Superconducting quantum magnetic sensor for neuroscience investigations

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Abstract: A superconducting quantum magnetic sensor for high-sensitivity applications has been developed by exploiting the flux focusing of the superconducting loop. Thanks to its high performance, it can be used for neuroscience investigations in magnetoencephalography systems.

New quantum technologies, developed within the so-called "second quantum revolution", represent a strategic sector that has attracted great scientific interest. Particularly interesting are quantum sensors, thanks to which it is possible to carry out both basic studies and highly sensitive applications [1]. In the field of high-sensitivity magnetometry, the investigation of the magnetic properties of matter at nanoscale level [2] and the functional imaging of the brain through the measurement of the very weak magnetic fields generated by neuronal currents are particularly interesting. For these studies, the most used quantum magnetic sensors are Superconducting Quantum Interference Devices (SQUIDs) [3], optically pumped atom magnetometers and diamond magnetometers based on nitrogen-vacancy centers.

In this framework, we have developed a high sensitive superconducting magnetometer based on a new design. The basic idea was to use the flux focusing effect in a washer-shaped dc SQUID (Fig.1 a,b,c) with a size that would guarantee enough of an effective area (about 2.5 mm^2) to allow high-sensitivity magnetometry applications [4]. A suitable damping of the SQUID inductance and an appropriate choice of fabrication parameters prevented us from degrading the performance of the sensor in terms of magnetic flux noise and the amplitude of the voltage–magnetic flux characteristics. The experimental results show us that it is possible to obtain a bare dc SQUID with a magnetic field sensitivity less than 8 $fT/Hz^{1/2}$ and with a low frequency noise knee less than 2 Hz below which the low frequency noise is mainly due to the amplifier noise (Fig. 1 d).

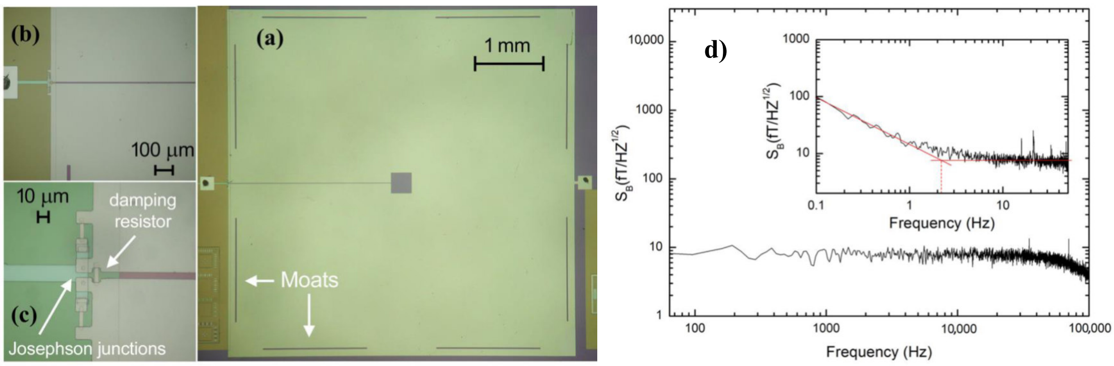

Fig. 1 (a) Pictures of quantum magnetometer. The large washer and the moats near the edge to trap magnetic vortices are visible. (b,c) Two details showing the Josephson junctions, the shunt resistors, and the damping resistor. d) Field noise spectral density of the investigated magnetic sensor measured at 4.2 K, the white magnetic noise is 8 $fT/Hz^{1/2}$. The intersection of the two red lines in the inset gives us the knee value of the low frequency noise.

The simplicity of the design allows us to obtain a high-performance quantum sensor that is very robust, stable, and reliable. Since there are no additional circuits, such as the superconducting flux transformer, fabrication is less critical, and results in a better yield. Furthermore, there are no resonances that degrade the performance of the device and make it less stable and noisy. We would like to stress that the performance of the SQUID magnetometer proposed here is similar to the one based on the superconducting flux transformer and has approximately the same dimensions. These results are significant and certainly of interest to the large community carrying out research on quantum sensors and their applications**.**

References

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