



Effects of viewing geometry on thermal infrared spectra of planetary surfaces: The case of enstatite

L.V. Moroz (1,2) and U. Schade (3)

(1) Institute of Planetology, WWU, Münster, Germany, (2) Institute of Planetary Research, DLR, Berlin, Germany, (3) Helmholtz Centre Berlin for Materials and Energy, BESSY II, Berlin, Germany (Ljuba.Moroz@dlr.de / Fax: +49-30-670-55-303)

Abstract

We discuss thermal infrared (TIR) spectral reflectance properties of pure enstatite single crystals and powders as a function of incidence angle. Using this example, we demonstrate that the viewing geometry together with crystal anisotropy may significantly affect the shapes and positions of diagnostic TIR spectral signatures. These effects should not be neglected in analysis of remote sensing spectra.

1. Introduction

An increasing number of space missions and space telescopes are equipped with spectrometers operating in the TIR. For example, the TES instrument aboard MGS and mini-TES instruments onboard MERS Spirit and Opportunity enriched our knowledge of Mars' surface mineralogy; the MERTIS spectrometer onboard the BepiColombo MPO spacecraft will map Mercury in the thermal infrared. In this spectral range, silicate spectra show diagnostic signatures – Christiansen features, Reststrahlen bands – associated with fundamental Si-O vibrational modes. Laboratory emission and reflectance spectra of minerals and rocks provide ground truth for analysis of remote sensing data. However, effects of viewing geometry on TIR spectra are poorly understood and usually ignored. Here we will use the detailed analysis of measured and calculated spectra of enstatite to show how viewing geometry may affect positions and shapes of diagnostic Christiansen features and adjacent Reststrahlen bands (or emissivity minima). Enstatite is a Mg-rich low-Ca pyroxene, which usually crystallizes in orthorhombic system. Together with other pyroxenes, it is a common rock-forming mineral of terrestrial planets, their moons, asteroids, meteorites and cometary dust.

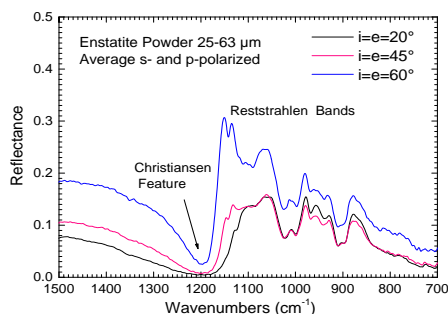


Figure 1: Biconical reflectance spectra of wet-sieved enstatite powder. Note the significant change in the appearance of the Christiansen feature and the adjacent Reststrahlen bands with increasing angle of incidence.

2. Procedures

We used a BRUKER VERTEX 80v FTIR-spectrometer and a Seagull™ variable angle reflectance accessory (BESSY II, Berlin) to acquire biconical IR spectra of pure enstatite single crystals and powders as a function of incidence angle. Orientations of the crystals were determined by x-ray diffraction and optical goniometry. Three planes perpendicular to a-, b-, and c-axes were saw-cut and subsequently polished. TIR reflectance spectra for p- and s-polarization as well as unpolarized spectra were acquired for powders and for each crystal plane at angles of incidence between 5° and 60°. Complex optical constants for a-, b-, and c-axes were derived and used to calculate specular reflectance for different angles of incidence and crystallographic planes, using the Fresnel equations for anisotropic media. The calculated spectra fit well the measured data set.

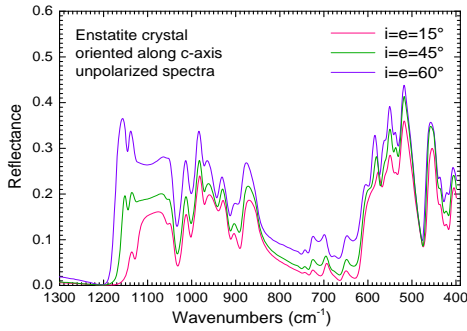


Figure 2: TIR reflectance spectra of an uncut single enstatite crystal. Note the significant change in shapes and positions of the Christiansen feature and the adjacent Reststrahlen bands with increasing angle of incidence.

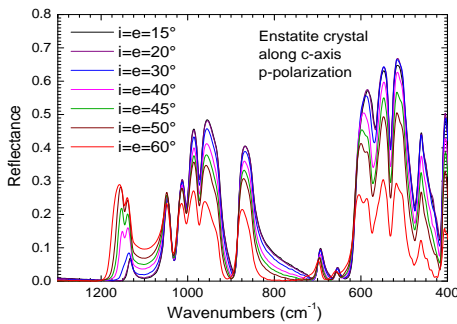


Figure 3: Reflectance spectra of an uncut single enstatite crystal for p-polarization. At low phase angles, the spectra are dominated by Si-O vibrations along the c-axis. With increasing angle of incidence, (1) specular reflectance peaks in the vicinity of Christiansen frequency undergo significant increase in intensity and move to higher frequencies (shorter wavelengths); (2) contribution from Si-O vibrations along the a- and b-axes increases for this particular crystal orientation.

3. Results and Conclusions

Our results show that the spectroscopic geometry together with the crystal anisotropy can cause

significant changes in the shapes and positions of Christiansen features and the Reststrahlen bands in their vicinities (e.g., Figs. 1, 2, 3). The observed geometry-related effects are equally applicable to TIR emissivity data [e.g., 1]. This means that only laboratory reflectance or emission spectra measured at relatively low incidence/emission angles should be used to analyze nadir remote TIR emission data. For example, reported discrepancies between measured nadir emission spectra and laboratory biconical reflectance data are associated with the unsuitable spectroscopic geometry of some biconical attachments, while biconical reflectance spectra of powders, acquired at low angles of incidence reasonably reproduce measured normal emissivity via Kirchhoff's law [2]. On the other hand, remote sensing TIR spectra taken at grazing angles of emission should be analyzed using the reflectance or emission lab spectra measured at suitably high angles of incidence/emittance. Otherwise, the distinct emission minima (corresponding to the reflectance maxima in Fig. 1) at $\sim 1150 \text{ cm}^{-1}$ ($\sim 8.7 \mu\text{m}$) in TIR spectra of a remotely-sensed pyroxene-rich rock or regolith at grazing emission angle would be misinterpreted as the indication for some additional (unknown) mineral. Our laboratory measurements of powdered and polished glasses and some scarce published data [3] show that TIR spectra of isotropic phases (e.g., silicate glasses) are also strongly affected by viewing geometry.

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