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标题: Quasi-Free Nanoparticle Vibrations in a Highly Compressed ZrO2 Nanopowder
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摘要: Several-nanometer-size mechanical oscillators, or nanoresonators, may complement electronic and optical technologies in future terahertz devices, but they can be useful only if they can be made to have relatively light damping, that is, a quality factor as high as possible. Completely mechanically isolated nanoparticles a few nanometers in size would of course be very high-quality factor terahertz nanoresonators but would be totally unsuitable for integration into practical devices. We report the fabrication of solid-embedded nanoparticles whose natural mechanical vibrations have a usefully high quality factor. In this proof-of-concept study, a powder of approximately spherical, monodisperse 5 nm diameter ZrO2 nanoparticles is compressed to 20 GPa, whereas their mechanical vibrations are directly observed using Raman spectroscopy. Even though they are compressed very tightly in a solid, the individual nanoparticles vibrate essentially independently, being minimally coupled to their neighbors. This mechanical isolation is attributed to a subnanometer-thickness adsorbed water molecule layer, which we theoretically show to be more than sufficient to create a significant impedance mismatch. We also investigated the propagation of sound waves through the nanopowder using Brillouin scattering. The speed of long-wavelength acoustic waves is strongly dependent on the internanoparticle coupling, as revealed by the extreme variation with pressure of the speed of sound. In addition, the low-frequency Raman spectra provide an indication of the solid-state character of nanoscale ZrO2. There is a transition of the Zr-O bonds from being primarily ionic at low pressures to being primarily covalent at high pressures. Finally, a strong background in these Raman spectra is due to quasielastic scattering, which disappears at high pressure or low temperature.
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