

Title : Ferromagnetic Resonance Imaging using a submicron localized spin wave mode

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Abstract : Ferromagnetic Resonance (FMR) is a powerful spectroscopic tool for the study of internal magnetic fields and dynamic properties in ferromagnetic systems. In recent research related to spin-based nano-devices, nanoscale imaging of buried interfaces and structures are important for understanding and applications. Ferromagnetic Resonance Force Microscopy (FMRFM) is a promising approach based on high sensitivity, high resolution sub-surface scanning force microscopy. Currently, for FMRFM, it is difficult to achieve the spatially well-resolved FMR signal due to the strong spin interactions which lead to collective spin wave excitation, containing global properties of the sample. In order to overcome this problem, a new concept of a probe is necessary such as localized FMR modes which have not yet been demonstrated. Here we show submicron localized FMR modes defined by a strong inhomogeneous probe field in the ferromagnetic thin film, and propose them as a probe for FMRFM imaging. The strong inhomogeneity of probe field, aligned anti-parallel to magnetization in sample, localizes FMR modes in the small area allowing high spatial resolution FMRFM imaging. The highest resolution obtained in our experiment is 200 nm with relatively large probe ($\sim 1.2 \times 1.2 \times 1.5 \mu\text{m}$) and probe-sample separation ($\sim 1.3 \mu\text{m}$), showing sub-surface scanning capability. Furthermore, we visualize the non-uniform demagnetizing field of an individual $5 \mu\text{m}$ Permalloy disk and variation of internal magnetic field in the Permalloy film with high sensitivity ($\sim 1 \text{ G/Hz}^{1/2}$). Our method opens a way to explore nanoscale magnetism as well as spin dynamics in inhomogeneous magnetic field. The resolution and sensitivity can be improved by using ferromagnetic film in which parameters like film thickness, FMR linewidth, have been optimized. The application of localized FMR modes are not limited to FMR imaging, but different applications to highly sensitive field sensing and point microwave sources are also possible. This work was supported by the U.S. Department of Energy through Grant No. DE-FG02-03ER46054.