Electronic Thermal Expansion in Ferromagnetic Transition Metals

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Introduction

The electronic thermal expansion in ferromagnetic transition metals and their alloys has been a subject of intensive research for many years. However, a quantitative description of the electronic thermal expansion is still lacking. This can be largely attributed to the lack of quantitative description of mechanism of magnetism in ferromagnetic transition metals at finite temperature and the scarcity of experimental measurements of electronic thermal properties at high temperatures. Here we have conducted the first measurement of electronic Grüneisen parameter γ_e of ferromagnetic transition metal nickel using femtosecond electron diffraction. This method overcomes the restriction of extremely low sample temperature demanded in traditional methods and offers a unique path to study electronic thermal expansion in magnetic metals. This measurement would serve as an important test of current models regarding the magnetism in ferromagnetic transition metals.

Results and Discussion

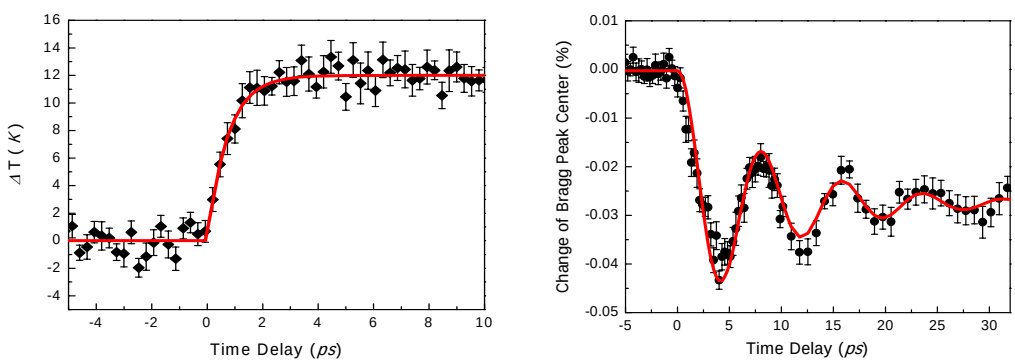

Fig. 1 Left panel: The temporal evolution of lattice temperature. The solid line is a fit to the data using an exponential function with a time constant $\tau_{e\text{-}p}$ = 820 ± 90 fs. Right panel: The temporal evolution of Bragg peak positions. The data are obtained by arithmetic averaging the vibration data of all Bragg peaks. The error bars represent one standard deviation. The solid curve is a fit to the experimental data using Equations [1] as described in the text.

The method is based on the real time probe of both thermal and coherent lattice dynamics following the fs laser excitation. By differentiating the electronic and lattice contribution to thermal expansion in the time domain, we are able to make an accurate measurement of γ_e in paramagnetic state of nickel. The value of γ_e is obtained by fitting the above coherent vibrations data to a damped harmonic oscillator driven by both lattice and electronic heating:

$$\frac{d^2Q}{dt^2} + 2\beta\frac{dQ}{dt} + \omega_0^2 Q = \gamma_e e^{-t/\tau_{e-ph}} + \gamma_l(1 - e^{-t/\tau_{e-ph}}) \qquad [1]$$

Using γ_l =1.9 measured at room temperature, we obtain γ_e=1.4 ± 0.3, where the uncertainty of 0.3 is calculated by convoluting all the errors involved in the fitting. This measurement is in excellent agreement with the calculation by ignoring the persistence of local magnetic moment in paramagnetic state of nickel. The coherence provides the experimental evidence that local magnetic moment does not contribute significantly to electronic thermal expansion in paramagnetic state of nickel and supports the calculation of electronic thermal expansion in nickel on the basis of variational theory.

Acknowledgements

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References

[1] S. Nie, *et al.*, submitted for publication.