Broadband Room-Temperature Mid-infrared Detection with Nanoparticles

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Abstract: By utilizing ratiometric luminescence, which can be modulated at MIR radiation under ambient conditions, a novel lanthanoid nanocrystal-based transducers for broadband mid-infrared (MIR) sensing is created. The high photostability and simplicity of processing provide opportunities for developing low-cost, scalable MIR imaging and spectroscopy techniques with unprecedented sensitivity.

MIR spectroscopy is widely used in life sciences, remote sensing, security, industrial imaging, and environmental monitoring. Despite significant attempts, the development of simple, low-cost, low-noise systems for MIR detection and imaging at room temperature remains a challenge. Converting MIR radiation to visible and near-infrared regions is an ideal approach, which can be easily detected and imaged with silicon photodetectors due to their high sensitivity, low cost, and CMOS compatible. Current MIR conversion technology is limited to nonlinear optics with bulky crystals [1] or resonant nanocavities [2], which suffer from low efficiency and phase match requirement.

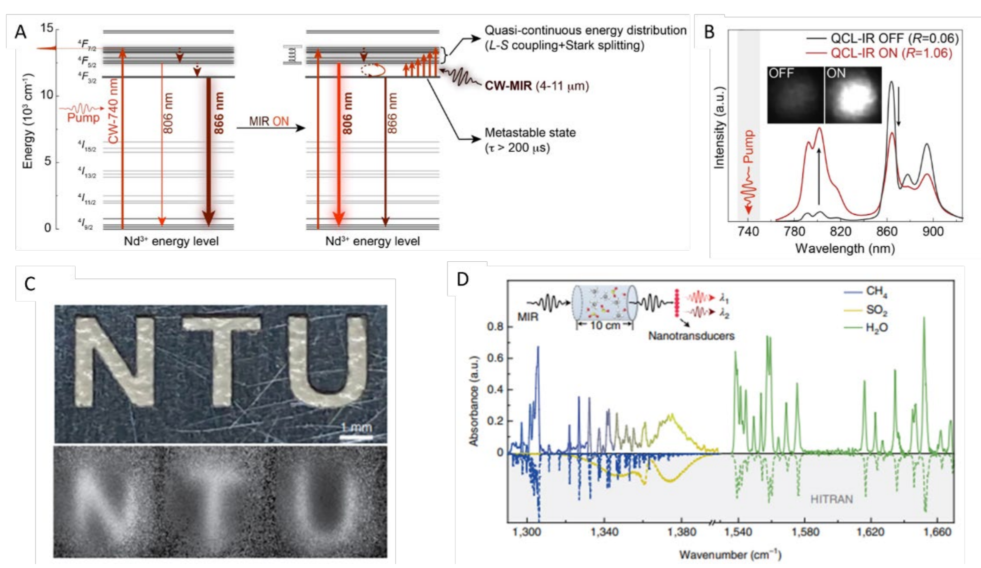

Fig. 1 (A) Working principle of broadband MIR sensing using Nd^{3+} nanotransducers. (B) Change in ratiometric luminescence nanotransducers with and without MIR radiation. (C) MIR imaging (7.3 μm) using lanthanide film captured by a CMOS camera. (D) Gas sensing for a mixture of CH_4, SO_2 and water using Nd nanotransducers. [3]

Here, we report a transducer using lanthanide nanocrystals that realize broadband MIR detection under ambient conditions. The Nd doped NaYF4 has two emission bands around 806 nm (4F5/2 → 4I9/2) and 866 nm (4F3/2 → 4I9/2), The 806 nm emission band is much weaker than that at 866 nm due to a nonradiative multiphonon-assisted depopulation process. Thanks to the ultralong luminescence lifetime of the metastable 4F3/2 state, efficient MIR back-pumping from 4F3/2 to higher energy levels (4F5/2, 4F7/2) is possible. Consequently, the emission at 806 nm enhances drastically while that at 866 nm decrease significantly. With the improved sensitivity, stability, and fast response, we further performed proof-of-principle measurements for room-temperature MIR imaging using a low-cost CMOS camera. The broadband wavelength response ensures its application for MIR spectroscopy. The absorption spectra are recorded for gas mixture of CH_4, SO_2 and water from 1290 to 1670 cm^{-1} using lanthanide transducer.

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