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Low-Frequency Raman Spectroscopic Methods for Characterizing Nanostructured and Nanoscale Layered Materials

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Abstract

Raman spectroscopy is a powerful technique for identifying chemicals and characterizing materials. Raman spectra can provide insight into numerous properties, including morphology, stress/strain, crystallinity, doping level, conductivity, local temperature, and polarizability, whether in bulk, thin film, monolayer or nanostructure form. Raman spectroscopy finds applications in physical sciences, life sciences, medicine, drug discovery, and semiconductor metrology. Due to instrumental limitations associated with filtering out the incident laser from being detected by the spectrometer, the Raman spectrum is typically obtained for Raman shifts of 100 cm^{-1} away from the laser up to 3500 cm^{-1}, which is more than sufficient range to capture the whole "chemical fingerprint region". Modern laser filters, based on volume holographic gratings amongst other approaches now make it relatively straightforward to obtain Raman spectra from 100 cm^{-1} down to 5 cm^{-1}. In this low-frequency spectral range, the Raman scattering is sensitive to the phonon dispersion relation and vibrational modes associated with the nanostructure of the material. Here we present the methodology and applications of Low Frequency Raman (LFR) Spectroscopy to characterize nanoscale layered materials, chiral purity of organic crystals and formulations, biomolecular assemblies, hybrid organo-metallic perovskites, and metal-organic frameworks. We show how the LFR spectrum can be related to the mechanical vibrational modes that are present at the molecular level, and discuss research on boosting the LFR signal by using nonlinear optical excitations, as well as optical microcavity resonators