

# Applications of Raman Spectroscopy in 2D Materials

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## Abstract

Raman spectroscopy has become one of the most essential and versatile characterization techniques in the study of two-dimensional (2D) materials. Its ability to probe vibrational, structural, and electronic properties with high sensitivity and spatial resolution makes it uniquely suited for investigating atomically thin systems such as graphene, transition-metal dichalcogenides (TMDs), hexagonal boron nitride (hBN), and emerging van der Waals heterostructures. Because Raman scattering responds strongly to changes in bonding, symmetry, strain, doping, defects, and layer number, it offers a rapid and non-destructive means to assess material quality and understand structure–property relationships at the nanoscale. A key application is layer-number identification, where characteristic Raman modes in graphene or in MoS<sub>2</sub>—provide precise fingerprints of monolayer, few-layer, and bulk-like behaviour. Raman spectroscopy also plays a central role in analysing strain and doping, both of which cause systematic and quantifiable shifts in phonon frequencies. This makes Raman an indispensable tool for evaluating device fabrication processes, such as lithography or transfer steps, that can unintentionally modify material properties. Raman mapping enables high-resolution visualization of defects, grain boundaries, and domain structures, supporting quality control in large-area CVD-grown materials. By examining defect-activated modes (e.g., the D-band in graphene), researchers can quantify disorder and monitor damage during processing or laser-induced modification. In TMDs, Raman scattering provides insight into exciton–phonon interactions and phase transitions, enabling characterization of semiconducting, metallic, and charge-density-wave phases. Advanced Raman techniques further expand the analytical reach. Resonance Raman enhances phonon modes associated with specific electronic transitions, offering deeper insight into band structure and excitonic states. Tip-enhanced Raman spectroscopy (TERS) enables nanoscale vibrational imaging well below the diffraction limit, allowing direct correlation of local chemistry with electronic behaviour in devices. Temperature-dependent Raman measurements are widely used to probe thermal conductivity, interlayer coupling, and anharmonic effects in ultrathin crystals.