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In-situ Magnetodynamic Experiments Achieved with the Design of an In-plane Magnetic Field Specimen Holder

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With the diminishing of physical dimensions in magnetic recording media, it has become invaluable for the scientific community to understand fundamental magnetism at extreme length scales. Understanding the interaction and general properties of small-scale magnets is crucial to the development of magnetic data storage devices. Some of our objectives are: to understand magnetic reversal behavior (such as domain wall motion vs. domain rotation), to study the nucleation of the vortex state (stability of domain structures as a function of material volume and aspect ratios), and the spatial interaction between magnetic elements. The development of an in-plane field holder is therefore integral to our goal.

We have successfully modified a Gatan double-tilt TEM specimen holder that can provide a pure in-plane magnetic field of up to 26 G. The construction consists of a single solenoid, where the specimen is embedded in the geometric center (fig. 1). Recently, Uhlig et al. have reported a specimen holder design for the Philips TEM. This versatile design can generate a field up to 63 G in any arbitrary direction at the cost of 2.5 G of remnant induction[1]. Our holder is used specifically with the JEOL 3000F TEM. The narrow gap formed by the high resolution pole piece poses as a serious design limitation. Our holder does not generate any remnant field, as we do not use a magnetic core in our solenoid. The applied field is calibrated by measuring the beam deflection in diffraction mode. Figure 2a is a plot of applied current vs. beam displacement, measured with a camera length of 200 cm. Figure 2b tabulates the fields corresponding to currents in Fig. 2a. Part of the work in progress is to improve on the strength of the magnetic field.

The primary means of observing magnetic domain configurations in a TEM is with Lorentz microscopy[2]. We have performed in-situ study following a hysteresis loop of 6 μm x 6 μm x 30 nm permalloy elements. Figure 3 shows a series of Lorentz images at various stages of the hysteresis loop. The dynamics of domain motion behavior can be realized by phase retrieval using transport of intensity (TIE) formalisms to post-process experimental images. Semi-quantitative color maps denoting relative directions of magnetization can be derived from the TIE treatment.

The advantage of the in-situ magnetic holder design is demonstrated by our 2D in-plane visualization capabilities. Our plans involving the study of smaller magnetic structures and quantitative treatment of finer details is very promising. The immediate implication of this work is the real-time and on-line visualization of magnetodynamics on the nanoscale.

References

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2. Edington, J.W., *Practical electron microscopy in materials science*. 1976, New York: Van Nostrand Reinhold Co.

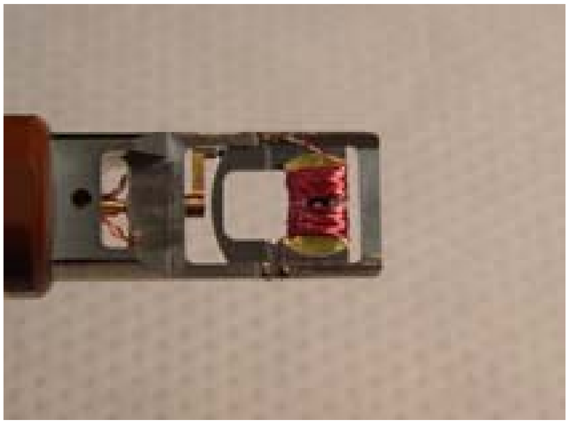

FIG 1: Single solenoid attachment that allows for the application of precise and well-calibrated in-specimen-plane magnetic field

Current (mA)	Beam Deflection (m)	θ (rad)	B (G)
0.00	0.00E+00	0.00E+00	0.00
20.24	6.50E-04	3.24E-04	3.24
39.50	1.44E-03	7.18E-04	7.18
60.00	2.25E-03	1.12E-03	11.20
79.50	2.88E-03	1.43E-03	14.31
100.70	3.54E-03	1.76E-03	17.59
121.30	4.04E-03	2.01E-03	20.12
128.60	4.16E-03	2.07E-03	20.68
134.00	4.35E-03	2.16E-03	21.63

Figure 2b – Values for beam displacement, deflection angle and magnetic field corresponding to current applied through the solenoid

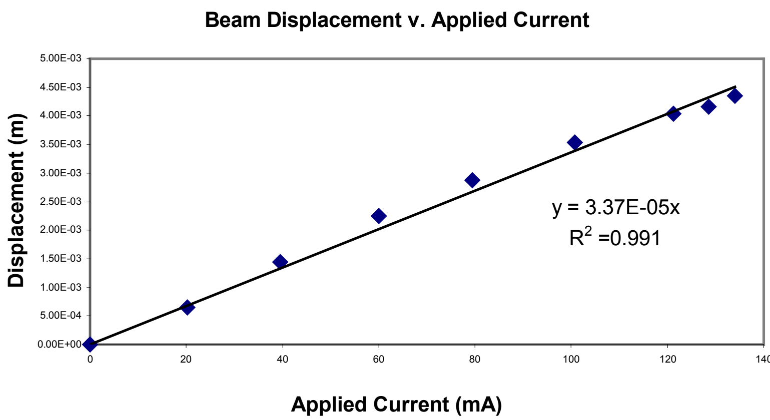

Figure 2a – Plot used for calibrating the applied magnetic field. Here we observe a linear relationship between applied current and beam drift distance

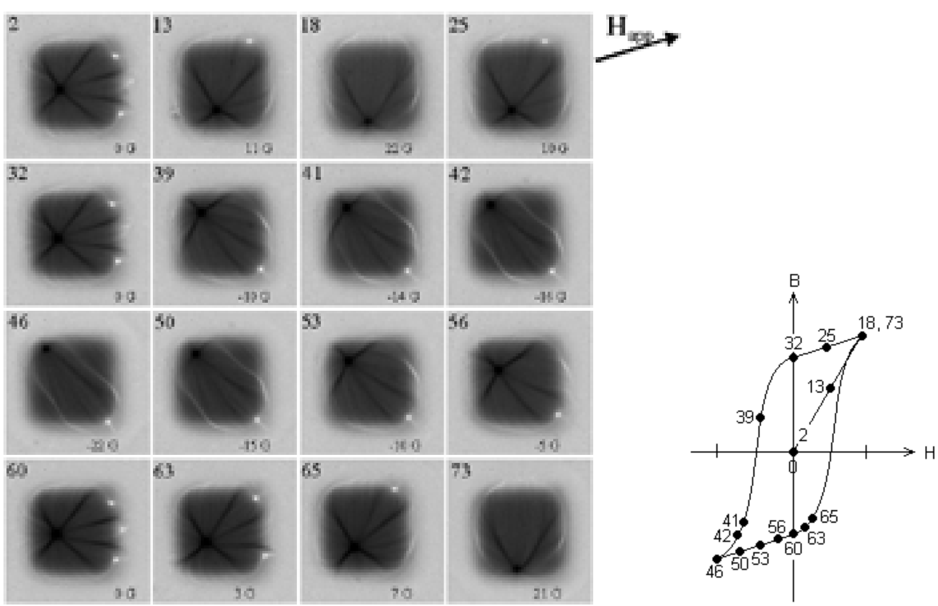

FIG 3: A single permalloy element (6 µm x 6 µm) at various stages of a hysteresis loop (22 G maximum)

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