

Irradiation of Ammonia-Water Mixtures at 20 K and 120 K: A Complement to Previous Laboratory Studies.

M.J. Loeffler¹, U. Raut¹ and R.A. Baragiola¹. ¹ Laboratory of Atomic and Surface Physics, University of Virginia, Charlottesville, VA 22904.

Introduction: Enceladus, a small satellite of Saturn, has received a great deal of attention since the Cassini spacecraft detected a spectacular fountain of water ice particles and vapor emanating from its south-polar region [1-4]. Ever since this discovery, many theories have been proposed to explain how such a unique phenomena could exist on this icy body [5-12].

Here, we present additional laboratory results on the effects of ion irradiation on ammonia water mixtures at different temperatures – 20 K and 120 K. The results complement our previous work on the irradiation of ammonia-water mixtures at 70 K [5].

Experimental Details: The experiments were performed in vacuum at 2×10^{-10} Torr using a mass-analyzed beam of 100 keV protons. Solid ammonia-water films were grown at 80 K on the gold mirror surface of a quartz-crystal microbalance (QCM) to a thickness of $\sim 2 \mu\text{m}$ ($148 \mu\text{g}/\text{cm}^2$), slightly larger than the depth of penetration of the ions. The mixtures were grown using two separate gas dosers with the 1:2 $\text{NH}_3:\text{H}_2\text{O}$ ratio of the dihydrate, as this is one of the equilibrium phases for ice mixtures with $< 65.4 \text{ wt}\%$ ammonia [13]. The samples were then annealed to 120 K to achieve uniform mixing. Irradiations were done at 20 K and 120 K while monitoring the samples with infrared reflectance (IR) (1.5-15 μm), a mass spectrometer (MS) aimed at the surface, and gravimetry using the microbalance.

Irradiation results at 20 K: Figure 1 shows the fluence dependence of the infrared absorption band area of NH_3 , N_2 , H_2 , and NO . We note that the band area of the hydrogen absorption peaks at a value that is four times larger than in the experiments at 70 K. This is probably due to both an increase in the retention of hydrogen at low temperatures, and to a large temperature dependence in absorption coefficient, which we have seen in these diatomic molecules [14]. Also we detect NO (1871 cm^{-1}), which is not observed 70 K.

Figure 2 shows the formation of OH dangling bonds as a function of ion fluence; this feature was not observed at 70 K, but has been observed in ion irradiation of hydrogen peroxide [14]. The band position of the dangling bond (here: 3671 cm^{-1} ; pure water: 3696 cm^{-1}) observed here suggests that gas is attached to it, which is likely H_2 and/or N_2 . We note that in previous experiments the position of the dangling bond shifted from 3692 to $\sim 3676 \text{ cm}^{-1}$ when N_2 was codeposited with water ice [15].

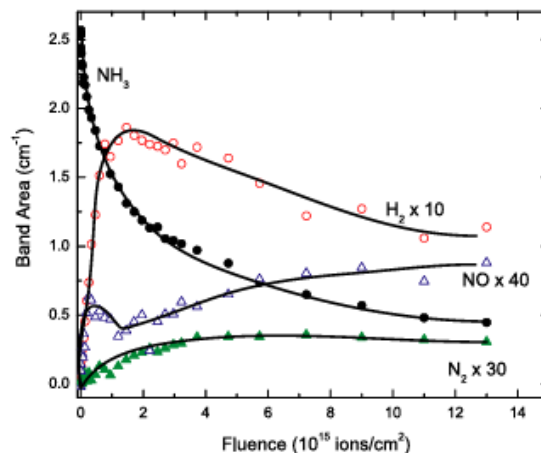


Figure 1. Fluence dependence of the infrared band area of NH_3 , H_2 , N_2 , and NO absorptions in a 1:2 ammonia-water mixture (thickness $\sim 2 \mu\text{m}$) during irradiation with 100 keV protons at 20 K. The lines are to guide the eye.

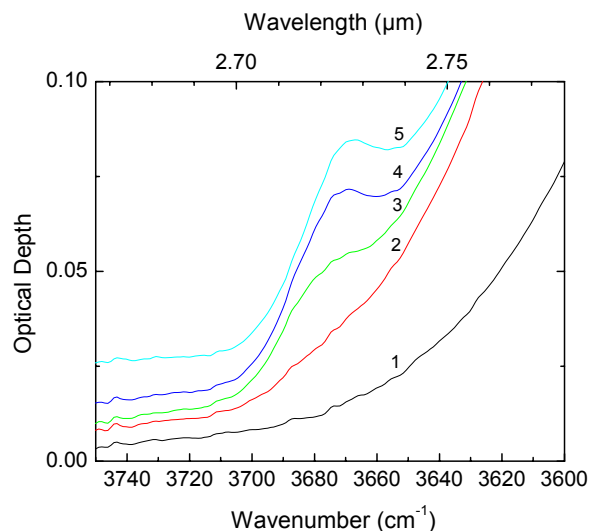


Figure 2. Production of OH dangling bonds as a function of fluence for a 1:2 ammonia-water mixture (thickness $\sim 2 \mu\text{m}$) irradiated at 20 K with 100 keV protons to a fluence of (1) 0, (2) 9.5, (3) 22, (4) 57, and (5) $13 \times 10^{15} \text{ ions}/\text{cm}^2$.

Irradiation results at 120 K: Under otherwise the same experimental conditions as at 20 K, we irradiated samples at 120 K to study effects that temperature has on the irradiation chemistry. Figure 3 shows the destruction of ammonia versus irradiation fluence. We note that other new bands were observed at 2225 (N_2O), 1300, 1263 cm^{-1} and no bands were

observed for N_2 and H_2 . At high fluences, the concentration of NH_3 remaining in the ice is about a factor of 5 less than it is at 70 K.

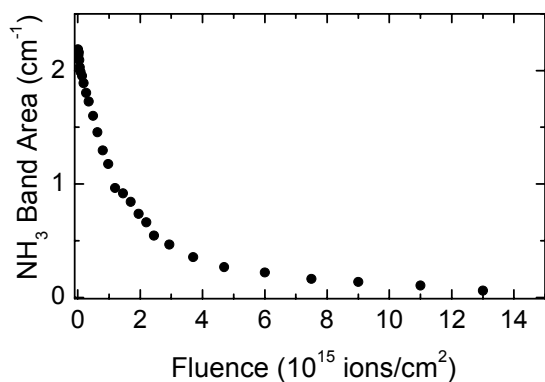


Figure 3. Fluence dependence of the infrared band area of NH_3 (4523 cm^{-1}) in a 1:2 ammonia-water mixture (thickness $\sim 2\text{ }\mu\text{m}$) during irradiation with 100 keV protons at 120 K.

Heating of irradiated films at 20 and 120 K: After irradiation, we warmed the films at 0.2 K/min and monitored changes with the MS, QCM, and IR. For the sample irradiated at 20 K, we observe some mass loss in the QCM, which probably is desorption of N_2 and H_2 from the surface that has not been caught in a trapping site. The remainder of the trapped gas stays in the ice until the high frequency spikes in the chamber pressure begin to occur as they did for irradiation at 70 K (Fig. 4). Here they appear to be stronger and they peak at a higher temperature ($\sim 135\text{ K}$ rather than 127 K). As for irradiation at 70 K, these bursts correlate with drops in the infrared reflectance.

Heating of the sample irradiated at 120 K yielded no outbursts like it did for irradiation at 20 and 70 K and no hydrogen desorbed below 150 K either. More details on all these results will be given at the conference.

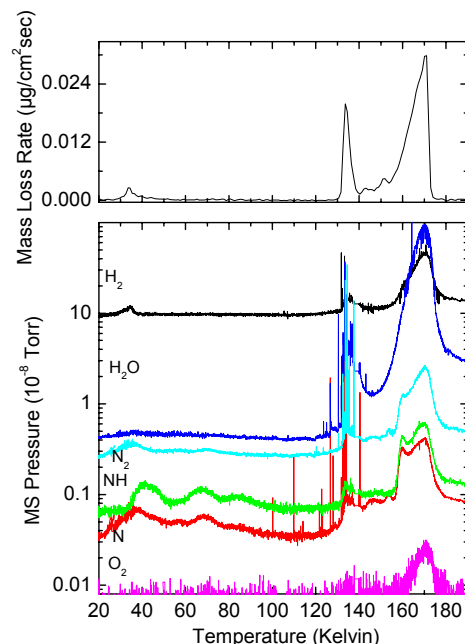


Figure 4. Mass loss rate (top) and mass spectrometer signal uncorrected for relative efficiencies (bottom) during post irradiation heating of a 1:2 ammonia-water mixture ($148\text{ }\mu\text{g cm}^{-2}$; thickness $\sim 2\text{ }\mu\text{m}$) irradiated with 1.3×10^{16} 100 keV H^+ / cm^2 at 20 K.

References: [1] Hansen, C. J., et al. 2006, *Science*, 311, 1422. [2] Porco, C. C., et al. 2006, *Science*, 311, 1393. [3] Spahn, F., et al. 2006, *Science*, 311, 1416. [4] Waite, J. H., et al. 2006, *Science*, 311, 1419. [5] Loeffler, M.J. et al. 2006, *ApJ*, 649, L133. [6] Hurford, T.A. et al. (2007) *Nature*, 447, 292-294. [7] Nimmo, F. et al. (2007) *Nature*, 447, 289-291. [8] Matson, D.L. et al. 2007, *Icarus*, 187, 569-573. [9] Kieffer, S.W. et al. 2006, *Science*, 314, 1764. [10] Fortes, A.D. (2007) *Icarus*, 191, 743-748. [11] Dombard, A.J., 2007, *Nature*, 447, 276. [12] Cooper, J.F. 2007, JGR submitted. [13] Hogenboom, D. L. et al. (1997), *Icarus*, 128, 171. [14] Loeffler, M. J. et al. 2006, *J. 2006, ApJ*, 639, L103. [15] Buch, V., & Devlin, J. P. 1991, *J. Chem. Phys.*, 94, 4091