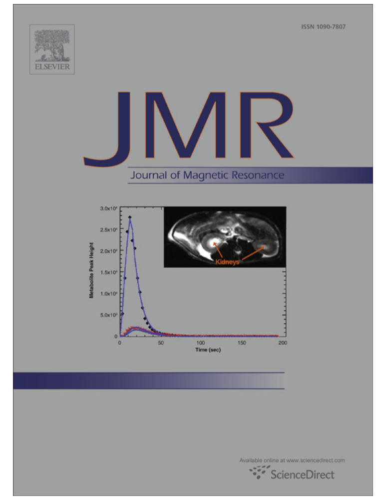

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A capacitive probe for Electron Spin Resonance detection

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The use of the magnetic field associated with Maxwell displacement current in a capacitor is proposed for the detection of Electron Spin Resonance. A probe based on this concept is realized and successfully tested with CW radio-frequency in the band going from 200 MHz to 1 GHz with a DPPH sample. A significant increase of Signal to Noise Ratio is observed while increasing the frequency.

INTRODUCTION

The invention of the Scanning Tunneling Microscope (STM) [1] gave the possibility to investigate sample properties with such a high resolution to make "atomic resolution" a common expression in surface science. The fundamental idea of Binnig and Rohrer, i.e. scanning the surface with a very sensitive and local probe, stimulated the research in developing a large variety of probes, introducing a vast family of new microscopies collectively known as Scanning Probe Microscopies (SPM)[2].

Among SPMs recent research has been addressed to develop probes for Electron Spin Resonance (ESR), which would allow investigation of the electronic properties of a surface. A first approach was to scan the surface using a microwave resonant cavity with a small aperture. The best resolution attained with this approach was of the order of 10^{-3} m [3, 4].

Scanning micro-coils have been proposed for ferromagnetic surfaces investigation by many authors [5–8] and also used for ESR detection [9, 10]. The reported resolution is as well of the order of 10^{-3} m, limited by the size of the scanning coil.

The reduction in size of coils down to 10^{-4} m actually increased the sensitivity up to 10^8 spins [11–16], and a similar sensitivity has been obtained with surface loop-gap microresonators [17–19] and striplines [20] and demonstrated in microscopes with better than $500nm$ resolution [10, 21].

Techniques alternative to ESR induction detection, suitable for SPM, have been explored.

Electrical probes in the form of small antennas have been tested to detect nuclear magnetic resonance [22, 23] by sensing the radio-frequency electric field associated to the oscillating magnetic field. Sensitivity was very good but spatial resolution as a scanning imaging technique was still in the millimetric domain [24].

Very high sensitivity, i.e. single spin detection, and a resolution of the order of 10^{-9} m have been obtained by combining ESR detection either with AFM [25, 26] or with STM [27, 28]. At present, while the former technique requires an Ultra High Vacuum environment coupled with a very low temperature, the combination with STM, which relies on the detection of high frequency spin noise in the tunneling current, has been successfully implemented at room temperature and pressure, although high vacuum and low temperature can further improve sensitivity and reproducibility [29]. Electron Spin Noise-based detection of local properties represents a very promising approach towards the development of local readout of magnetic spin states. At present its application is limited to magnetic fields of the order to 10^{-2} T, but relevant improvements can be foreseen by using stronger external fields, as it is well known that the ESR sensitivity rises with field intensity [30]. Some open questions persist in the theoretical interpretation of this last technique [31], and one of these is how a magnetic spin can interact with the electric field in the tunnelling gap.

In a recent paper Gregorovic [32] pointed out that Maxwell displacement current in a capacitor is associated with a magnetic field and suggested that this spatially localized magnetic field can be used to detect magnetic spin resonance in a region of space between two conductive surfaces. He also demonstrated the successful detection of nuclear quadrupole resonance in a planar capacitor with a diameter of a few centimeters.

With the aim to verify if it is possible to use this approach in ESR detection and to develop a probe suitable for SPM, we investigated the behavior of an open coaxial cable, connected to a RF source and facing, at the termination, the sample to be analyzed, spread on a conducting surface.

DESCRIPTION OF THE PROBE

The structure and the principle of operation of the capacitive probe are shown in fig. 1.

The flat end of a coaxial cable faces a conductive plate, with the gap between the two surfaces filled with a thin film of paramagnetic sample. The gap thickness d is kept small enough to describe the assembly as composed by two concentric parallel plane capacitors, a central circu-