Modification and Monitoring of Magnetic Properties with Ultrafast Laser Pulses

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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Abstract

Investigations of the static and dynamic electronic, optical and acoustic properties of different nanostructures are presented. Magneto-optical Kerr effect (MOKE) magnetometry has been used to probe the magnetic properties of the magnetic nanostructures. A time-resolved all-optical pump-probe technique, using femtosecond laser pulses, has been employed to investigate the ultrafast magnetisation dynamics, and transient polarisation and reflectivity responses. The magnetic samples studied were permalloy (NiFe) nanowire arrays and multilayered CoNi/Pt films and nanodot arrays, while the non-magnetic samples were phase change GeSbTe thin films. These structures have attracted much attention because their properties can be advantageous in data storage applications.

Static MOKE measurements of the NiFe nanowires revealed zero coercivity and remanence, regardless of the direction of the applied magnetic field, with the magnetic easy axis perpendicular to the axis of the nanowire. This is the result of antiferromagnetic alignment of the magnetization in adjacent nanowires at remanence. Time-resolved MOKE (TRMOKE) measurements performed upon the nanowires showed increasing demagnetisation with increasing pump fluence, with a larger response being observed when the magnetic field was applied perpendicular to the nanowire axis. This behaviour, together is believed to result from the formation of vortices at the end of the nanowires. Moreover, the TRMOKE response revealed oscillations due to modes of magnetic precession with frequencies that have minima at a field rather close to the saturation field of the samples. For lower fields, the frequencies decrease with increasing applied field, while for higher fields, they increase with increasing applied field. This behaviour is believed to result from the strong dipolar interactions that can overwhelm the shape anisotropy of an individual nanowire leading to a switching of the easy axis from parallel to perpendicular to the nanowire axis. The magnetisation may also break up into domains for field values less than the saturation value, which results in a decrease in the dipolar coupling with decreasing applied field.

Static MOKE measurements of the CoNi/Pt multilayers showed that the saturation Kerr rotation increases with increasing packing density of the sample, while the coercive field decreases after patterning, but increases with decreasing diameter among the patterned samples. AC-MOKE measurements revealed that increasing pump fluence

leads to decreasing coercivity and increasing demagnetisation, which is attributed to the increased heating of the surface of the dots and, thus, an increased temperature. Full demagnetisation and total loss of coercivity were achieved for all the nanodot arrays. The AC-MOKE results are in good agreement with the results of TRMOKE measurements.

Transient polarisation measurements showed a clear specular-optical Kerr effect (SOKE) response for all the samples. This response appears as a peak at the zero delay position that has maximum (zero) effect when the pump and probe electric fields lie 45^0 (0^0 or 90^0) apart, and is accompanied by longer-lived damped oscillatory modes for the nanowires and nanodot arrays. A mechanism involving the optically induced electric polarisation of the nanodots and nanowires has been suggested to explain this response. Moreover, an epitaxial GeSbTe film revealed a robust dependence of the transient polarisation upon the sample orientation which suggests a strong influence of the crystallographic structure for this sample.

The time-resolved reflectivity (TRR) measurements for the nanowire and nanodot arrays revealed a linear dependence of the amplitude of the transient reflectivity upon the pump fluence. A number of oscillatory modes with different GHz frequencies were observed to be superimposed upon an exponentially relaxing background, while a single mode was observed in the CoNi/Pt continuous film. These oscillations are believed to result from the excitation of surface acoustic waves (SAW). Two principal mechanisms have been suggested to explain the excitation of SAWs within the nanodot arrays. A discrepancy between the experimental and frequencies predicted by an existing model was found which is believed to be due to the neglect of the sample composition and the SAW velocity of the nanostructures within this model. The development of a model that overcomes these weaknesses is suggested for future work. An additional THz frequency mode was observed within the GeSbTe which is believed to arise from the excitation of optical and acoustic phonon modes. Further work is required to identify the observed phonon modes and to relate the associated optically induced linear birefringence to a specific structural distortion.

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