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Thermometry of Nanoparticles: Technique, Pitfalls and Challenges

Bibash Sapkota[1], Prakash Parajuli[1], Serdar Ogut[2] and Robert Klie[1]

[1]University of Illinois at Chicago, Chicago, Illinois, United States, [2]University of Illinois at Chicago, United States

According to the free electron model, the plasmon resonance energy of a material is related to the temperature through its electron density. Using this property, several studies [1-2] have shown that the nanoparticles, such as Al, or Si can be used as nanothermometers to measure the local temperature with high resolution and high accuracy. For more generalized application of such nanoparticles to measure the local temperature, it is paramount to make sure that the plasmon energy of the nanoparticles varies with temperature in a consistent manner across different experimental conditions and the effects (if present) of size, orientation, heating method etc. need to be studied thoroughly.

In present work, we will explore the potential pitfalls and challenges encountered during the high-resolution nano-thermometry by using $SrTiO_3$ nanoparticles and we will explore the effects (if present) of the particle thickness, crystal orientation and heating method on this approach of measuring the local temperature. In addition, we will also utilize a novel approach of non-contact thermometry based on the combination of low-loss electron energy-loss spectroscopy (EELS) with first principles density functional theory (DFT) modeling to measure the thermal expansion coefficient (TEC) of materials with nano-meter resolution. The approach has been well-tested on 2D materials, such as transition metal dichalcogenides (TMDs), graphene and MoS_2 by Hu *et al* [1]. In present work, we will extend the approach to $SrTiO_3$ nanoparticles to determine its TEC as a function of the temperature.

We will use the atomic-resolution imaging and electron spectroscopy technique with the help of an aberration-corrected scanning transmission electron microscope (JEOL-ARM200CF) at the University of Illinois at Chicago, equipped with a cold-field emission electron source and a Gatan Continuum Gif. The nanoparticles are heated up to 500 degree Celsius by using Protochips Fusion double-tilt stage and corresponding plasmon energies are measured.

Figure 1 shows the low-loss EEL Spectrum of SrTiO3 nanoparticles at different temperatures measured experimentally. For a 200 °C change in temperature, there plasmon peak position shifts by 100 meV. The plasmon peak of $SrTiO_3$ is fitted by the Lorentzian function to determine its center.

Figure 2 shows the fitted plasmon peak energy of $SrTiO_3$ nanoparticle as a function of temperature. The estimated plasmon peak energy, based on free electron model, is also shown as the solid line. It can be clearly seen that the experimental observations differ from the expected plasmon energy values towards lower temperatures. In current presentation, we will explore various reasons to explain this systematic deviation, including the effects of crystal orientation on the plasmon shift in addition to the effects of lens and spectrometer instabilities. [5]

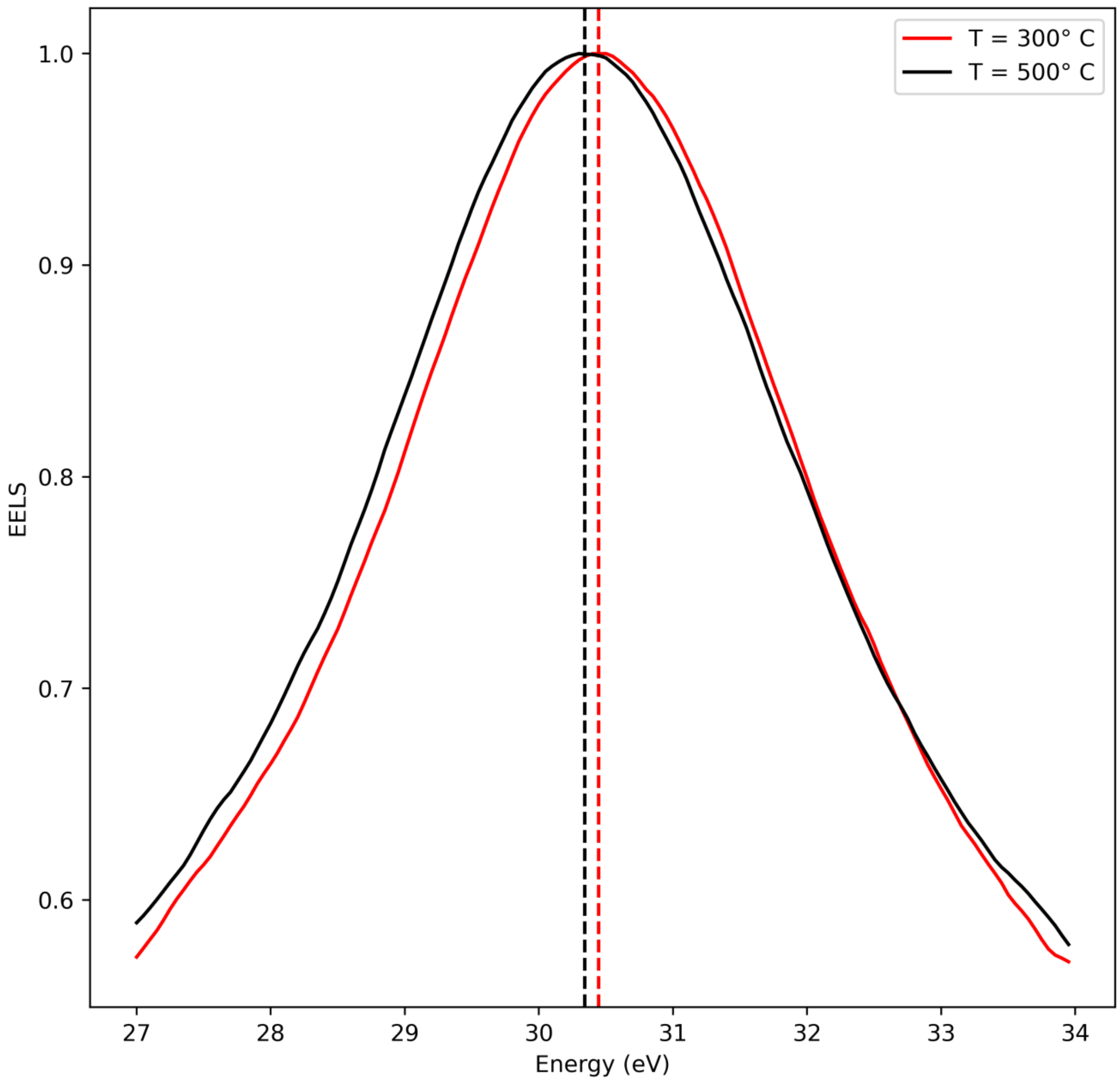

Figure 1. Figure 1: EELS of SrTiO3 at different temperatures measured experimentally. Plasmon peaks are normalized such that maximum intensity of each peak is 1. Vertical dashed lines represent plasmon peak center.

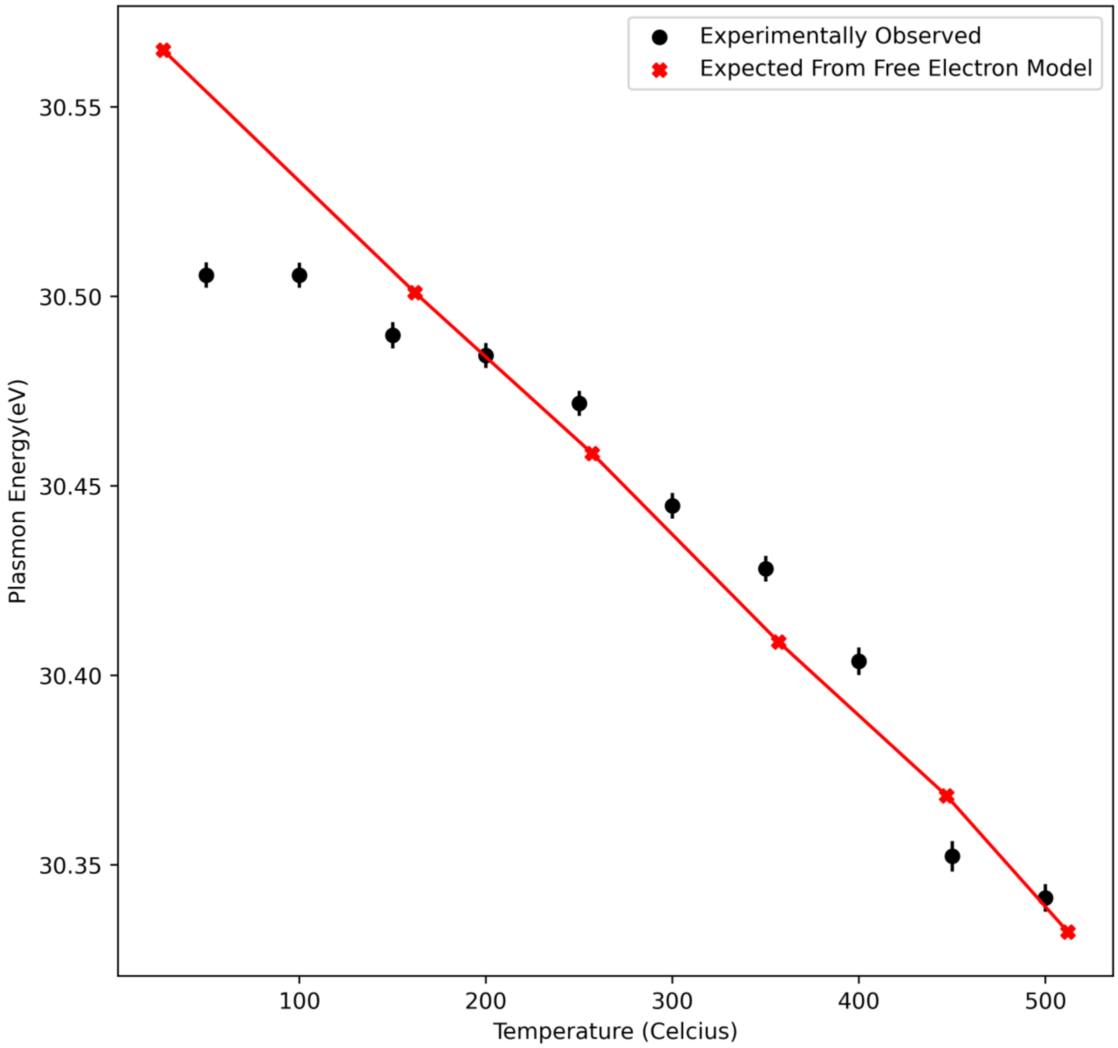

Figure 2. Figure 2: Change in plasmon energy as a function of temperature measured experimentally. Red line represents the expected value of plasmon energy of the SrTiO3 by taking plasmon energy at room temperature = 30.565 eV and using the thermal expansion coefficient values obtained from Ligny et al [4]. Black dots represent the experimentally measured plasmon energies.

References

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