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Determination of optical constants for Titan aerosol-, and exoplanet and brown dwarf cloud particle analogs from the visible to the far infrared

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Abstract

Here we present optical constants covering a broad wavelength range, from the visible to the far infrared, for Titan aerosol analogs produced in the Titan Haze Simulation (THS) experiment at Ames COSmIC facility, as well as other exoplanet-relevant materials.

1. Introduction

Clouds and hazes play a major role in (exo)planetary atmospheres. They can absorb and reflect light from UV to thermal infrared wavelengths, changing the atmospheric emission, reflection, and transmission spectra dramatically. Refractive indices are critical input parameters for radiative transfer models, exoplanet and brown dwarf cloud models, and other models used for the interpretation of observational data from past, current and future (exo)planetary missions. We have developed a new NIR-FIR optical constant facility that allows the optical property characterization of various inhomogeneous samples from 0.74 to 200 µm.

2. Aerosol and cloud analogs

Titan aerosol analogs (or tholins) were produced in the COSmIC/THS, a unique experimental platform developed at NASA Ames that allows the simulation of Titan's complex atmospheric chemistry at Titan-like temperature (200 K)[1,3]. COSmIC/THS uses a pulsed discharge nozzle (PDN) to generate a free jet supersonic expansion, cooling the injected gas mixture to 150 K before inducing the chemistry by plasma discharge. In this study, different gas mixtures were used: N_2/CH_4 (95:5), $N_2/CH_4/C_2H_2$ (94.5:5:0.5) as well as Ar/CH_4 (95:5) to investigate the influence of the gas composition on the optical constants. The THS tholins were deposited on Si for 10-20 hours, then their optical properties were characterized ex situ. We also initiated a study of the optical properties of ammonium-bearing phosphates, which are potential candidates for cloud particles forming in temperate exoplanets and brown dwarfs[4,5].

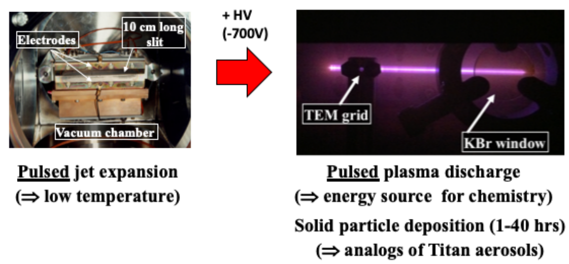

Figure 1: Pictures of the THS PDN (*left*) and plasma discharge during sample deposition (*right*).

3. Optical constant determination

The real and imaginary refractive indices, n and k, were obtained with a new optical constant facility developed at NASA Ames that allows the determination of optical constants in the infrared of various materials, analogs of hazes and cloud particles in (exo)planet atmospheres and brown dwarfs. This facility is composed of a FTIR spectrometer continuously covering the NIR to FIR range (from 0.74 to 200 µm), coupled to variable angle transmittance and reflectance accessories that allow the characterization of the scattering properties of non-homogeneous samples (laboratory planetary aerosol analogs, films, slabs of material, crystals, powders…) over a wide incidence and emittance angle range (0-90 degrees). This permits the angular light distribution in both transmission and reflection measurements to be characterized. Figure 2 shows the transmittance spectra of the N_2-CH_4 (95:5) sample obtained at different angles using the Ames optical constant facility. With this information in hand, we can begin applying the techniques of extracting the absorption coefficient α, that is related to k via the dispersion equation $\alpha=4\pi k/\lambda$, where λ is the wavelength, by describing the diffuse reflectance and transmittance in an inhomogeneous layer. Hapke[6] presents the diffusive two-stream solution to the radiative transfer equations for isotropic scattering, which have the general solutions of:

$$I_1 = \frac{1}{2}\left[A(1-\gamma)e^{-2\gamma\tau} + B(1+\gamma)e^{2\gamma\tau}\right] \quad (1)$$

and $$I_2 = \frac{1}{2}\left[A(1+\gamma)e^{-2\gamma\tau} + B(1+\gamma)e^{2\gamma\tau}\right] \quad (2)$$

where I_1 and I_2 are respectively the reflected and transmitted radiances in the layer, γ is the albedo factor ($\gamma=(1-\omega)^{1/2}$, ω is the single scattering albedo), τ is the optical depth, and A and B are constants to be determined by the boundary equations. For non-isotropic scatters γ and τ are replaced by γ^* and τ^* (Hapke[6]). These quantities are given by: $\tau^* = (1-\beta\omega)\tau$, and $\gamma^* = (1-\beta)\omega / (1-\beta\omega)$, where β is the asymmetry factor. The complex refractive indices are incorporated into both τ and ω. We extract their values by calculating the reflected and transmitted spectra of the samples and comparing them to the measured values using a least-squares technique. Both n, and k, are iteratively changed until the measured and calculated values agree enabling the determination of the complex indices of refraction over the full NIR-FIR range. The optical constants were determined in the visible by Filmetrics using an F40 microscope.

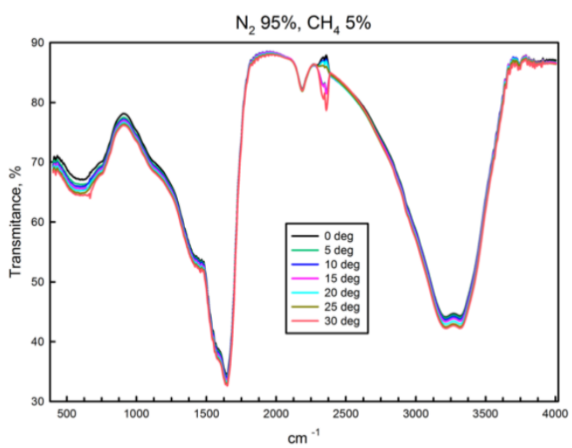

Figure 2: Transmittance spectra of the N_2-CH_4 (95:5) obtained at different angles. (NB: contribution from gaseous CO_2 from the FTIR spectrometer purge can be seen around 680, 2300 and 3400-3800 cm^{-1}).

Acknowledgements

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