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Laboratory studies on the formation mechanism of Fe-Ni and their sulfides finding in IDPs and their IR spectra

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Iron sulfide, Iron-nickel and Iron-nickel sulfide have been found in interplanetary dust particles (IDPs).Infrared observations of a number of carbon-rich stars, planetary nebulae (PNe) and young stellar objects have revealed a strong emission feature at 23 um by the ISO (Infrared Space Observatory). Iron sulfide and iron-nickel sulfide have been suggested as the candidate material for the 23 um. Thermodynamic modeling has clearly shown that produced iron sulfide is stoichiometric troilite (FeS) in the early solar nebular. However, since pyrrhotite ($Fe_{1-x}S$) has been found in greater quantities than troilite in chondritic IDPs, it can be considered that pyrrhotite forms directly from their gas phase or changes from troilite. Iron particles regularly include nickel of approximately 3-50 at.% and make their alloy, such as kamacite (alpha(Fe,Ni)), taenite (gamma(Fe,Ni)), and tetrataenite (gamma"(Fe,Ni)), in IDPs. Especially, the tetrataenite has been found only in meteorites, i.e., does not form as terrestrial material. Therefore, laboratory synthesis of tetrataenite is useful to understand the formation environment of tetrataenite grains in the solar nebula. In the case of iron-nickel sulfide, pyrrhotite ($(Fe,Ni)_{1-x}S$) and pentlandite ($(Fe,Ni)_9S_8$) were found in IDPs. Since these materials differ from composition and structure of the material on the earth, the fields of mineralogy and astronomy are interested in to reveal the generation condition. Therefore, we produced sulfide nano-crystals with a homogeneous phase which had not achieved due to their many formable polycrystal phase, and measured their IR spectra of individual phase. We discovered that iron sulfide is formed selectively by the difference of formation condition. A troilite film and a greigite (Fe_3S_4) film were formed by the reaction between iron film and sulfur vapor and by simultaneous evaporation of sulfur and iron, respectively. The troilite film was annealed at 300 degree centigrade in a vacuum at 10^{-7} Torr, and then appeared pyrrhotite phase. The greigite film changed to a mixture film of troilite and pyrrhotite film in the similar annealing condition. Nickel sulfide formed polydymite (Ni_3S_4) by the both methods, which are reaction between nickel film and sulfur vapor and simultaneous evaporation of sulfur and nickel. A millerite (NiS) phase was appeared in the polydymite film by annealing at 300 degree centigrade.

An Iron-nickel film is produced by vacuum evaporation at 10^{-6} Torr. It was found that the formation phase in depend on the atomic ratio of iron and nickel. In the case of nickel contents more than 40 at.%, taenite was formed although exist at more than 10 at.% nickel for the bulk material. Therefore, the phase diagram in nano-material would become different from that in bulk material. Once upon heating the specimen up to 400 degree centigrade, kamacite and tetrataenite, which are an ordered alloy phase, were formed when the specimen cooled down to about 300 degree centigrade. Finally, we formed troilite ((Fe,Ni)S) and polydymite ($(Fe,Ni)_3S_4$) films by iron-nickel reacted with sulfur vapor. A pyrrhotite phase was also formed in the troilite film including nickel as well as troilite film of FeS by annealing at 300 degree centigrade in a vacuum at 10^{-7} Torr. Moreover, polydymite changed pentlamdite at 300 degree centigrade in the vacuum at 10^{-7} Torr.

The spectra of the sulfide films showed characteristic infrared peaks at 16.2, 17.5, 21.6, 25.2, and 26.8 ums in iron sulfide and iron-10 at.% nickel sulfide, and at 17.3, 18.6, 21.4, 25, 26.8, and 43 ums in nickel sulfide and iron-20-50 at.% nickel sulfide. The 21.5 um feature of iron and/or nickel sulfide correspond to the spectral feature at 23 um of the carbon-rich evolved star. These infrared features of the sulfides are well duplicate that of M2-43 (PNe).