Ion Irradiation Induced Electrostatic Charging Effects on Solar Ices. J. Shi[1], M. Famá[1] and R. A. Baragiola[1], [1]University of Virginia, Laboratory for Atomic and Surface Physics, Thornton Hall, Charlottesville, VA 22904-4238 (Contact email: raul@virginia.edu)

Introduction: Water ice is abundant on the surfaces of many objects in the outer solar system, where they are exposed to UV photons, solar wind, cosmic rays and energetic charged particles trapped by the planetary magnetic fields. Radiation effects induced by energetic ions in ice such as sputtering, secondary ion emission, amorphization of crystalline ice, compaction of microporous amorphous ice, and chemical radiolysis (molecular decomposition and synthesis) have been extensively studied in laboratory conditions [1-4]. In comparison, electrostatic charging effects on ice induced by ion irradiation have been barely studied and consequently the level of charging on icy astrophysical surfaces is relatively unknown. So far, no mission has landed on any icy object in space, and therefore there is no information on surface electric fields. For example, electrostatic charging of ice could be important for charged small ice particles in planetary rings because these particles are so small that electrostatic forces could be comparable to gravitation [5, 6].

The process of charge trapping starts with the creation of electron/hole pairs from the ionizing energy deposited by an incoming particle. Electrons that do not immediately recombine are much more mobile than holes. They can be trapped in the solid contributing to a negative charging, or can escape from the film (in times typically ~1 ps) resulting in secondary electron emission. They also can drain through the substrate and leave an excess of positive charges in the film. The holes are relatively immobile and can be easily trapped by localized defects or long-lived trapping levels (energy states located between the valence and conduction bands) resulting in an effective positive polarization. The electric field produced by the trapped charges is limited to the value at which dielectric breakdown occurs, as long as potentials are high enough to allow for cascade multiplication of electrons. The presence of an internal electric field can affect the energy and trajectory of ejected species such as secondary electrons and ions. One must also consider the hypothesis of a net electrical polarization of ice during condensation (ferroelectricity) [7]. However, should ferroelectricity exist in solar ices, it could be masked by charging effects induced by particle or UV irradiation.

Condensed gases are a convenient group of insulators to study charging effects; they are simple in composition (usually one type of molecule), can be easily vapor deposited to form thin films, and most of their physical properties can be measured with appropriate spectroscopy tools. Electrostatic charging effects in solidified noble gases caused by ion bombardment have been previously studied in our laboratory [8,9].

Here we propose a different approach to study charging effects on ice induced by ion bombardment, which is the measurement of the energies of ejected secondary ions. We bombarded ice films with 100 keV Ar^+ and measured the kinetic energy of secondary H_3O^+ sputtered from the surface for different film thicknesses and ion fluxes. The energy of the sputtered ions results a direct measurement of the ice surface potential induced by electrostatic charging.

Experiments: The experiments were conducted in a cryopumped ultra high vacuum chamber with a base pressure of ~10^{-10} Torr. Using a microcapillary array doser, 0.2 to 7 μm ice films were vapor deposited at 80K onto a Liquid Helium cooled gold-coated quartz crystal microbalance, which measures the mass column density of the films [10]. Mass analyzed ion beams of 100 keV Ar^+ were scanned uniformly over the sample. Secondary ions emitted at 45° from the surface where analyzed with a Hiden EQS 300 sector field electrostatic energy analyzer and quadrupole mass spectrometer. As soon as the ion beam is turned on, we observe a build up of the kinetic energy of secondary ions sputtered from the ice which eventually saturates. All measurements were taken at saturation conditions.

Results: [I] *Thickness Dependence*. Fig. 1 shows the dependence of the kinetic energy of the ionized protonated water molecule on film thickness. A typical energy scan for H_3O^+ is shown in the lower-right inset of this figure.

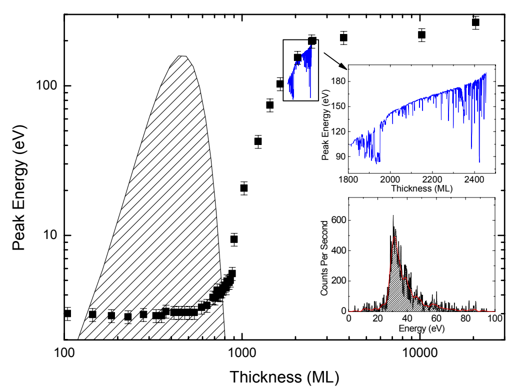

Figure 1 *Peak H_3O^+ energy vs. ice film thickness. Films were grown at 80K and the ion energy was measured using a flux of $7.8x10^{11}$ $Ar^+cm^{-2}s^{-1}$. The shaded area is the range distribution of the projectiles calculated with TRIM. The lower-right inset shows a typical energy distribution scan. The energy of secondary ions abruptly decreases when dielectric breakdown occurs, shown in the upper-right inset.*

For thicknesses below the maximum range of the projectiles ~600 monolayers (ML), the kinetic energy of the emitted ions is relatively constant and between 4~5 eV. We assume this is the intrinsic kinetic energy value for the secondary H_3O ions due to sputtering. For film thicknesses larger than the maximum projectile range, the kinetic energy of the secondary ions rises sharply up to hundreds of eVs, saturating for thicknesses greater than 1800ML. Above this thickness the surface potential reaches ~150 V and the corresponding internal electric field a value of ~2.5 MV/cm, similar to the dielectric strength of ice, and dielectric breakdown occurs as shown in the upper-right inset. Between 600ML and 1800ML, the peak energy increases linearly with a slope of ~0.05 eV/ML.

[II] *Discharging*. When the beam is turned off the ice starts to discharge through self-drifting of the charges to the substrate due to the electric field they generate. We measured the H_3O^+ kinetic energy as a function of time since the beam was turned off, but using an ultra low flux of 100 KeV Ar ions to avoid additional charging up of the films. An example of discharging is shown in Figure 2.

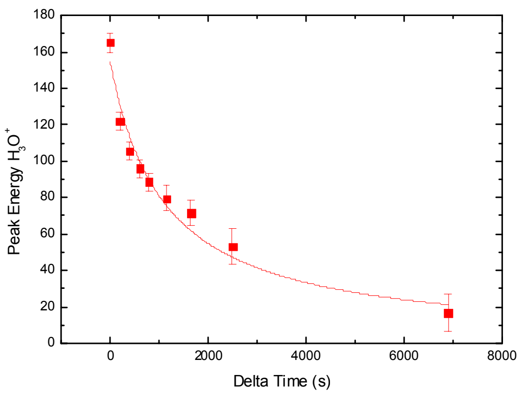

Figure 2 *Discharging of saturated charged ice films by ion irradiation.*

[III] *Temperature Effects*. We studied the temperature dependence of the kinetic energy of secondary ions by changing the ice temperature from 20 to 140 K and vice versa. For ices grown and measured at 130K (crystalline phase) the secondary ions are sputtered at energies corresponding to their intrinsic values (~4 to 5 eV), as seen in Figure 3. Cooling these ices down to 20K increases the kinetic energy of secondary ions up to ~20 eV. By increasing the ice temperature back to 130-140K the secondary ion energies return to their original values. Using a different approach, we repeated these measurements for films grown at 80K and annealed up to 130K. The results are not reversible as shown in the inset of Figure 3.

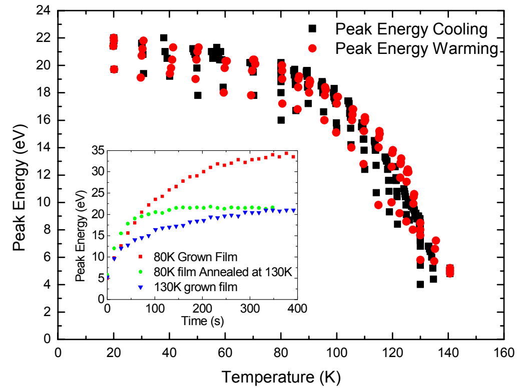

Figure 3 *Temperature dependence for peak energy of H_3O^+. Inset: Time dependence of charging of films grown at 80 K before and after annealing at 130K.*

[IV] *Ferroelectricity*. To test the ferroelectric properties of vapor deposited ice, we examined the charging up curves of 2500ML films grown at 40K, at very low ion fluxes. We found that the initials scans of the secondary ion energies do not show a secondary ion signal immediately; but require an incubation time. An extrapolation of the peak energy to zero fluences gives a negative initial offset for the potential of the ice surface. This value is similar to those found in ferroelectricity studies [11].

Discussion: Icy surfaces in the solar system are susceptible to charging effects due to energetic particle irradiation. The voltage created at the surface is limited by the drifting of charges due to the internal electric field they generate.

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