SPUTTERING OF SOLID SO_2 BY HIGH ENERGY IONS, D.J. LePoire, B.H. Cooper, C.L. Melcher, and T.A. Tombrello, Kellogg Radiation Laboratory, Caltech, Pasadena, CA 91125

Sputtering of frozen SO_2 is of interest both in regard to the modification of planetary surfaces and generation of coronae, and as part of an investigation into the mechanism of enhanced high energy sputtering of dielectric materials. Io and possibly part of Europa are covered with SO_2 frost and are bombarded by a variety of energetic ions from the Jovian magnetosphere. Sputtering may be an important mechanism for mass redistribution on the surface as well as for the generation of an SO_2 atmosphere on Io (1). Anomalously high sputtering rates have previously been observed for other dielectrics, including UF_4 and frozen H_2O (2,3), bombarded by ions with MeV/nucleon energies (electronic stopping power regime). Significant progress toward understanding the mechanism responsible for these high yields is reported by Watson and Tombrello (4).

The sputtering yields (number of SO_2 molecules removed per incident ion) for He and F ions incident on solid SO_2 targets were measured at energies ranging from 1.5 to 25 MeV. Solid SO_2 targets (2000-4000 Å thick) were vapor deposited by directing a controlled flow of SO_2 gas onto a cold (10°K) substrate situated in an ultra-high vacuum chamber with a base pressure of $\sim 10^{-9}$ torr. The substrate was a thick Be disk coated with a thin Au film. Temperatures of 10°K were achieved by flowing liquid He through an open cycle transfer line on which the substrate was mounted. Following target formation, the chamber pressure returned to $\sim 10^{-9}$ torr. A detailed description of the apparatus may be found in (5).

Sputtering yields were obtained by measuring the initial target thickness, bombarding the target with a known dose of energetic ions, and then measuring the final target thickness. Target thicknesses were measured by backscattering spectrometry of 1.5 MeV $^4He^+$ ions using a silicon surface barrier detector. Three methods of calculating the SO_2 thicknesses from the backscattering spectra were used: the energy shift of the substrate Au peak, the number of S counts, and the number of O counts. The sputtering yields calculated using these methods always agreed to within ± 15%.

Targets deposited at 10°K were non-stoichiometric, with 10-25% more O than expected for pure SO_2. Several attempts were made to remedy this. The most successful was to raise the temperature of the target substrate to 30°K during target formation. Using this technique, the O excess was reduced to 5-10%.

The results of sputtering SO_2 with 1.5 MeV He and 1.6-25 MeV F ions are listed in Table 1. The sputtering yields of SO_2 with F ions are plotted as a function of bombarding energy in Fig. 1. The dashed line shows the yield for H_2O ice multiplied by 5 (from ref. 5). Also shown in Fig. 1 is the stopping power of ^{19}F in SO_2. The yields, ranging up to $\sim$ 7000, are the largest yet measured for any material. They are much larger than predicted on the basis of classical sputtering theory (6) and are apparently associated with energy loss of the incident ions to electronic processes in the target. This phenomenon has previously been observed in H_2O ice and UF_4, and the bombarding energy dependence for SO_2 is remarkably similar to that seen in those materials.

After a sputtering run, the SO_2 was removed from the target by elevating the substrate to room temperature. Surprisingly, some S and O remained on the Be/Au substrate even at 300°K. Backscattering analysis showed that this residue was O enriched by a factor $\sim$2. The residue was typically $\sim$ 5% of the original target thickness and located predominantly where the sputtering beam had hit the target. The sputtering yield of the residue was an order of

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magnitude less than that for frozen SO_2, and O was preferentially removed by the sputtering.

The 0.54-1.05 MeV ion flux at Io was observed by Voyager 1 LECP to be $\lesssim 10^8$ cm^{-2} s^{-1} (7). A comparable flux of 1.6 MeV F ions would yield an erosion rate for frozen SO_2 of ~ 5 meters/10^6 yrs. This is probably an upper limit to the sputtering rate of SO_2 on Io by MeV ions since most of the observed flux is probably due to ions lighter than F which are expected to have smaller yields. The actual erosion rate will be orders of magnitude less if the ion flux consists mainly of H and He. The combined effects of sputtering and heating which produced residues on our target substrates may also occur on Io from sputtering by magnetospheric ions and heating by volcanism.

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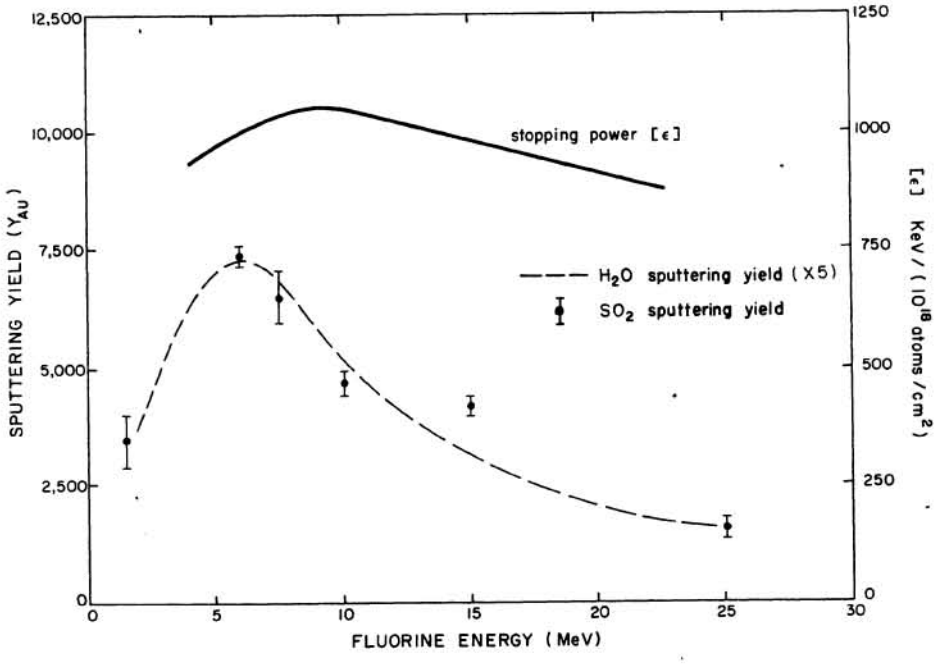
REFERENCES: (1) Watson, C.C. et al. (1981) LPS XII, 1164; (2) Griffith, J.E. et al. (1980) Rad. Effects 51, 223; (3) Brown, W.L. et al. (1980) Nucl. Instr. Meth. 170, 321; (4) Watson, C.C. and Tombrello, T.A. (1982) these abstracts; (5) Cooper, B.H. (1981) Ph.D. thesis, Caltech; (6) Sigmund, P. (1969) Phys. Rev. 184, 383; (7) Krimigis, S.M. et al. (1979) Science 204, 998.

Table 1. Sputtering Yields[a]

Ion	Energy (MeV)	Y_{Au}	Y_O	Y_S
He^{+1}	1.5	50 ± 10	57 ± 7	51 ± 2
F^{+2}	1.6	3516 ± 321	3097[b]	2731[b]
F^{+3}	6.0	7325 ± 42	7167 ± 466	6282 ± 11
F^{+3}	7.5	6493 ± 562	8203 ± 1091	6441 ± 855
F^{+3}	10.0	4647 ± 260	5280 ± 170	3815 ± 577
F^{+4}	15.0	4176 ± 75	4917 ± 653	3866 ± 464
F^{+5}	25.0	1632 ± 141	1698 ± 112	1345 ± 190

[a] Number of SO_2 molecules removed per incident ion; errors are experimental uncertainties based on 3 or more points except where noted.

[b] Only one data point recorded.



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