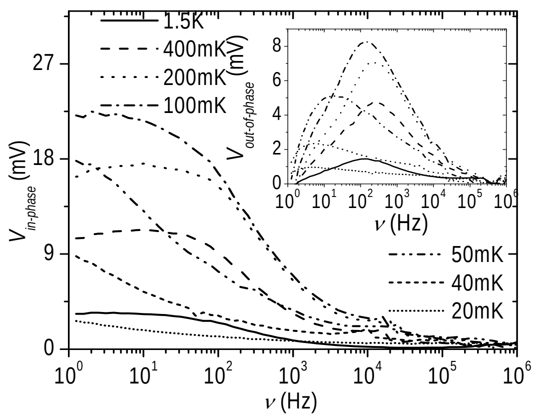


Fig. 3: In-phase and Out-of-Phase (inset) frequency response of the ErW_{10} crystal.

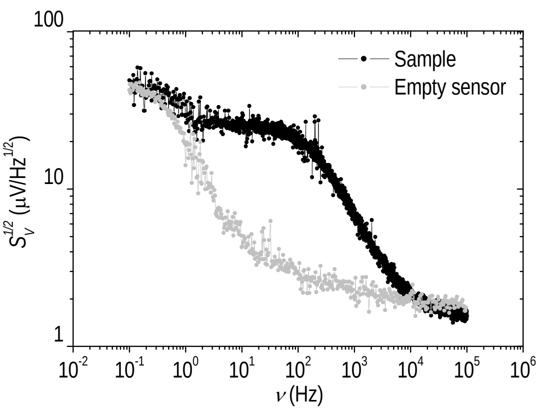


Fig. 4: Voltage noise of the system (grey line). When the ErW_{10} crystal is present (black line) the peak associated with the superparamagnetic blocking of the susceptibility is visible.