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Ultrafast demagnetization of $Co_{25}Ni_{75}$/Pt multilayers with perpendicular anisotropy at elevated temperatures

R. Wilks and R. J. Hicken[a)]
School of Physics, University of Exeter, Exeter EX4 4QL, United Kingdom

M. Ali and B. J. Hickey
Department of Physics and Astronomy, E.C. Stoner Laboratory, University of Leeds, Leeds LS2 9TJ, United Kingdom

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Ultrafast demagnetization has been studied in Si/Pt(160 Å)/[$Co_{25}Ni_{75}$(x)/Pt(8 Å)]$_{20}$ (x=3, 4.5, and 6 Å) multilayers with perpendicular anisotropy by magneto-optical pump-probe measurements in the polar geometry. Time-resolved measurements made in the saturated state showed that maximum demagnetization was achieved within 300 fs. Hysteresis loops were measured at a time delay of 1.3 ps for temperatures from 20 to 300 °C. The Curie temperature was found to increase from 150 to 250 °C with increasing $Co_{25}Ni_{75}$ thickness. By comparing the loops obtained with and without pump excitation, the increase in electron temperature due to the pump was estimated to be about 60 K. © *2005 American Institute of Physics*. [DOI: 10.1063/1.1847991]

Ultrafast magnetic switching has recently attracted great interest. Precessional switching of permalloy elements has been achieved within 200 ps after the application of a picosecond magnetic field pulse,[1] while the magnetization of GdFeCo has been aligned with a reverse magnetic field within 190 ps following complete demagnetization by an ultrafast laser pulse.[2] Laser-induced ultrafast demagnetization was first observed in Ni[3,4] while femtosecond spin dynamics[5] and full demagnetization[6] have been studied in $CoPt_3$. Little attention has been paid to other candidate magneto-optical recording media such as Co/Pt-based multilayers. The relatively high Curie temperature (T_C) is a disadvantage for ultrafast pump-probe studies but can be lowered by alloying the Co with other materials such as Ni.[7] By varying the thickness of each of the layers both T_C (Ref. 8) and the magneto-optical properties[9] of CoNi/Pt multilayers can be tailored. In this paper we present measurements performed on three $Co_{25}Ni_{75}$(x)/Pt(8 Å) structures. We have characterized the static magnetic and magneto-optical properties of the samples and investigated the effect of an annealing treatment. Optical pump-probe experiments performed at different ambient temperatures allow us to estimate the increase in electron temperature induced by the pump and infer that full demagnetization has been achieved.

Three Si(100)/Pt(160 Å)/[$Co_{25}Ni_{75}$(x)/Pt(8 Å)]$_{20}$ samples with x=3, 4.5, and 6 Å were fabricated by dc magnetron sputtering, and will be referred to as samples 1, 2, and 3, respectively. The static magnetic response of the as-deposited samples was characterized in air using a polar magneto-optical Kerr effect (MOKE) apparatus at a wavelength of 633 nm. Polar and longitudinal electromagnets provided fields of up to 11 and 3.3 kOe, respectively. The sample was mounted on a heater that was controlled by a proportional differential integral (PDI) temperature controller and allowed the temperature to be stabilized to better than +/−2 °C from room temperature (RT) to 300 °C.

Optical pump-probe measurements were performed with pulses of 785 nm wavelength and 100 fs pulse width from a Ti:sapphire laser[10] at an 80 MHz repetition rate. Both pump and probe were focused to a spot with a diameter of 15 μm, which was limited by the beam divergence, and then carefully overlapped. Although the area of the probe spot should ideally be subject to uniform pump intensity, the minimum pump diameter was used so as to maximize the fluence to about 1.4 mJ/cm^2 and hence the demagnetization effect. Both beams were always plane polarized. For the dynamic measurements the pump and the probe beam were chopped at a fixed frequency ratio of 5:6 and the magneto-optical response of the sample was measured at the sum frequency of 575 Hz. This dual chopping scheme was found to give similar signal quality to the single pump chopping used in previous studies.[10,11] It also allowed the demagnetization to be observed directly on an oscilloscope connected to the output of the high-pass filter on the front end of the lock-in amplifier. The time delay was set using a translation stage with a stepper motor and encoder resolution of 0.1 μm. The zero time delay position was defined to lie at the peak of the specular inverse Faraday effect (SIFE) signal measured in a GaAs wafer with a circularly polarized pump beam.

Static polar MOKE loops were measured at selected temperatures from RT up to 300 °C in order to determine T_C. At RT the as-grown samples showed a "wasp-waist" shape with small remanence and coercivity, as shown in Fig. 1, that is characteristic of stripe domain formation.[12] After heating the samples to 300 °C in air, the RT loops became almost square with high remanence and coercive fields of 0.9, 1.9, and 1.5 kOe for samples 1, 2, and 3, respectively. By contrast, heating to 200 °C had little effect upon the RT loop. The observed annealing behavior is in good agreement with that reported previously.[13] Loops were recorded during a second annealing cycle up to 300 °C and afterwards the shape of

a)Electronic mail: r.j.hicken@ex.ac.uk

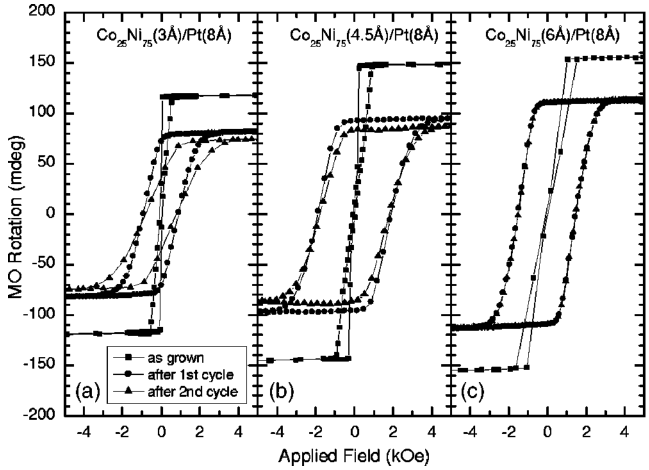

FIG. 1. MOKE rotation hysteresis loops taken at room temperature at 633 nm wavelength are shown for the samples as grown (squares), after annealing up to 300 °C (circles) and after a second annealing up to 300 °C (triangles). The thickness of the CoNi layers within the multilayers was (a) 3 Å in sample 1, (b) 4.5 Å in sample 2, and (c) 6 Å in sample 3.

the RT loop was found to be almost unchanged. The RT saturation polar Kerr rotation had values of 118, 145, and 155 mdeg at 633 nm wavelength, and 70, 95, and 95 mdeg at 785 nm for samples 1–3, respectively. The polar ellipticity signal was found to be about four times smaller in each case. The observed trends are consistent with previous studies[9] of different CoNi compositions. Selected polar loops measured from sample 1 at elevated temperatures are shown in Fig. 2. The coercivity and remanence disappear above 90 °C although the signal at 100 °C still rises quickly and appears to saturate at a field of about 500 Oe. At 130 °C the loop is reminiscent of a Langevin curve while at 200 °C the loop is essentially flat. Arrott plots[14] were made of the cube of the rotation versus the applied magnetic field. These showed T_C to be about 130, 150, and 250 °C for samples 1, 2, and 3, respectively. Longitudinal MOKE measurements were made on sample 1 from RT to above T_C. A linear unsaturated response was observed at all temperatures. This suggests that

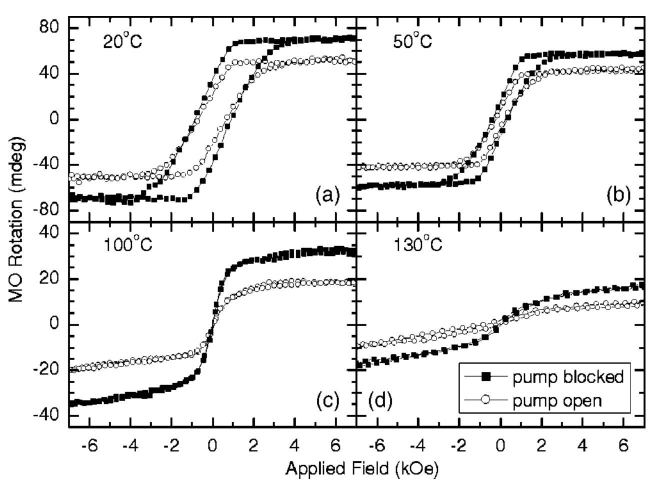

FIG. 2. MOKE hysteresis loops of sample 1 at selected ambient temperatures taken at 785 nm wavelength are shown without (solid squares) and with (open circles) excitation by the pump. The probe pulse delay was set to 1.3 ps.

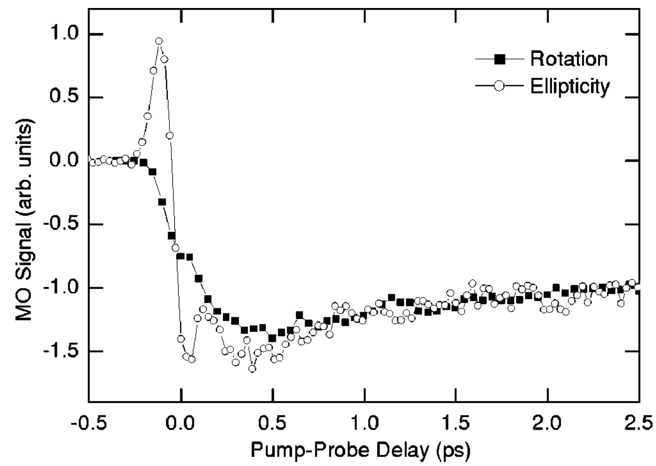

FIG. 3. Pump-induced change in the MOKE response of sample 1 at 785 nm wavelength following pump excitation. The rotation and ellipticity signals have been normalized to show the same height at long time delays.

the easy axis remains perpendicular to the sample plane up to T_C even though the perpendicular remanence has disappeared.

The following studies of the pump-induced magnetization changes were performed on sample 1 because it showed the lowest T_C. This allowed the data to be taken at lower temperatures where the signal-to-noise quality was found to be highest. The transient rotation and ellipticity signals obtained from pump-probe measurements on sample 1 are shown in Fig. 3. The signals reach their maximum values, corresponding to a demagnetization of about 25%, at a time delay of about 300 fs, similar to that observed previously for pure Ni,[10] before exhibiting a slow recovery. A background of about 3%, resulting from the average heating by the pulse train, has been subtracted. The shapes of the rotation and ellipticity signals differ only within the temporal overlap of the pump and probe pulses. At zero delay, a small peak and a large bipolar contribution are superimposed upon the rotation and ellipticity signals, respectively. Both peaks change sign with the demagnetization signal if the direction of the static field is reversed. At longer time delays, where the pump and probe no longer overlap in time, the transient rotation and ellipticity signals have the same shape, and the rotation signal provides a reasonable measure of the transient magnetic response.

Hysteresis loops were also acquired with the probe beam following excitation by the pump. Selected loops obtained from sample 1 have been shown together with the static loops in Fig. 2. At very short time delays, the transient rotation and ellipticity are not necessarily proportional to the transient magnetization due to the presence of additional nonmagnetic contributions to the signal.[15] Hysteresis loops were therefore acquired at a time delay of 1.3 ps, where the measured signal was expected to be representative of the magnetic state of the sample, while being of similar magnitude to the peak signal value. The difference of the peak signal and that at 1.3 ps was within 15% at room temperature (see Fig. 3) and decreased with increasing temperature. The loop half-height both with and without pump excitation is plotted against ambient temperature in Fig. 4. Due to the loss

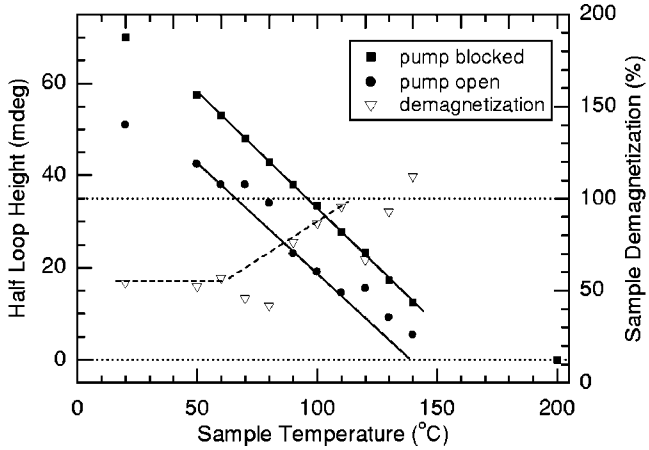

FIG. 4. The solid symbols show the dependence of the half MOKE loop height of sample 1 on the temperature. The values were taken at a constant field of 7 kOe without (squares) and with (circles) previous excitation by the pump beam. The open triangles show the percentage demagnetization calculated for the pump spot center. The solid and dashed lines are guides to the eye and show the largest demagnetization for optimal alignment.

of remanence at elevated temperatures, the half-height was measured at a finite field of 7 kOe. As the field affects T_C, a finite loop height is still measured to up to about 170 °C. The measured Kerr rotation value is an intensity-weighted average over the area of the probe spot. Since the pump and probe spots are of similar size, the pump intensity varies over the area of the probe spot. Let us assume that the distribution of the pump and probe intensity on the sample surface has a Gaussian profile and that the demagnetization effect has a linear dependence upon the local pump intensity. Then when less than 100% demagnetization is obtained at the center of the pump spot, the signal integrated over the area of the probe spot will be a factor of 2 smaller. However, if the pump intensity is sufficiently large that 100% demagnetization is achieved within the central region of the pump spot, then the integrated probe signal will exceed 50% and gradually approach 100% with increasing pump intensity. The demagnetization achieved at the center of the pump spot has been estimated, by multiplying the measured value by a factor of 2, and plotted in Fig. 4. Due to thermal expansion of the sample mount the overlap of the pump and the probe spot had to be readjusted for each value of the ambient temperature. Consequently, some scatter is observed in the loop half-height measured with pump excitation, and hence in the calculated percentage demagnetization. A line has been drawn through the points in Fig. 4 that show the largest demagnetization. The curves suggest that full demagnetization is achieved at the center of the spot for ambient temperatures in excess of 110 °C. The curves formed from the squares and circles are seen to be shifted by approximately 30 K. We therefore estimate that the pump-induced increase in electron temperature after the optically excited hot electrons have thermalized is about 60 K.

In summary, the magnetic behavior of $[Co_{25}Ni_{75}(x)/Pt(8\ Å)]_{20}$ multilayer samples with $x=3$, 4.5, and 6 Å has been investigated by means of static and time-resolved MOKE measurements. All samples showed perpendicular anisotropy. As-deposited samples showed a small RT remanence and coercivity that increased markedly after annealing at 300 °C. For the sample with $x=3$ Å, it was deduced that an ultrafast demagnetization of about 50% occurred at the center of the pump spot at RT, while full demagnetization was achieved above 110 °C. The associated increase in electron temperature was found to be about 60 K. The demagnetization measurements are complicated by a loss of perpendicular remanence as the temperature approaches T_C. Patterning of the multilayers into submicron size elements might be used to maintain the remanence[16] so that the demagnetization effect may be observed more clearly.

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