THE MINERALOGY AND GRAIN PROPERTIES OF THE DISK SURFACES IN THREE HERBIG Ae/Be STARS D. E. Harker[1], D. H. Wooden[2], and C.E. Woodward[3], [1]University of California, San Diego, Center for Astrophysics and Space Sciences, 9500 Gilman Dr., La Jolla, CA 92093-0424, [2]NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035-1000, [3]University of Minnesota, Astronomy Department, School of Physics and Astronomy, 116 Church Street, S.E., Minneapolis, MN 55455.

Introduction: The ubiquity of accretion disks around pre-main sequence and young main sequence stars having the potential to form planetary systems is now well established [1]. However, unknown is an accurate estimate of the fraction of single stars with disks that have produced planetary systems. Theoretical models of particle aggregation show that if particles can grow from submicron to mm to cm in size, then the formation of planetesimals is possible in the time before the disk dissipates [2]. The problem remains to understand how grains condense from nebular gases, and how relic interstellar grains survive and are modified by their transport in the disk. If grains are lofted above the disk photosphere by processes such as winds, turbulent convection, or changes in vertical structure, the evolution of dust can be investigated by observing the properties of the small ($\leq 1\mu$m) grains in the optically thin disk surface layer or atmosphere.

In this work, we examine the thermal emission from three Herbig Ae/Be stars of similar spectral type: HD150193 (A1V), HD100546 (B9V), and HD179218 (B9). The stellar ages of the objects are: 2×10^6 yrs, 10×10^6 yrs, and 0.5×10^6 yrs for HD150193, HD100546 and HD179218, respectively [3]. We chose these objects for study because they are isolated (not belonging to any know star forming region), have little to no active accretion, possess possible processing circumstellar disks, and have varying degrees of silicate crystallinity [4]. We assemble and model SEDs for each system using a passive reprocessing circumstellar disk to constrain the amount of crystals and flaring of the disk in each of the systems.

Observations: Spectrophotometry of HD150193, HD100546, and HD179218 was obtained using the NASA Ames Research Center *HI*gh efficiency *F*aint *O*bject *G*rating *S*pectrometer (HIFOGS) [5]. The spectrum of HD179218 was obtained on the 2.34-m telescope at the Wyoming Infrared Observatory using 32-bit FORTH telescope software. The spectra of HD150193 and HD100546 were obtained on the 4-m Blanco telescope at the National Optical Astronomical Observatories Cerro Tololo Inter-American Observatory in Chile.

We also obtained $1.2 - 23.0$ μm IR broad- and narrow-band photometric observations of HD179218 on 2001 April 30.42 UT using the University of Minnesota Mount Lemmon Observing Facility 1.52 m telescope and the UM multi-filter bolometer [6].

SED Assembly: Data from the European Space Agency Infrared Space Observatory (*ISO*) Short-Wavelength Spectrometer (SWS) and the Infrared Astronomical Observatory(IRAS) are used to expand the wavelength coverage of the spectral energy distribution (SED) of each of our three HAEBEs. All of the data sets for each object were scaled to the HIFOGS spectra.

Disk Model: We use a mineralogically enhanced version of the radiative, hydrostatic models of passively irradiated circumstellar disk [7] (hereafter CG97) that had been developed to include some discrete minerals [8] (hereafter C01). The CG97 disk is composed of two parts: an optically thin surface layer and an optically thick interior. C01 updated the CG97 model by adding a range of grain sizes and incorporating a simple mineralogy through the use of laboratory determined optical constants, including water ice, amorphous olivine, and metallic Fe. In this work, we use the updated model of C01 with our own enhanced feature of adding crystalline olivine grains into the optically thin surface layer. We also divide the disk into an inner and outer region in which we can independently vary the crystalline to amorphous silicate ratio to provide the best fit to the SED.

Crystalline Silicates: It is difficult to model the thermal emission from crystalline silicate grains [9]. In this work, we choose to calculate the crystalline silicate emission from ellipsoids by elongating the crystals along one of the three crystalline axes [10]. Based on the location of the resonance peaks in the HIFOGS and *ISO* SWS spectra of HD150193 and HD179218, we use an axis ratio of 10:1:1 to compute the optical efficiencies of the crystals. The crystalline silicates are not coated with ice since to do so requires mixing theory which eliminates the distinctive crystalline resonances. We compute the thermal emission from the crystals in the disk surface layer of each object. By dividing the disk into two regions, (inner and outer) we can vary the crystalline to amorphous silicate ratio to fit the model to the SED.

Results: Our model results are displayed in Fig. 1. To produce the best-fit model to the SEDs, HD100546 and HD179218 are both modeled with a disk 150 AU in radius, while HD150193 is modeled with a disk 5 AU in radius. The best fit SEDs for HD 100546 uses a photosphere to gas scale height (H/h) of 4, H/h = 3 for HD150193, and H/h = 1 for HD179218. This means at a disk radius of 5 AU the disk around HD100546 flares about 80% more than the disk around HD179218, and about 25% more than the disk around HD150193. The model fits suggests that the measured emission from HD150193 is dominated by warm dust in a flaring disk close to the central star, and that the emission from grains in an extended disk (> 5 AU) is relatively small compared to the other two objects.

HD100546 and HD179218 show evidence of crystalline silicates, while the emission from HD150193 is dominated by amorphous silicates. For the two objects with crystalline silicates, we find that a better fit is produced to the observed SEDs of the objects if we use a model in which a higher ratio of crystalline to amorphous silicates is located in the inner regions of the disk (< 5 AU) compared to the outer regions of the disk (5 – 150 AU). The inner region of HD100546 has 30% more crystalline silicates compared to the outer region. This is contrary to the findings of [11] who used a spherical shell model to calculate a factor of almost 10 higher fraction of crystalline silicates in regions greater than 10 AU. The inner region of HD 179218 has 76% more crystalline silicates compared to the outer region.

All three SEDs are best fit using a grain size distribution with a slope of $q = -3.5$ (i.e., $a^{-3.5}$) .

Discussion: It is difficult to make any statistically significant conclusions about disk evolution from modeling only three objects. However, we can make some interesting observations based on our results. Although there is no evidence for grain growth (all three SEDs are modeled with the same grain size distribution) there is a difference in the radial distribution of crystalline silicates. A possible evolutionary scenario is one in which when circumstellar disks form around young stars, they are thought to be primarly composed of amorphous ISM grains [12]. As the disk evolves, crystalline silicates are condensed [13] or annealed [14] in the inner radial regions of the disk, either through heating [15] or through shocks in the disk [16]. The crystals are then transported to the outer regions of the disk [17]. Therefore, from this scenario, we can conclude that the disk around HD150193 is the least evolved since it does not contain any crystals, followed by HD179218 which has an even larger amount of crystals in the inner radial region compared to the outer radial region, and finally HD100546 which has a larger amount of crystals in the outer regions of its disk compared to HD179218.

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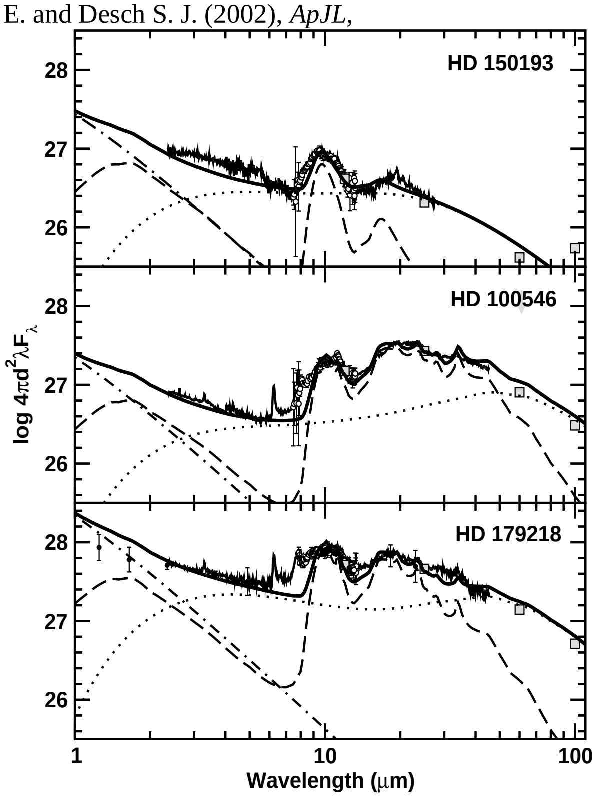

Figure 1. C01 model computed for HD150193, HD100546 and HD179218. The disk interior (dotted line), disk surface (dashed line), and stellar blackbody (dot-dash line) are co-added to produce the model SED (solid line). The model SED is compared to the assembled data sets including: *ISO* SWS spectra (solid, jagged line), HIFOGS spectra (open circles) and IRAS photometry points (gray squares). HD 179218 also has MLOF photometry points (filled circles).