Temperature Measurement by a Nanoscale Electron Probe Using Energy Gain and Loss Spectroscopy

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Heat dissipation in integrated nanoscale devices is a major issue that requires the development of nanoscale temperature probes. Here, we report the implementation of a method that combines electron energy gain and loss spectroscopy to provide a direct measurement of the local temperature in the nano-environment. Loss and gain peaks corresponding to an optical-phonon mode in boron nitride were measured from room temperature to ~ 1600 K. We find that both peaks present a red shift (towards lower energies) as the sample is heated up, with a linear behavior over the temperature range studied here. First-principles calculations reveal that the red shift is due to a combination of lattice thermal expansion and anharmonic phonon scattering, with the latter being the dominant factor to reduce the energy of the optical phonon as the temperature of the sample increases. The gain peak exhibits a clear increase of intensity as a function of temperature, in accordance with the occupation probability of the phonon energy state. The spectroscopy presented here shows that by detecting both gain and loss peaks, the local temperature of a material can be obtained directly by statistical principles; and in conjunction with theory, open the doors to the study of anharmonic effects in materials by directly probing phonons in the electron microscope [1,2].

[1] J.C. Idrobo, *et al.*, *Phys. Rev. Lett.* (2018), *In press*.

[2] This research was supported by the Center for Nanophase Materials Sciences, which is a DOE Office of Science User Facility (JCI & RRU), and by the Materials Sciences and Engineering Division Office of Basic Energy Sciences, U.S. Department of Energy (ARL). This research used resources of the National Energy Research Scientific Computing Center, which is supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. This work used the Extreme Science and Engineering Discovery Environment (XSEDE). Theoretical work at Vanderbilt University was supported by DOE grant DE-FG02-09ER46554 and by the McMinn Endowment (TLF, STP).