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Relative sputtering rates of FeS, MgS, and Mg silicates: implications for ISM gas phase depletions of rock-forming elements

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Astronomical measurements of S abundances in the diffuse interstellar medium (ISM) indicate ionized S is a dominant species with little (< 5%) S residing in grains (e.g. Jenkins 2009). This is an enigmatic result, given that abundant Fe-sulfide grains are observed in dust around pre- and post-main sequence stars (Keller et al. 2002; Hony et al. 2002) and are also observed as major components of primitive meteoritic and cometary samples. These disparate observations suggest that the lifetime of sulfide grains in the ISM is short because of destruction processes. Our previous work has shown that FeS and MgS retain their crystallinity and do not amorphize during radiation processing, whereas enstatite and forsterite are readily amorphized (Keller et al. 2013; Christoffersen and Keller, 2011). We have extended this study to measure the relative sputtering rates of FeS and MgS compared to enstatite and forsterite.

Irradiation of FeS with 4 keV He+ results in preferential sputtering of S and the formation of a thin 2-3 nm, compact Fe metal layer that armors the surface. The zone of S loss extends to a depth of ~8-10 nm below the exposed surface (Keller et al. 2013). Despite this S loss, the FeS retains its crystallinity and shows no sign of incipient amorphization. Irradiation of FeS with 5kV Ga+ in a focused ion beam (FIB) instrument resulted in preferential sputtering of S and the formation of a 5-8-nm thick surface layer of nanophase Fe metal. X-ray mapping shows that the zone of S sputtering extends to a depth of nearly 20 nm, but there is no evidence for FeS amorphization, consistent with our previous work.

The irradiation experiments show that the relative sputtering rate of FeS and MgS are much higher than olivine or enstatite. Sputtering experiments utilizing 30 kV and 5 kV Ga ions in the FIB produced volume loss in troilite that was ~4X greater than in enstatite or forsterite. The sputter yield under these conditions is such that for every Si atom sputtered from enstatite, ~14 S atoms are sputtered from FeS. We have performed similar sputtering experiments on Fe-bearing niningerite (MgS) and co-existing enstatite from the ALH 84170 EH3 chondrite. MgS also sputters much more rapidly than enstatite with a relative Si:S sputter yield of 1:8. For MgS, sulfur is highly depleted at the surface and the S-depletion zone extends to a depth of ~15 nm (using 5 kV Ga+). There is a corresponding zone of Mg and especially Fe enrichment that extends from 5 to ~10 nm below the surface, respectively.

The dominant grain destruction mechanism in the ISM is sputtering from passage of supernova-generated shock waves (Jones and Nuth 2011). This process also results in the amorphization of crystalline silicates in the ISM. Our results indicate that FeS and MgS grains produced in evolved stars and injected into the ISM will be destroyed more rapidly than crystalline silicates. This process may account for the lack of significant depletion of S from the gas phase in the ISM. However, rare nanophase FeS grains occur as inclusions in circumstellar amorphous silicate grains found in comet dust particles analyzed in the laboratory (Keller and Messenger 2011). These results show that a finite amount of S in the ISM is sequestered in solid grains.

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