AN INTEGRATED MODEL UTILIZING THE MODIFIED GAUSSIAN MODEL, A MINERAL-MIXING MODEL, AND A SPACE-WEATHERING MODEL. T. Nimura[1,2], T. Hiroi[3], and C. M. Pieters[3], [1]Dept. of Earth & Planet. Sci., Univ. of Tokyo 113, Japan, [2]JAXA Inst. of Space & Aeronautical Sci., 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan. (nimura@planeta.sci.isas.jaxa.jp), [3]Dept. of Geological Sci., Brown Univ., Providence, RI02912, USA.

Introduction: Visible and near-infrared reflectance spectroscopy has been a useful method for remotely detecting mineralogy of planetary surface materials. However, There are two problems whitch exist in this analysis. (1) In the case of airless bodies, space weathering effects may be so strong that their surface reflectance spectra show reddened continua, lowered albedos, and attenuated absorption features (e.g., [1]). Thus, it is more difficult to use important diagnostic features for detecting component minerals and their chemical compositions. (2) In the surface reflectance spectra of planets, we often fined a composite absorption band due to the component silicates. As a method of deconvolvig this complex absorption band into those of its component minerals, modified Gaussian model (MGM) is used as a standard ways [2]. However, each mineral species usually has multiple bands which overlap with one another and those of other minerals, making it difficult to assign the deconvolved bands into individual mineral components. The purpose of this study is to solve these two problems.

Space Weathering Model: One form of space weathering products is a vapor coating containing nanophase reduced iron ($npFe^0$) particles around each regolith particle. Transmission electron microscope (TEM) images show the details of layering of $npFe^0$ along the rims of lunar soil grains [3, 4, 5]. Simulation of micrometeorite bombardment has been proven to form a vapor deposited layer containing $npFe^0$ particles [6]. Hapke (2001) modeled the optical effect of $npFe^0$ particles in a semi-transparent matrix [7]. We has introduced that an improved version of this Hapke's model [8].

The basic scheme of our model is depicted in Fig. 1. Each regolith particle consists of a host mineral of d_h in diameter, covered with a vapor coating layer of d_w in thickness, containing $npFe^0$ particles by a volume fraction of ϕ_w. They are formed in an amorphous matrix having an assumed refractive index (the real part n_h only). Real and imaginary refractive indices n_w and k_w of that layer are calculated based on Hapke's space weathering model [7]. Wavelength-dependent refractive indices of Fe were taken [9] and linear interpolation and extrapolation were performed to cover the necessary wavelength range. Then the absorption coefficient of the vapor coating layer given by:

$$\alpha_w = 4\pi k_w/\lambda \,, \quad (1)$$

where λ is wavelength. We created an improved model for this space weathering process, accounting for its effect on the boundary reflectivity of regolith particles, and applied it to reflectance spectra of lunar soils. A new scheme of applying Hapke's space weathering model has been proposed which accounts for the change in surface reflectivity of a vapor-coated particle. This model can provide reasonable estimates of the total amount of $npFe^0$ particles formed in the coating layer, as well as the absorption coefficient spectrum of the host material fit for analyzing its composition.

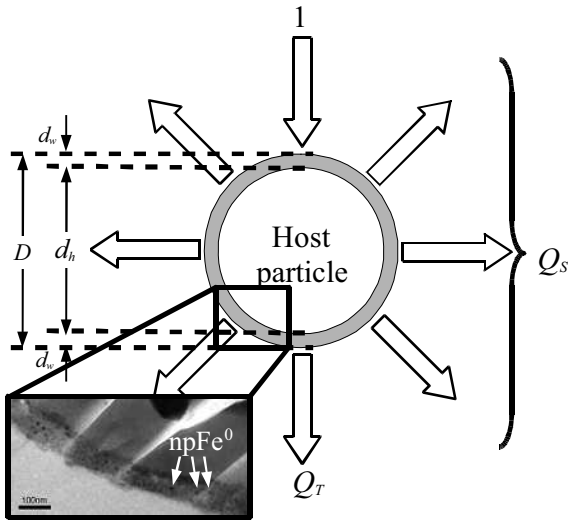

Fig. 1. A schematic view of a space-weathered particle, wherein D, d_h, and d_w denote diameters of the whole particle, the host particle, and the weathering layer, respectively, and a TEM bright-field image of a lunar plagioclase grain with a $npFe^0$-rich coating [10]. Q_S and Q_T denote scattering and transmitting efficiencies, respectively.

The Modified Gaussian Model and a Mineral-Mixing Model that Considers Mineral Bands: In MGM [2], natural log of each reflectance spectrum is modeled as:

$$\alpha(\lambda) = c_0 + c_1/\lambda + \sum_i^N s_i \exp\left[-\frac{(\lambda-\mu_i)^2}{2\sigma_i^2}\right], \quad (2)$$

where λ denotes wavelength, α(λ) is absorption coefficient at wavelength λ, and *s*, μ and σ are band strength, center, and width, respectively. Defining each absorption band requires those three parameters. The suffix (i = 1~N) indicates the band number. For example, in case of olivine, there are three bands, making the number of parameters 11 (3×3+2) in Equation (2). Because the relationship between the chemical composition and absorption band characteristics of some minerals are known to some extent, it is expected that the above problem can be solved by utilizing such knowledge. Especially, absorption bands of olivine and pyroxene are studied relatively well [11, 12]. In this study, we investigated a relationships between the Fe content and band center, band width and relative strength of olivine and pyroxene and decided band center and width of plagioclase. Reflectance spectra were taken from [11, 12] and some data (e.g., RELAB). This relationship are utilized in our MGM calculation.

In case of olivine, we model each relationship between the Fa value and the band centers of absorption bands using a linear function:

$$\mu_i = M_i \cdot Fa + N_i, \quad (3)$$

where M_i and N_i are constants, and the subscript *i* indicates the band number. Equation (3) enables us to obtain three band center values from just one Fa value. The band widths of the three absorption bands are modeled a linear function:

$$\sigma_i = X_i \cdot Fa + Y_i, \quad (4)$$

where X_i and Y_i are constants, and the subscript *i* indicates the band number. Equation (4) enables us to obtain three band width values from just one Fa value. The band 1 and 2 strength relative to the band 3 strength seems to change linearly along with the Fa value such as:

$$\frac{s_i}{s_3} = A_i \cdot Fa + B_i, \quad (5)$$

where *A*, *B*, *C*, and *D* are constants. Equation (5) shows that three strength parameters can be expressed by one for a given Fa value. Based on Equations (2)~(5), We can model each olivine spectrum using, instead of 11 variables, only 4 variables c_0, c_1, Fa, and s_3, and 16 constants M_i, N_i, X_i, Y_i (i=1~3), and A_i, and B_i (*i*=1~2).

An integrated Model and Future Improvements: One of the example analyses of Apollo sample (61221) is depicted Fig. 2. This scheme can produce the correct features of absorption band due to the component silicates. An integrated model utilizing the modified Gaussian model, a mineral-mixing model, and a space weathering model give degree of space weathering, mineral and chemical composition, structure of the regolith particles, and mixing ratio of minerals in the regolith. Future improvements are expected to increase its usefulness, for laboratory determination, ground-based observation, and future lunar missions equipped with a spectrometer with a wide wavelength range and high spectral resolution, such as the Spectral Profiler onboard SELENE/KAGUYA and the M^3 onboard Chandrayaan-1.

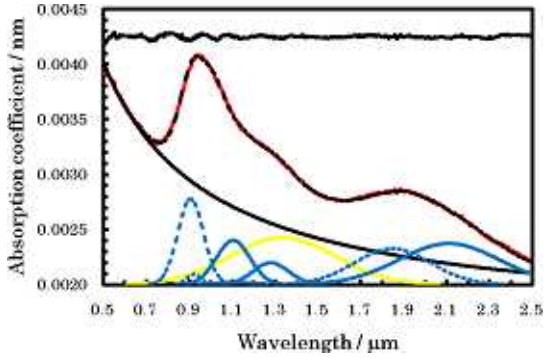

Fig. 2. A model fit of the absorption coefficient spectrum of 61221 that is derived from reflectance spectrum of [13, 14]. Absorption coefficient is shown as a thick red curve. The model fit is displayed as a dashed black line on the data. The top black line above the 0.0040 represents the error in the fit as a function of wavelength. The continuum is directly under the data. The modified Gaussians are for low-Ca pyroxene (thick green line), high-Ca pyroxene (dashed green line), and plagioclase (thick yellow line).

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