A turn-key ultra-stable cryo-microscope for variable temperature applications

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A major challenge in low-temperature microscopy is the collection efficiency of radiation. The conventional approach to sample temperature control consists of a flow cryostat coupled to a long working distance objective through a vacuum window, resulting in a low numerical aperture (NA), window reflections, and mandatory corrective optics. Since the collection efficiency scales with the square of the NA, while reflections and additional corrective optical elements reduce the signal intensity, a major improvement over conventional cryo-microscopy can be achieved by incorporating an objective inside the vacuum housing, see Fig. 1. Here we describe the design and characterization of a turn-key, closed cycle, ultra-stable cryo-microscope coupled to a spectrometer, in which a 100X, 0.9 NA objective has been integrated into the sample space. With mechanical stability within tens of nanometers, fully automated closed-cycle temperature control from 4K - 350K, nanometer resolution sample translation, and unsurpassed collection efficiency over the full visible and into the near infrared spectral range, we have developed a versatile and highly efficient Cryo-microscope. To illustrate its capabilities, we collected temperature dependent Raman spectra of a bulk Bi_2Se_3 crystal. Resolving Raman signatures in these compounds typically requires long data integrations times, and therefore are compromised by noise and error. Our design emphasizes high mechanical and thermal stability, and dynamic temperature agility that significantly minimizes the time required for a full sweep, leading to good signal quality. A comparison with previous Bi_2Se_3 phonon spectra shows good agreement, and emphasizes our signal-to-noise, mechanical stability, and ease of use with minimal time required for a full temperature sweep. In addition we discuss our Raman measurements of a V_2O_3 thin film with a spectral resolution below 2 cm^{-1} and temperature resolution of 1K, shown in Fig. 2. Our data show clear evidence of a structural phase transition spread out over several degrees around 160K. Moreover, a careful comparison of warm-up and cool-down temperature sweeps shows slight hysteresis, which can be resolved only with high temperature resolution. We concentrate on Raman spectroscopy in this demonstration, however this can easily be used for stable imaging and light collection for quantum optics, chemistry, and other applications.

Figure 1. Cryo-microscope components shown designed within a low-vibration closed-cycle cryostat platform.

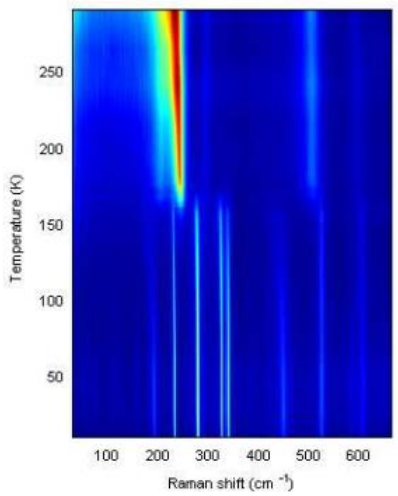

Figure 2 Contour temperature map of V_2O_3 showing a phase transition spread out around 160K with 1K resolution.