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# The Optical Constant of Crystalline Spinel

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**Abstract.** For the natural and synthetic crystalline spinel ($MgAl_2O_4$), the mass absorption spectra of the fine particles and the reflectance of the bulk crystals were measured in the mid- and far-infrared region. The absorption spectra showed the prominent peaks at 14.7, 19.7 and 32.4$\mu$m. The reflectance also showed three features at 13.8, 18.5 and 32.4$\mu$m. From the reflectance, the optical constants $(n, k)$ were derived on the natural spinels.

## 1. Introduction

The ISO SWS/LWS observations revealed the existence of the considerably large amount of the solid-state materials such as crystalline silicate and water ice in the circumstellar envelope of the oxygen rich young and evolved stars (Waters et al. 1996; Waelkens et al. 1996; Whittet et al. 1996; Malfait et al. 1998). These revolutionary results allowed us to study astronomy by means of a manner of material science. Especially the discovery of the crystalline silicate provided us a fundamental clue to understand the planet formation within the framework of the thermodynamic equilibrium condensation (Grossman & Larimer 1974). The precise laboratory data of the high temperature condensation materials are essential to solve the puzzle of the grain formation in the circumstellar disk and/or the early stage of the proto planetary disks.

Magnesium aluminum spinel ($MgAl_2O_4$) is one of the high temperature condensation species. Spinel is condensed at relatively high temperature 2378K $\sim$ 2408K (Alper et al. 1962; Roy & Hastert 1983) in the early stage of the thermodynamic condensation sequence (Tielens et al. 1998) and occurs in CAIs (Calcium and Aluminium Inclusions) in the primitive carbonaceous chondrite. The structure of spinel is face-centered cubic, and its chemical composition is expressed as $MgO \times m\ Al_2O_3$, where the $m$ varying between 0.9 and 4 in general.

Tropf & Thomas (1991) reviewed the optical constants for this species. In the astronomical context, it was discussed as a candidate for the carrier of the 13$\mu$m feature in a recent paper (Posch et al. 1999) from the observational point of view. In the field relevant to astrophysics, however, few accessible optical constants of this species exist. The precise data set in a wide wavelength range has been required. In this work, we report the measurement of the optical quantities of the crystalline spinel in the mid- and far-infrared region for the stoichiometric natural samples and a non-stoichiometric synthetic sample.

## 2. Experimental

The measured samples in this work were two natural crystalline minerals such as white spinel from Burma and pink spinel from Sri Lanka and a spinel synthesized with Verneuil method. The natural samples are almost stoichiometric, but the pink spinel includes very small amount of Cr ($\leq 0.5\%$) which is responsible for the pink coloration. The synthetic spinel was slightly $Al_2O_3$ rich ($m \approx 2$).

The mass absorption spectra and the reflectance were obtained with a Jasco-FT/IR-350 spectrometer (Kyoto Pharmaceutical Univ.) at resolution of 0.5 $cm^{-1}$ and 1.0 $cm^{-1}$ , respectively. For the mass absorption spectra, the bulk crystals were crushed and ground in a WC mortar. These fine particles sized less than $1\mu$m were dispersed in polyethylene and KBr matrix for far-IR and mid-IR measurements, respectively. For the measurement of the reflectance, the bulk crystals were cut and polished. The areas of the cross section of the surface are above $10mm^2$. The polarizer was not used because the optical properties of spinel is isotropic due to its cubic structure. The wavelength ranges were $6 \sim 50\mu$m for the mass absorption spectra and $1.5 \sim 100\mu$m for the reflectance.

## 3. Results

The mass absorption spectra and the reflectances for all samples are shown in Figure 1 and Figure 2, respectively. The natural samples (white- and pink-spinel) have three strong absorption bands at 14.8, 19.7 and 32.4 $\mu$m. The broad bands around $40\mu$m are artifacts due to the interference fringes. The significant discrepancy between two natural samples is not detected. Therefore the effect of Cr in pink spinel can be negligible. In the reflectance, there are also three prominent features at 13.7, 18.5 and $32.4\mu$m. Moreover, the small features and shoulders occur at 12.0, 17.0 and 20.8 $\mu$m. Small band at around $7\mu$m is detected in the absorption spectra, but it is not detected in the reflectance.

While for the synthetic spinel, four broad bands are detected at 12.1, 14.6, 18.8 and 31.8 $\mu$m in the mass absorption spectrum. The reflectance features are also different from the natural samples; the intermediate features are detected at 11.9, 14.0 and 18.4 $\mu$m. In the case of the non-stoichiometric spinel, the lattice defect tends to be occurred because of the enrichment of the $Al_2O_3$. It is difficult to synthesize the spinel stoichiometrically, in general. Therefore, the lattice structure of the synthetic spinel is apt to be an amorphous like. As a result, the absorption spectrum and the reflectance of synthetic spinel show broad features. The peak positions are summarized in Table 1 for all the samples.

For the natural crystalline samples, the reflectances were fitted with the multiple oscillator model (e.g. Bohren & Huffman 1983) in order to obtain the optical constants, $(n, k)$. The measured reflectances and the fitted results plotted in Figure 2(a) and 2(b) for the pink- and the white-spinel, respectively. From the fitted curves, the optical constants are derived in the wavelength range between

Table 1. The band positions for all samples ($\mu$m). The characters A. and R. mean the absorption spectra and the reflectance, respectively. The prominent peaks are emphasized by underlines.

| pink spinel | | white spinel | | synthetic spinel | |
|---|---|---|---|---|---|
| A. | R. | A. | R. | A. | R. |
| <u>32.4</u> | <u>32.4</u> | <u>32.4</u> | <u>32.4</u> | 31.8 | 32.3 |
| | 20.8 | | 20.7 | | |
| <u>19.6</u> | <u>18.4</u> | <u>19.8</u> | <u>18.6</u> | 18.8 | 18.4 |
| 17.3 | 17.0 | 17.3 | 17.1 | | |
| <u>14.7</u> | <u>13.7</u> | <u>14.8</u> | <u>13.8</u> | 14.6 | 14.0 |
| 13.1 | 12.0 | 13.2 | 12.1 | 12.1 | 11.9 |
| 11.4 | | 11.3 | | 11.3 | 11.2 |
| 7.2 | | 7.2 | | 7.2 | |

7$\mu$m and 90$\mu$m. Figure 3(a) and 3(b) show the optical constants $(n, k)$ for the pink- and the white-spinel, respectively. Our results are roughly consistent with the optical constants in Tropf & Thomas (1991). However, our data set shows the features more clearly and sharply, because the measurements were carried out at high resolution. Moreover, the strength of the prominent features approximately 10% larger, and the some small features are detected at 12.0, 17.0 and 20.8$\mu$m in our data.

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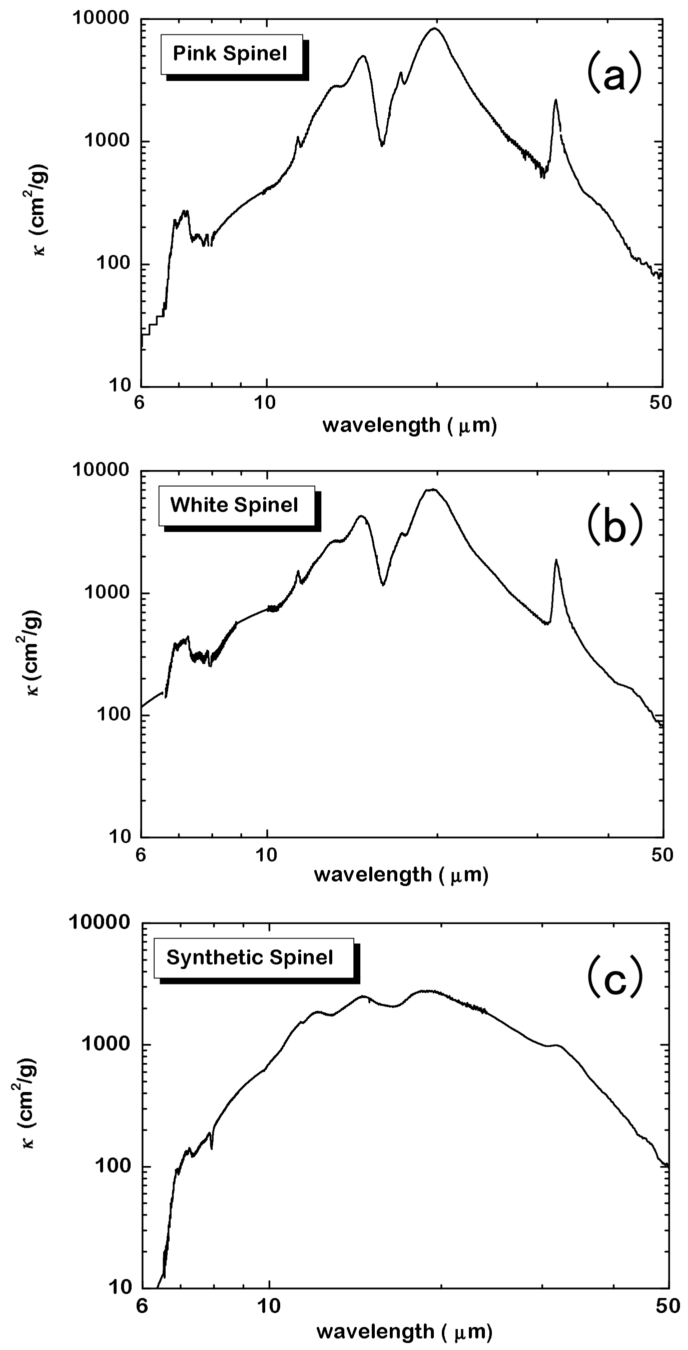


Figure 1. The mass absorption spectra for all the samples. (a) pink spinel (b) white spinel (c) synthetic spinel

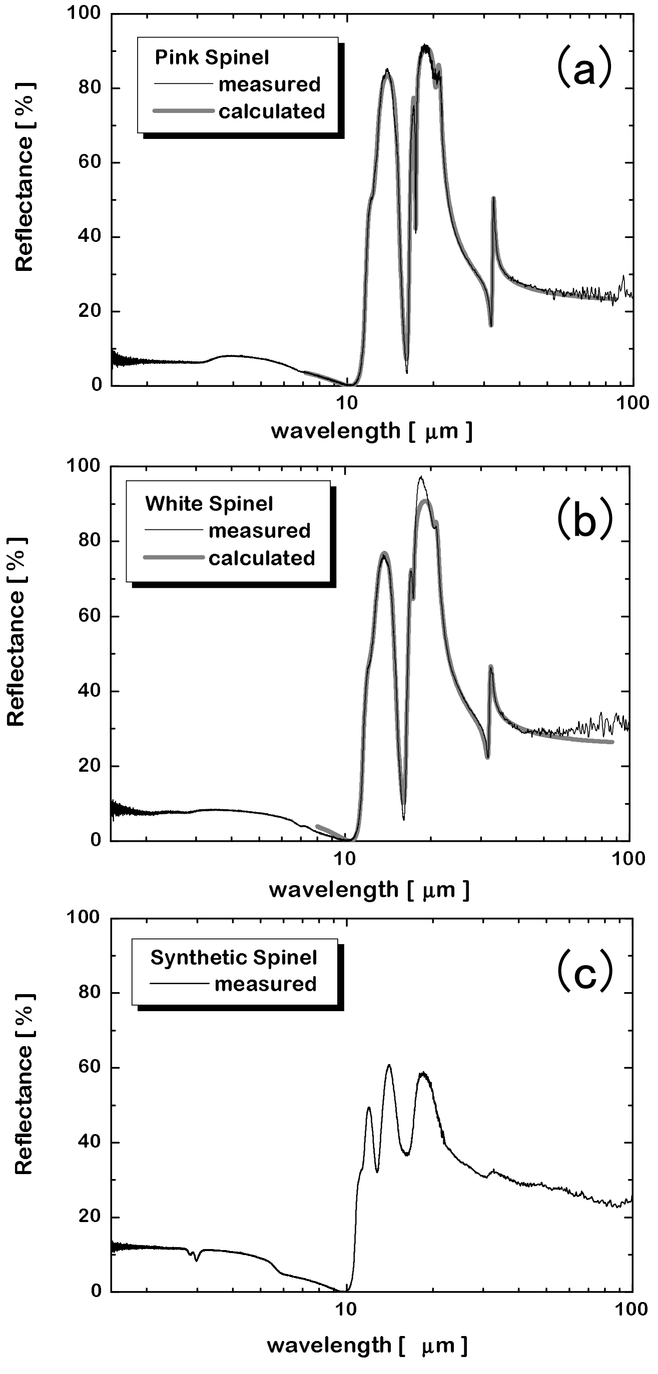


Figure 2. The reflectances for all the samples. For the natural crystalline spinels, the fitted curves are superposed. The solid lines indicate the measured spectra and the gray lines indicate the fitted curves. (a) pink spinel (b) white spinel (c) synthetic spinel

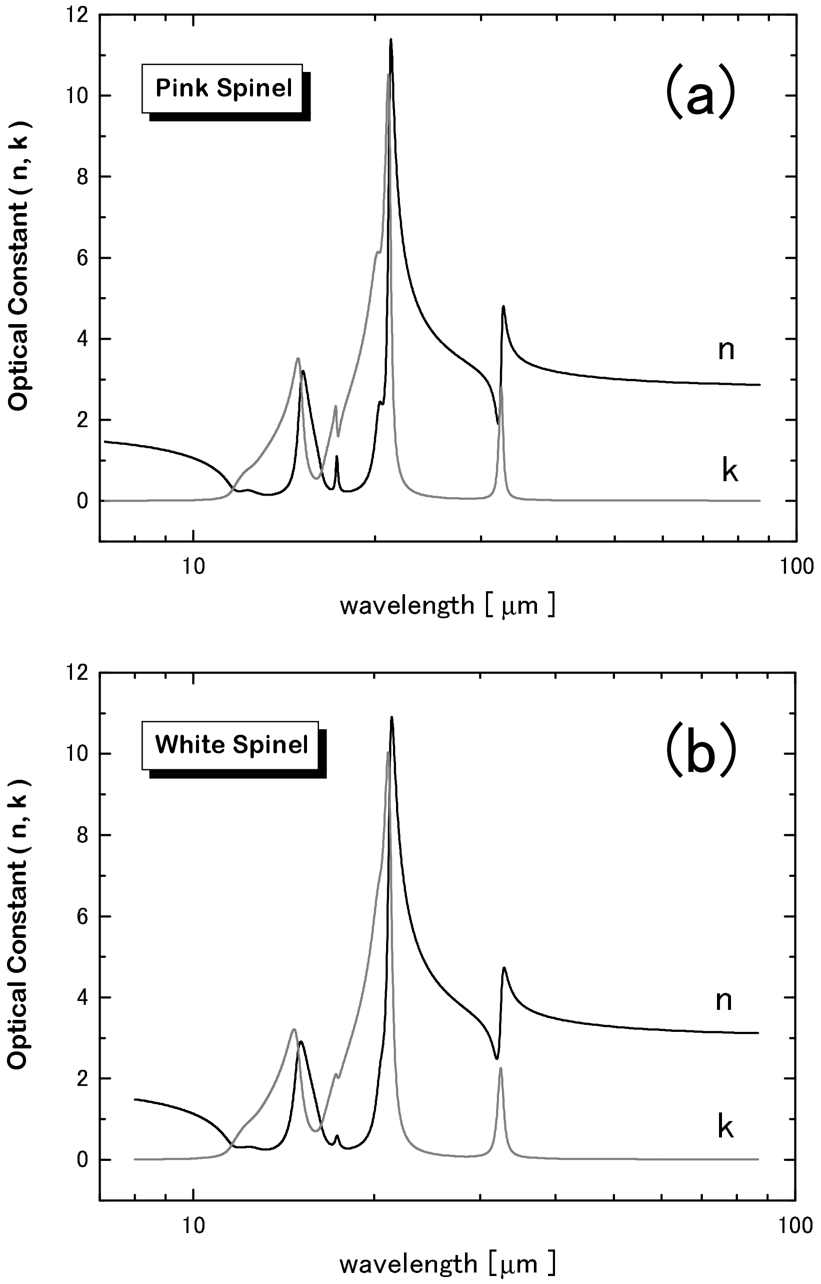


Figure 3. The optical constants $(n, k)$ for the natural spinels. (a) pink spinel (b) white spinel