Dynamics of Ultrafast Demagnetization Probed with Femtosecond Electron Diffraction

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Introduction

Since the first observation of sub-ps loss of magnetic order following a femtosecond laser excitation of a ferromagnetic Ni film [1], the research of ultrafast magnetization (spin) dynamics has developed into a rapidly advancing field attracting a great deal of interests in the past decade. These interests originate from both the scientific desire to explore the underlying mechanism of demagnetization dynamics and the industrial incentives for faster data processing in the magnetically based storage media. So far, all the ultrafast measurements of demagnetization were carried out using time-resolved optical techniques to probe electron/spin dynamics, leaving the other important degrees of freedom, e.g. the lattice, nearly unexplored. In the demagnetization process, the charge, spin and lattice are strongly coupled to each other. Therefore, an explicit monitor of the concurrent lattice dynamics would be an important supplement to the optical measurements of electron and spin dynamics, and could shed new light on our understanding of ultrafast demagnetization.

Results and Discussion

By measuring the concomitant structural dynamics of ferromagnetic films at atomic level time and length scales with femtosecond electron diffraction (FED), we can address a few important issues directly related to the ultrafast demagnetization. First, the measurement of the transient thermal stress and the associated coherent lattice vibration in thin ferromagnetic metal films will allow us to determine the electronic-magnetic Grüneisen parameter $\gamma_{em}$ in ferromagnetic metals under non-equilibrium conditions. The $\gamma_{em}$ value obtained under ultrafast heating and non-equilibrium conditions carries important information on how the laser-deposited energy is redistributed among the charge, spin and lattice. If there is no significant perturbation of the spins during the electron-phonon thermalization period, the $\gamma_{em}$ value would be the same as that of the paramagnetic state. However, if the $\gamma_{em}$ value obtained by FED equals the value obtained by the traditional low temperature method, where both charge and spin degrees of freedom are involved in the thermal expansion, there must be a ultrafast perturbation of spins. That is, ultrafast concurrent heating of the spins takes place. Therefore, by measuring the $\gamma_{em}$ value under the ultrafast heating conditions, we are able to distinguish if the magnetic ordering involves or ultrafast demagnetization occurs during electron-phonon thermalization in the first couple of picoseconds after the fs optical excitation. Using FED, we obtained $\gamma_{em} = 2.0 \pm 0.3$ at a sample temperature $T = 500$ K for a 20-nm Ni thin film. This $\gamma_{em}$ value in ferromagnetic Ni matches closely to the static value of $\gamma_{em} = 2.1$ [2] obtained in low temperature measurement. More interestingly, the ferromagnetic $\gamma_{em}$ is distinct from that of $\gamma_e$ (1.4) [3] in the paramagnetic state. This implies that $\gamma_{em}$ in ferromagnetic Ni contains contributions from both electron and spin subsystems. Thus, our results show that there is indeed an ultrafast demagnetization process within the timescale of electron-phonon thermalization and confirm the earlier observations.

According to our simulation, the electron-phonon thermalization time constant ($\tau_{e-ph}$) around the Ni Curie point is strongly correlated to whether the spin and charge maintains equilibrium during the demagnetization process. Therefore, a measurement of the temperature dependence of $\tau_{e-ph}$ value will provide new insights into the mechanism of laser induced ultrafast demagnetization. Such measurements are now being conducted for nickel films.

Acknowledgements

This work is supported by the National Science Foundation by grant number DMR- 0606431.

References