Tamm-plasmon-based Infrared Gas Sensor for Improved Sensitivity and Selectivity

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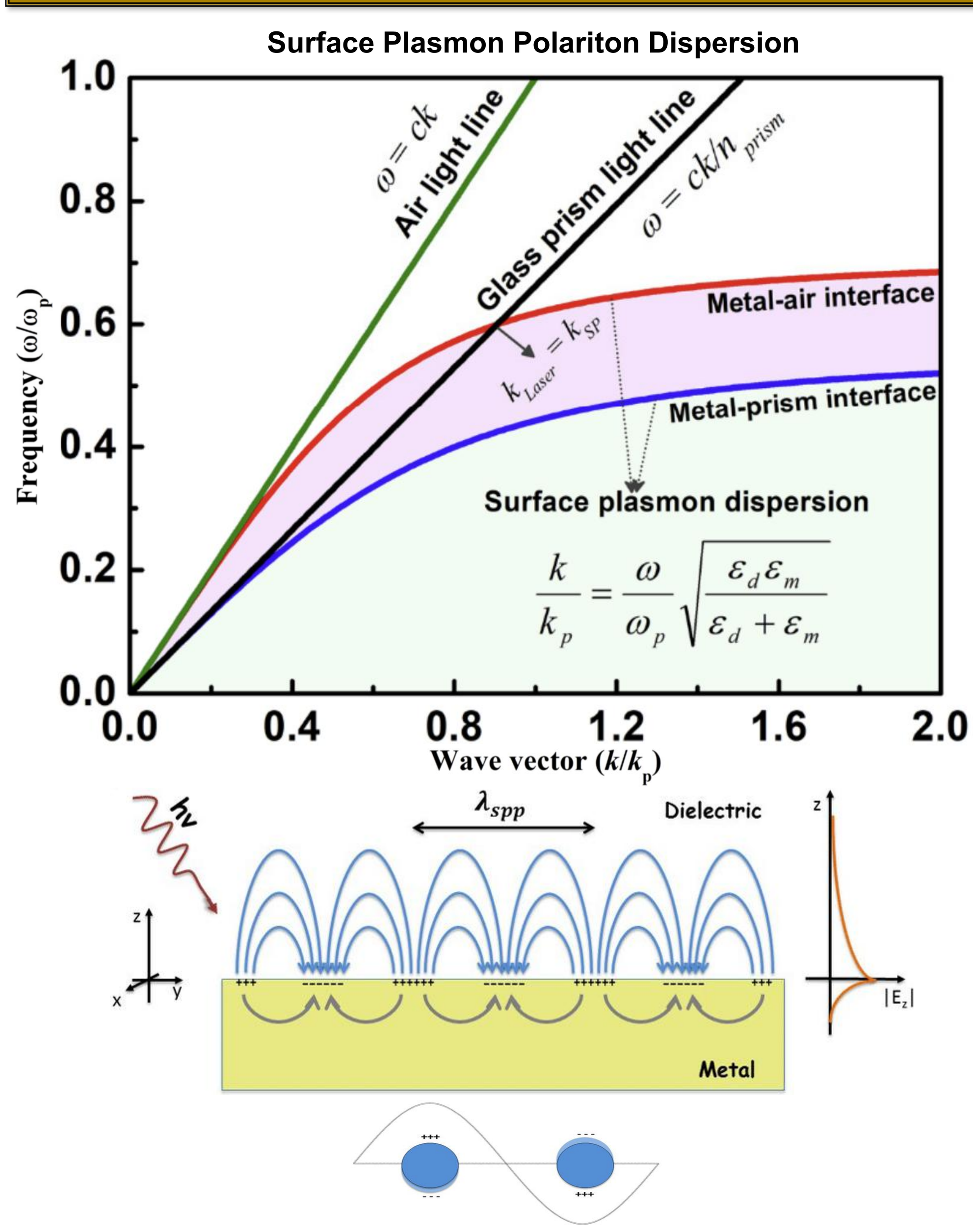
Motivation

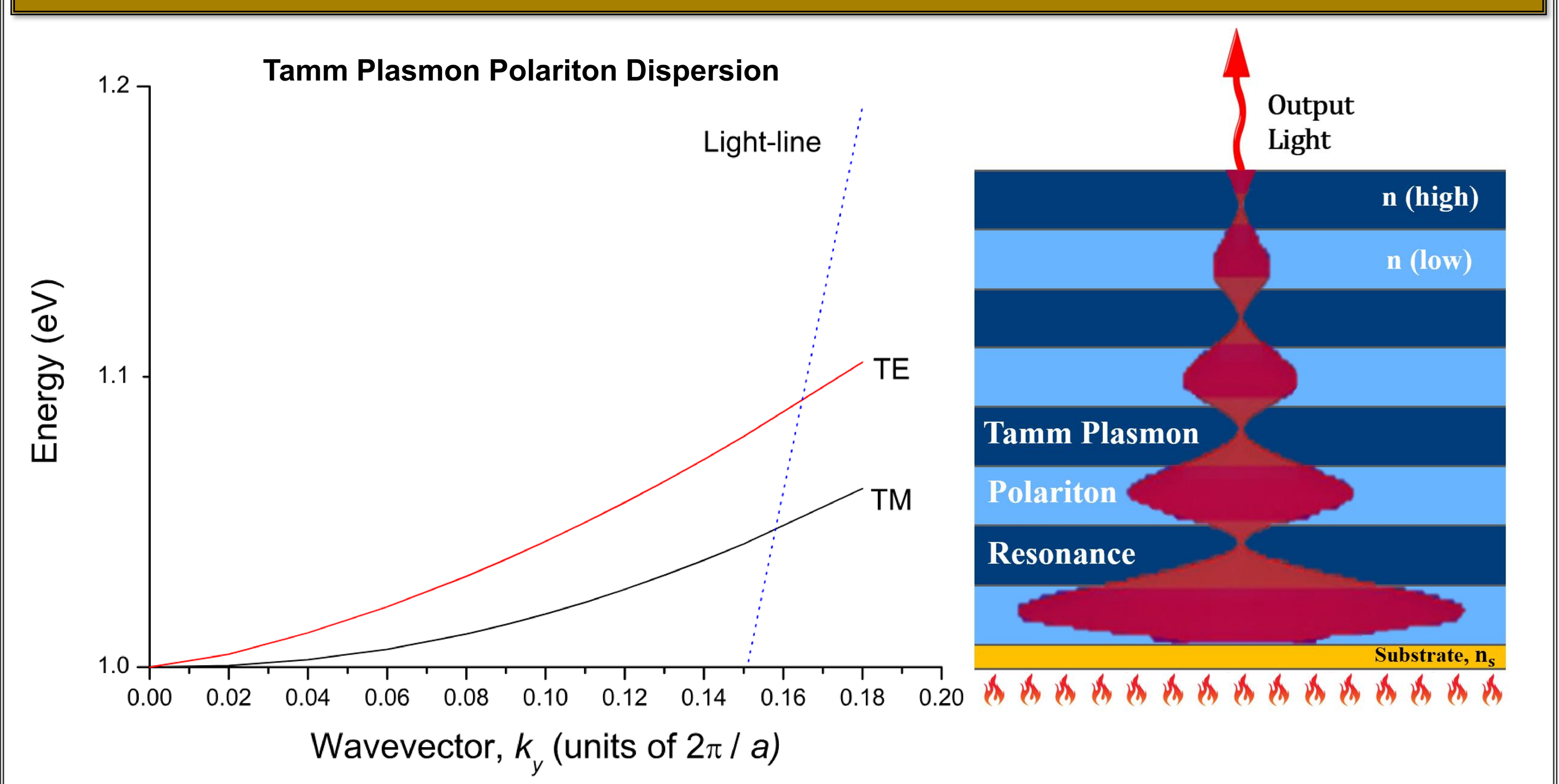
Limitations of Current Gas Sensors: Non-dispersive infrared (NDIR) sensors, a widely adopted and industry-preferred technology for gas detection, rely on narrowband filters tuned to detect a single gas.[1] Increasing sensitivity requires broadening these filters, risking false positives. Moreover, NDIR sensors cannot detect multiple gases simultaneously, therefore, requiring separate sensors for each target gas, making the approach inefficient and costly for diverse gas detection needs.

Surface Plasmon Polaritons



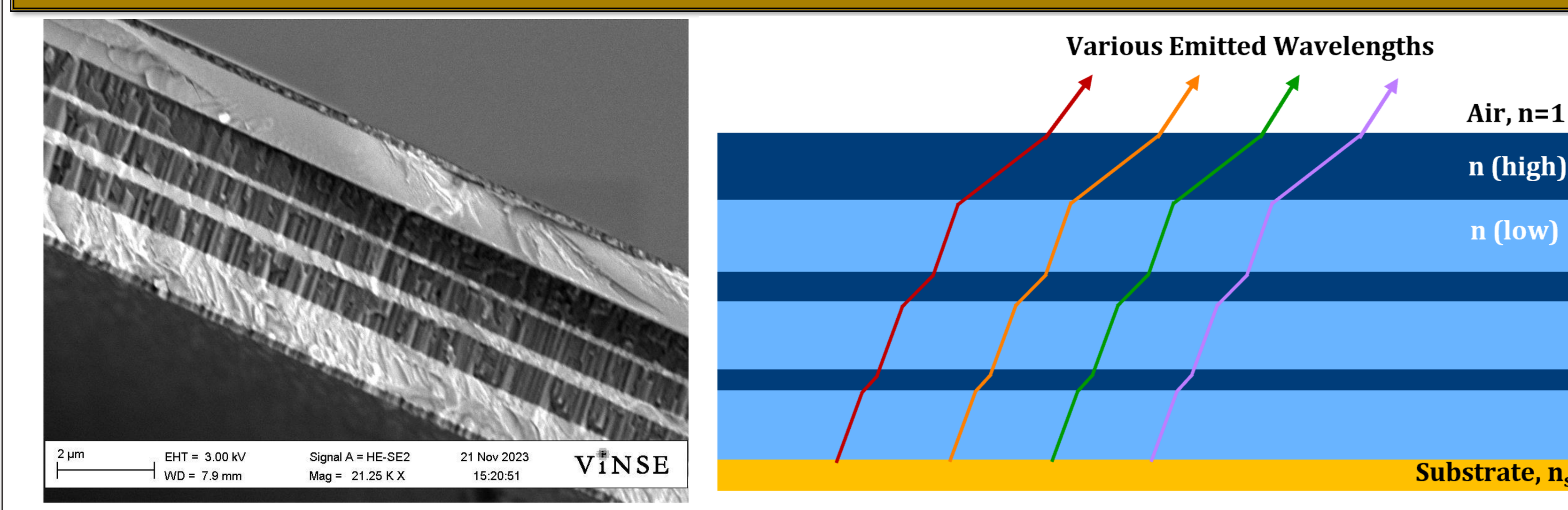
Polaritons are quasiparticles formed by light coupled with coherently oscillating charges in a material.[2] Surface plasmon polaritons (SPPs) emerge when free carriers in a conductor couple with electromagnetic waves, creating an evanescent wave that propagates along the interface between the conductor and the dielectric. Coupling photons into SPPs is difficult due to their momentum mismatch. Free-space photons lack the momentum needed to excite SPPs, especially as their dispersion deviates from the light line at higher wave vectors. This necessitates coupling mechanisms such as prisms or gratings.[3]

Tamm Plasmon Polaritons



Tamm plasmon polaritons (TPPs) occur when a SPP resonance is coupled to a wavelength matching photonic band gap of a photonic crystal. The dispersion of a TPP lies within the light cone, allowing it to be excited by both TM and TE modes ***without the use of prisms or gratings***.[4] This results in deep penetration length and optimized emission.

Aperiodic Distributed Bragg Reflector



Distributed Bragg reflectors (DBRs) are composed of alternating layers of high- and low-refractive index semiconductors, typically with quarter-wavelength thicknesses to induce constructive interference and strong reflection.[5] **Aperiodic DBRs (aDBRs)** extend this concept by varying layer thicknesses to suppress unwanted emission peaks and optimize quality factors, enabling precise control over resonant frequencies, line shapes, and spectral amplitudes while maintaining low fabrication cost and complexity through thin-film deposition alone.[6]

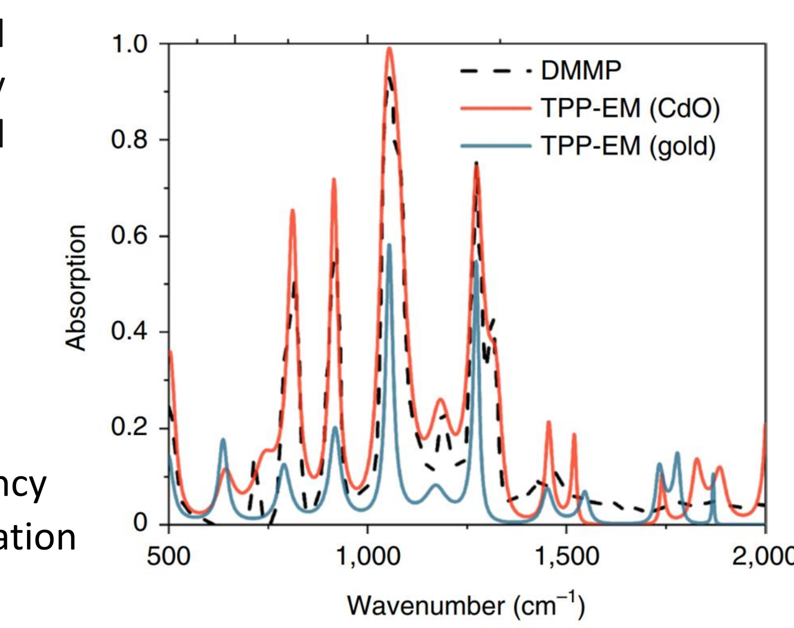
Tunability of Substrate

The aDBR is grown on a n-type, In-doped cadmium oxide (CdO) film.[7] CdO offers a broadly tunable plasma frequency, resulting in optimized spectral matching.[6]

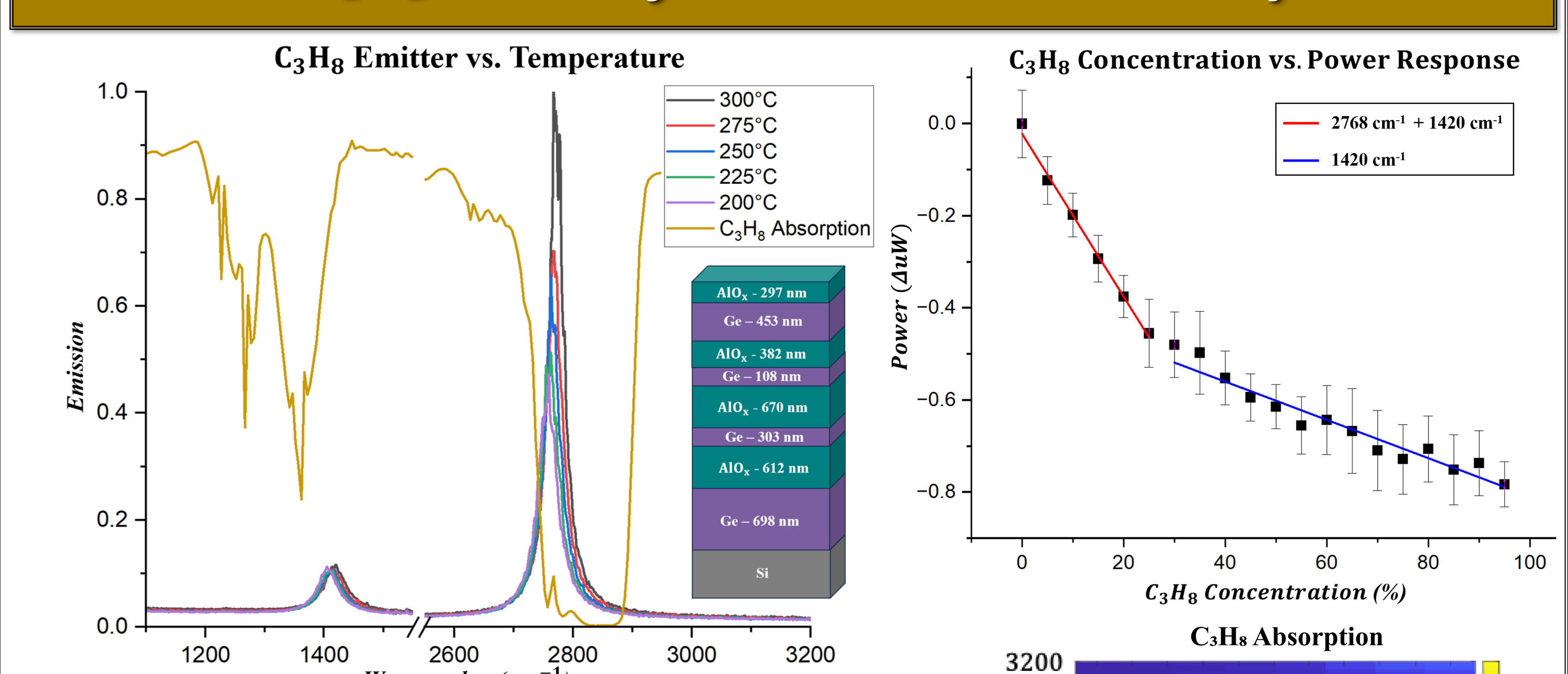
$$\varepsilon(\omega) = \varepsilon_\infty\left(1 - \frac{\omega_p^2}{\omega^2 - i\gamma\omega}\right)$$

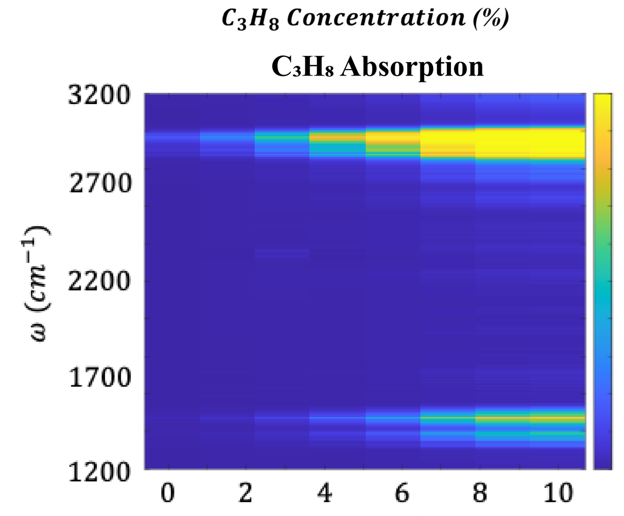
$$\omega_p = \sqrt{\frac{ne^2}{\varepsilon_0 \varepsilon_\infty m_e^*}}$$

ω_p = plasma frequency
n = carrier concentration



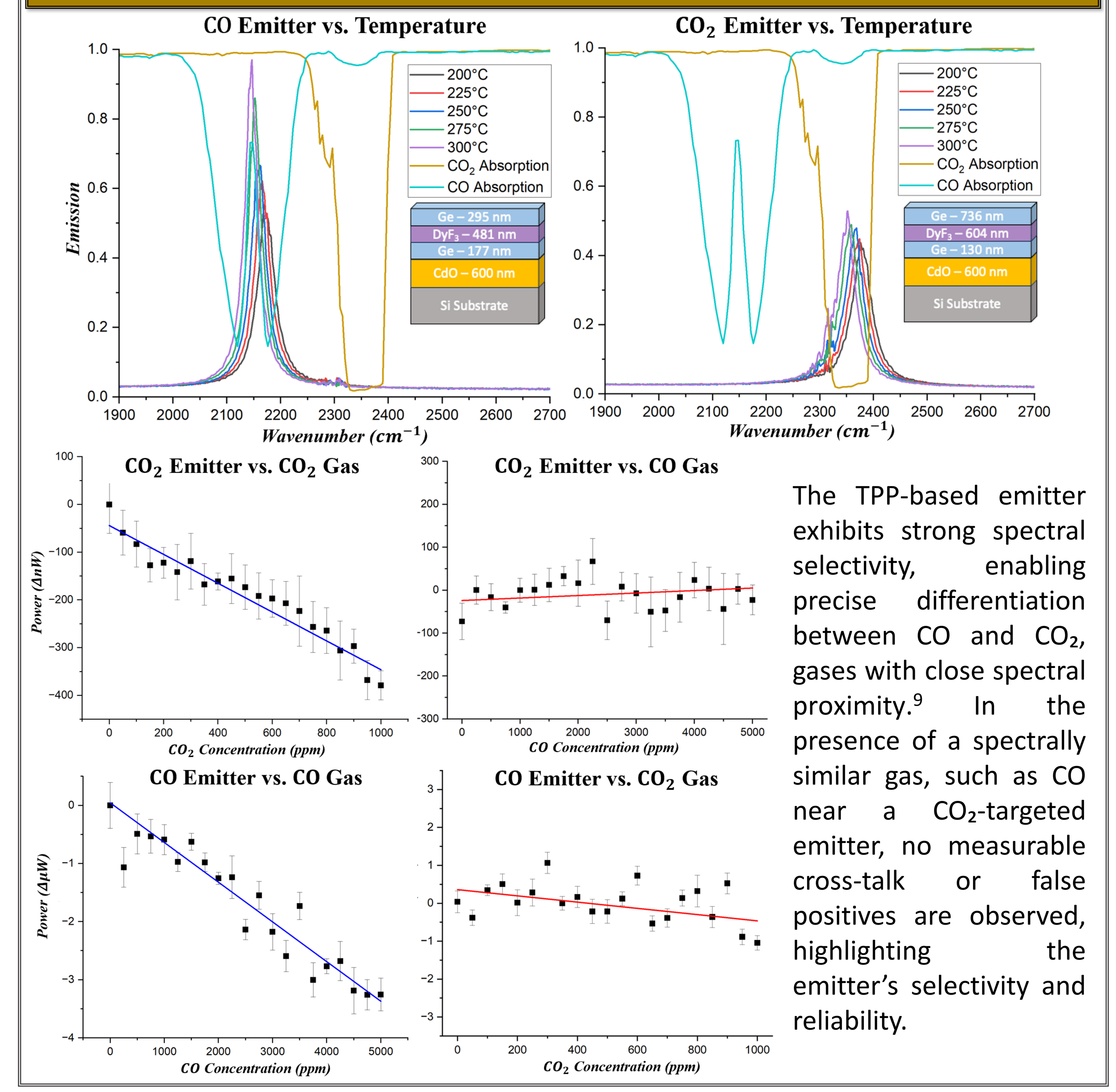
C_3H_8 Sensor for Enhanced Sensitivity





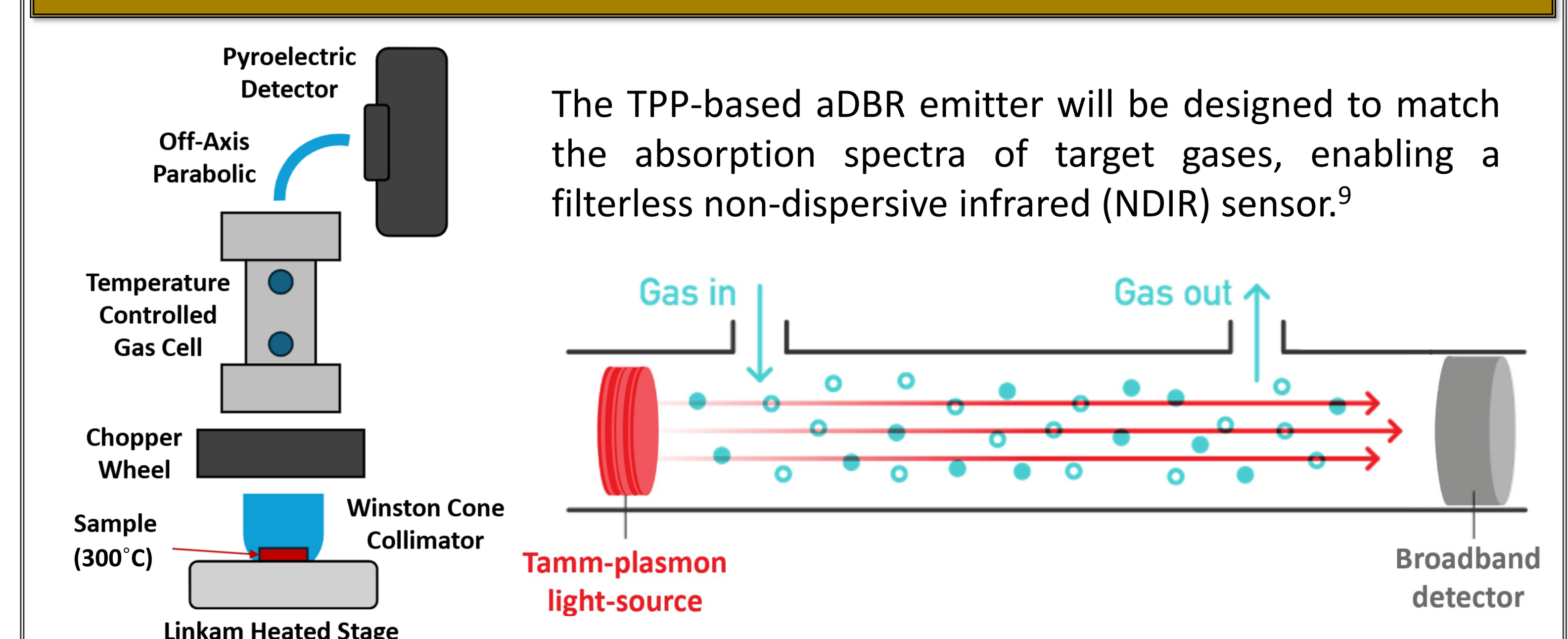
The C_3H_8 emitter showcases the advantage of multi-mode emission, significantly enhancing sensitivity by targeting multiple absorption bands simultaneously. This approach results in much higher combined absorption compared to NDIR sensors, which are limited to single-band emission[11]. By leveraging multiple vibrational modes, the propane emitter optimizes sensitivity and surpasses the limitations of traditional NDIR systems.[8]

CO & CO_2 Sensors for Enhanced Selectivity



The TPP-based emitter exhibits strong spectral selectivity, enabling precise differentiation between CO and CO_2, gases with close spectral proximity.[9] In the presence of a spectrally similar gas, such as CO near a CO_2-targeted emitter, no measurable cross-talk or false positives are observed, highlighting the emitter's selectivity and reliability.

Experimental Set Up



The TPP-based aDBR emitter will be designed to match the absorption spectra of target gases, enabling a filterless non-dispersive infrared (NDIR) sensor.[9]

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