

## In-Operando Time-resolved Vibrational Spectroscopy

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The time-resolved ultrafast nonlinear infrared (IR) spectroscopy has been contributed to studies of molecular dynamics and various chemical reactions such as energy transfer, proton hopping, protein denaturation, and chemical exchanges. With the advances in laser technology and optics, there has been improvements in spectral- and time-resolution, signal to noise ratio, and spatial resolution through adapting the development in microscopies. However, the application of advanced spectroscopies and microscopies still have been limited to studies of samples optimized for spectroscopic observation rather than function or performance of the sample. To expand the application of time-resolved vibrational spectroscopies, our group have been developing various methods to combine chemical reactor, a living cell, and electronic devices with nonlinear spectroscopies like polarization selective pump-probe (IR-PP), transient two-dimensional IR (2D-IR), time-resolved THz, IR-Vis sum-frequency generation (SFG), two-dimensional electronic spectroscopy (2D-ES).

In this talk, various nonlinear spectroscopies installed in our lab will be briefly introduced. Then, a couple of application will be discussed; 1) Observation of ultrafast intraband Auger decay in quantum dots 2) wettability of graphene and interfacial water structure observed with vibrational SFG 3) phase separation in highly concentrated aqueous electrolytes for a lithium-ion battery 4) Protein aggregation dynamics with 2D-IR.

