Sensitive surface loop-gap micro-resonators for electron spin resonance

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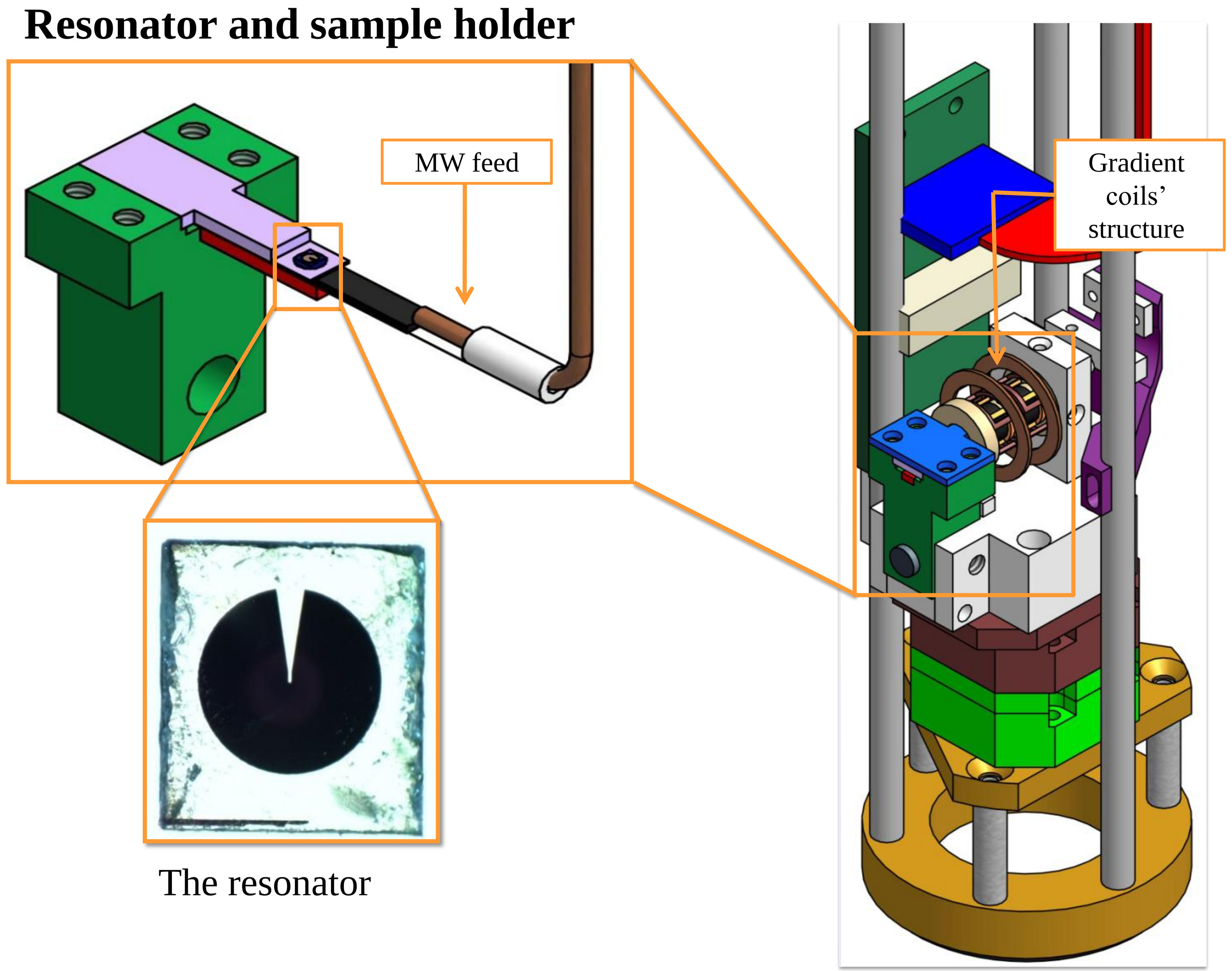
Abstract

Electron spin resonance (ESR) is a powerful spectroscopic method employed in the study of paramagnetic species. ESR is used in a variety of fields of science ranging from physics to biology. One of the most severe limitations of ESR is its relative low sensitivity, with modern conventional ESR spectrometers enable a typical sensitivity of ~10^8-10^9 spins.

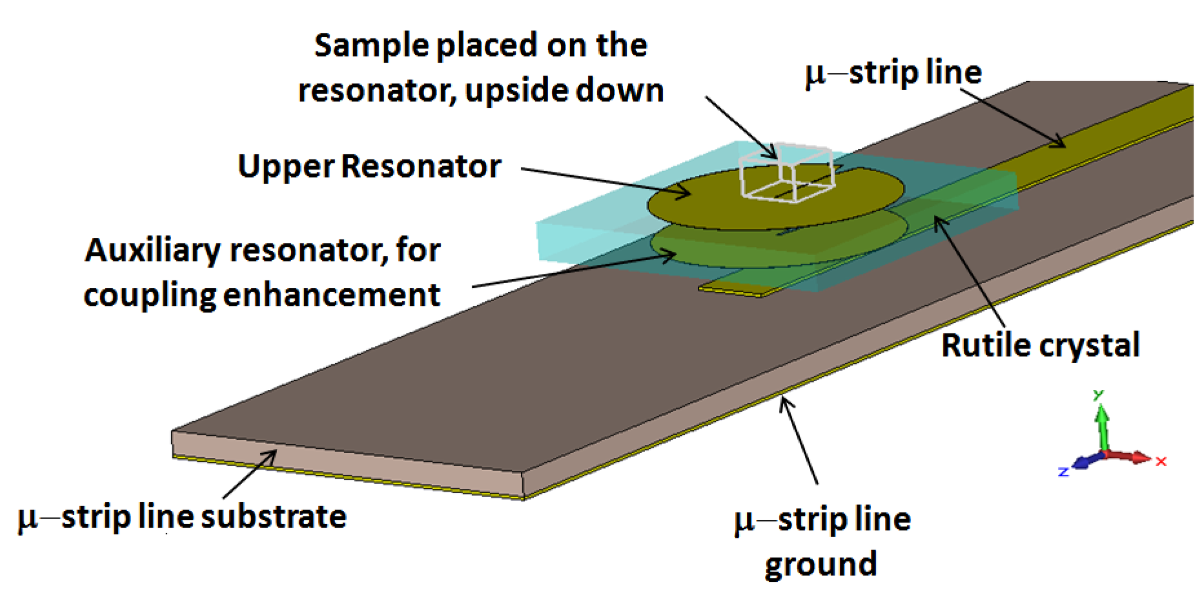
Here we present the design and experimental testing of a new family of surface loop-gap micro-resonators with variable coupling capabilities that can greatly improve the spin sensitivity of conventional ESR systems, based on induction-detection. We show that, by making use of the smallest ESR resonator constructed to date (~5µm), together with unique cryogenic amplification scheme and sub-micron imaging capabilities, a sensitivity of less than 1000 electron spin is obtained with spatial resolution of ~500nm. Such resonators can be useful for a variety of application. For example, detection and imaging of defects on the surface and subsurface of semiconductors, measurements of paramagnetic mono-layers and performing ESR spectroscopic measurements on spin-limited samples.

The cryogenic probe and the surface resonator

Resonator and sample holder

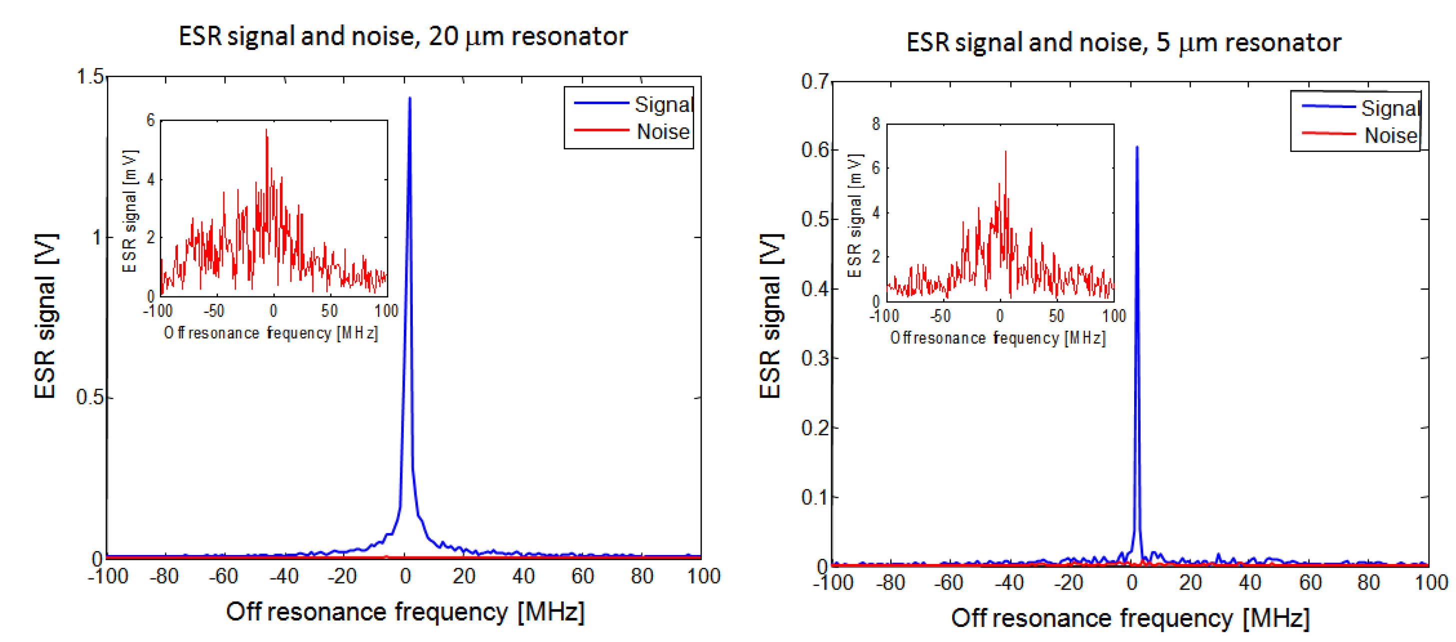


The new cryogenic probe that was employed in the experiments. The resonator is operated in reflection mode. Both the circulator and the first low noise amplifier are cooled to cryogenic temperatures. The probe has several functionalities: (a) It enables to generate static and pulsed magnetic field gradients and polarization fields in all 3 axes. (b) It has 2 independent piezo stages to control the coupling between the microwave line and the resonator.

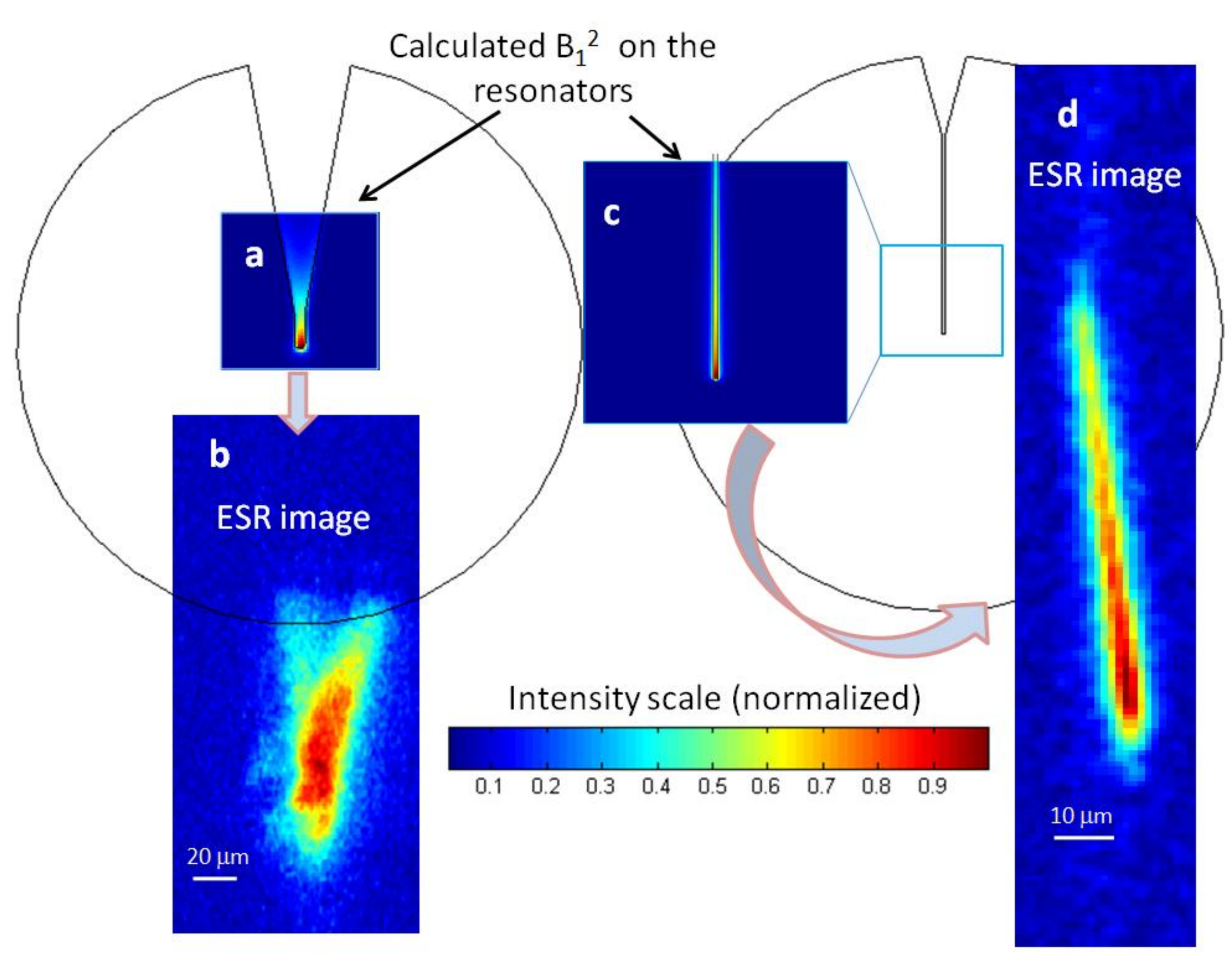


Details of the microwave coupling configuration and the position of the sample with respect to the resonator. The image shows the 5 micron resonator, which uses the 20 micron resonator on the bottom part as an auxiliary resonator to facilitate efficient microwave energy coupling .

Experimental Results



ESR signal (blue lines) compared to noise level (red lines, obtained at 100 G off-resonance wit 1 sec averaging time) for the ^{28}Si:P sample placed on the 20 µm (left) and 5 µm (right) resonators. The two inserts show the noise level in mV (blown up by a factor of 1000).



Calculated and measured microwave magnetic field distribution (B_1^2) close to the resonators surface. (a) Calculated B_1^2 on the 20 µm resonator, sum over the first 5 microns above the surface. (b) Two dimensional ESR image taken with a flat ^{28}Si:P sample placed on the resonator. (c) The same as in (a) but for the 5 µm resonator, sum overt the first 3 microns above the surface (the area in the center of the resonator is blown up for better clarity). (d) The same as in (b) but for the 5 µm resonator.