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LETTER TO THE EDITOR

Field assisted positron moderation by surface charging of rare gas solids

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Abstract. The field assisted moderation of positrons (e^+) has been achieved by charging the surfaces of argon and krypton rare gas solid (RGS) films. Following deposition the RGS surface was coated with a thin layer of molecular oxygen which serves to trap some of the charge which was then applied by low energy electron bombardment. Energy spectra of both the low energy e^+s and secondary electrons emitted from a charged argon surface were found to be consistent with the production of a surface potential of approximately −20 V. This resulted in a threefold enhancement of the slow e^+ yield and a reduction of around a factor of five in the emission of secondary electrons. Electron bombardment of RGS films not exposed to oxygen showed no such surface charge effects.

Since their discovery, low energy e^+ beams have found a large variety of applications, mainly in the areas of atomic and solid state/surface physics (see e.g. reviews by Charlton (1985) and Schultz and Lynn (1988)). Of major importance has been the understanding of the motion of positrons in the bulk of materials and their interactions at surfaces. This knowledge can then be used to produce more efficient moderation of the e^+s emitted from β^+ sources. Although progress in this area has been rapid over the last twenty years, with the quoted efficiency rising from 3×10^{-5} for the smoked MgO moderator of Canter *et al* (1972) up to 1.6% for the solid neon cone geometry moderator of Khatri *et al* (1990), further improvements remain an important goal in e^+-physics research. One method which has been proposed to achieve this is the application of an electric field across a semiconductor or insulator in order to drift a significant fraction of the e^+s to an emitting surface (e.g. Lynn and McKee (1979), Beling *et al* (1987) and Brandes *et al* (1991)). In this communication we report a new effect which has led to enhancements in the efficiency of rare gas solid (RGS) e^+ moderators, namely field assisted moderation using surface charging by low energy electron (e^-) bombardment.

The present study was performed with two uncovered ^{22}Na sources with strengths of approximately 0.22 MBq and 0.15 MBq deposited on a flat copper plate and a copper cup respectively. The cup and plate could be bolted onto the cold finger of an APD cryogenics model H-2 cryopump and thereby cooled to around 15 K. Argon or krypton moderators could then be frozen directly onto the sources by admitting these gases at various pressures into the vacuum chamber (base pressure 4×10^{-9} Torr). Typically 10^{-4} Torr was used with a deposition time of 15 min in order to produce

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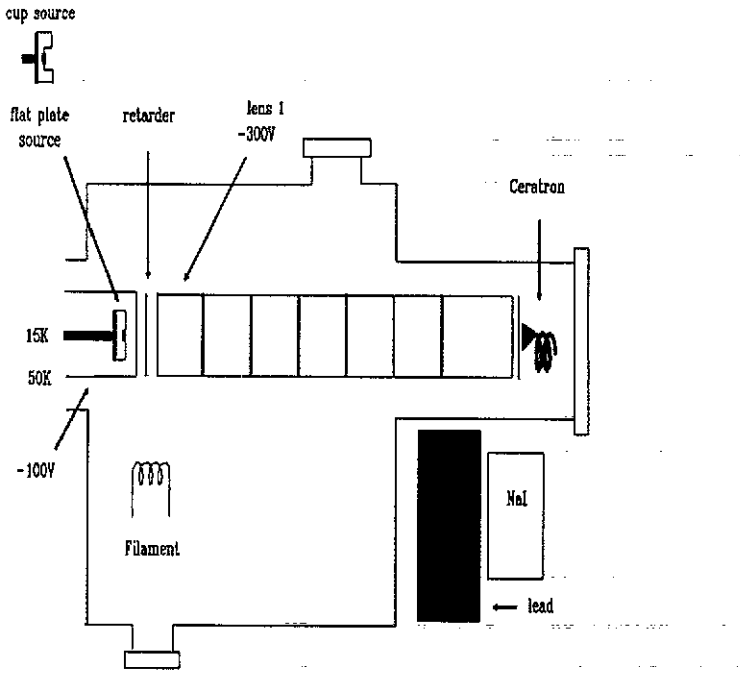

Figure 1. A schematic diagram of the apparatus used in these experiments. Not shown are two pairs of coils in the Helmholtz configuration which were orthogonally aligned with each other and also with the beam direction that were used to annul the earth's magnetic field.

an optimally thick moderating layer. A molecular oxygen overlayer was established by admitting this gas for 2 min at a pressure of 2×10^{-7} Torr.

The intensity of the moderated positrons was measured using the short electrostatic transport system shown in figure 1. The source holder was grounded to the cold finger and the e^+ (or β^+-induced secondary e^-s) were extracted by applying a voltage of $\mp$ 100 V to the surrounding copper radiation shield. A retarding grid was located between the radiation shield and the first lens element to facilitate determination of the energy of the emitted e^+s or e^-s. The beam was guided on to a ceratron detector and the absolute intensity of the e^+ beam could be found using a NaI γ-ray detector in coincidence with the former. In assessing the efficiency of the moderator, the only correction applied was for that of the ceratron detection efficiency, provided by the NaI coincidence. No allowance was made for grid attenuation of the beam. The transport efficiency of the present beam system could be experimentally assessed by comparison with the RGS e^+ moderator efficiency determined using a magnetic guiding field (with transport efficiency assumed to be unity). This suggested that the electrostatic system shown in figure 1 also had a transport efficiency of unity which is in agreement with a computer simulation performed using the Simion optics program. Electron bombardment of the moderator surface was performed using a heated tungsten filament held at -100 V. The current striking the moderator was found to be about 100 nA and most of this was due to secondary electrons with energies below 10 eV which were liberated from the grids near the source by the primary e^-s from the filament. Typically the filament was heated for a period of 20 s.

Figure 2(*a*) and (*b*) show the retarding voltage spectra of e^+ and β^+-induced

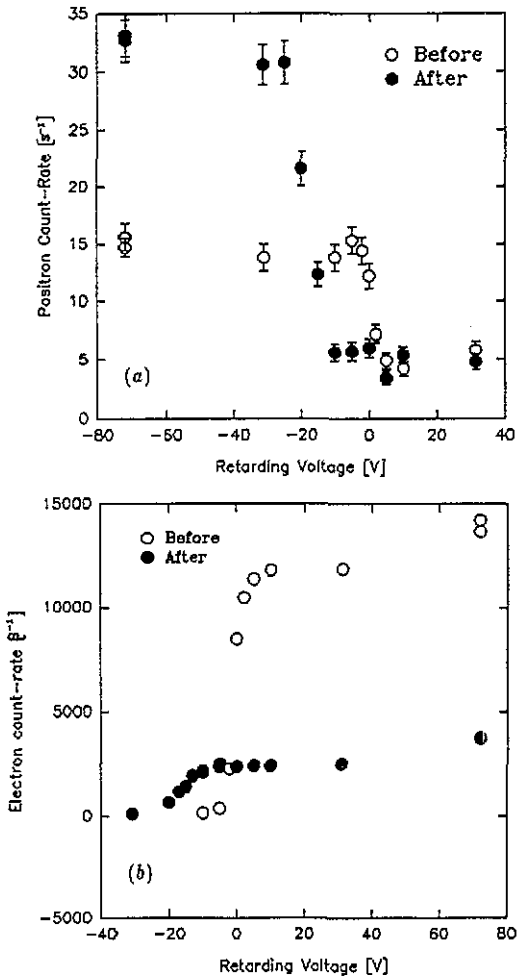

Figure 2. (*a*) Positron and (*b*) secondary electron retarding spectra taken before and after low energy electron bombardment of an oxygen-coated argon moderator.

secondary e^-s emitted from the plate source with an O_2-coated argon moderator both before and after e^- bombardment. These spectra were obtained by varying only the voltage applied to the retarding grid, such that the position and width of the cut-off voltage reflect the longitudinal energy and energy spread of the beams. It is noticeable that, after e^- bombardment, both the e^+ and β^+-induced secondary e^- spectra emitted by the moderator are shifted by around −15–20 V. This shift is attributed to the surface reaching this potential as a result of charging due to electrons which are captured by O_2 molecules that are adsorbed onto the RGS. In addition, the e^+ yield is enhanced by a factor of approximately three whilst that for the β^+-induced secondary e^-s is reduced approximately fivefold. Again these effects are consistent with the surface reaching an effective negative potential; here the e^+ (secondary e^-) yields are enhanced (reduced) due to the electric field acting across the RGS which may result in drift of the e^+ (e^-) towards (away from) the emitting surface. This explanation is supported by experiments performed on partially oxygen coated thin solid krypton films, where charge trapping at the surface is observed

using low energy electron transmission spectroscopy (see e.g. Sanche and Deschenes (1988) and Sambe *et al* (1990)). It should be noted that in our investigations, e^- bombardment of freshly deposited RGS films (i.e. with no O_2 coverage) produced no observable effect on either the yield of e^+ (e^-) or their respective retarding spectra.

A discussion of the effect of an electric field on the motion of eV energy electrons in solid Xe has been given by Gullikson and Henke (1989). These workers observed enhancements in the x-ray-induced secondary e^- emission from Xe when the solid was charged under certain conditions and also when a DC electric field was applied. The effects observed are similar to those reported here in that the transport of hot e^+ (e^-) in various RGS can be markedly altered by the presence of an electric field across the bulk of the sample.

Assuming that the RGS film is ≈ 10 μm thick then the electric field created corresponding to a 20 V surface potential is ≈ 20 kV cm^{-1}. At this field strength the thermalized e^- drift velocity is saturated in pure RGS at a value around 10^6 cm s^{-1} (Spear and Le Comber 1977). If this value of the drift velocity can be used, too, for the case of hot e^+ then the drift distance during a typical e^+ lifetime of 400 ps will be about 4 μm. This value is greater than the diffusion length for e^+ in solid argon of 0.5 μm derived from the study of Gullikson and Mills (1986). It is thus plausible that it is the effect of the electric field throughout the bulk of the RGS that is responsible for the enhancement of the e^+ yield rather than some modification of the process occurring at the surface.

The yield of moderated e^+s shown in figure 2 after electron bombardment corresponds to an actual efficiency of 0.2%. It should be noted that the e^+ yield before e^- bombardment (approximately 0.07%) was the same with and without O_2 coverage. At the time when this experiment was undertaken, the ceratron detection efficiency was only about 10%. This was due, not only to the presence of two grids in front of the ceratron (annihilations here were registered by the NaI detector), but also to a combination of gain degradation with time after the beginning of the investigations and the high input energy of the particles (2 keV). Even though the ceratron detection efficiency was found to change over a period of months, that of the NaI detector and the derived moderation efficiency were constant.

The stability with time of the charged surfaces was also investigated. Over a period of three hours the e^+ yield fell by about one half, although the degree of charging, indicated by the shifts observed in the e^+ and e^- retarding spectra, fell by around a factor of three. Further evidence for a non-linear relationship between surface charge and e^+-yield enhancement came one hour after surface charging, at which time a 5 V ($\approx 25\%$) drop in the surface potential was observed, whereas no significant decrease in e^+ yield could be measured ($<10\%$). This suggests that the electric field in the RGS was then still large enough to saturate the hot-e^+ drift velocity.

Several other investigations of the charging phenomenon were carried out, including some employing the cup geometry. Without electron bombardment the cup geometry was found to have an e^+ moderation efficiency greater than the flat plate geometry by a factor of approximately two. Following, as outlined above, exposure to O_2 and low energy e^-s a threefold increase of up to 0.6% was observed for an argon moderator. Krypton however gave a slightly lower enhancement from around 0.3% to 0.6% whilst the β^+-induced secondary e^- yield fell by a factor of four. Retarding spectra were again taken and showed significant energy shifts after e^- bombardment, although in this case the resolution, or width of the cut-off, was broadened, probably

as a result both of the wider range of angles of emission available and the poorer electrostatic optics of the cup geometry.

Using deposition and electron bombardment as described above for O_2, an overlayer of air gave practically the same enhancement in moderation efficiency indicating, possibly, that adsorbed molecular nitrogen may also play a role in charge trapping. This is supported by the work on electron impact on N_2 coated RGS surfaces (Marsolais and Sanche 1988, Michaud and Sanche 1990). The reduction in e^+-yield enhancement appeared more rapid for surface-charged air-coated RGS moderators than for their O_2-coated counterparts, falling by a factor of approximately two in one hour. It was then found that an argon moderator with a condensed air overlayer could be charged repeatedly by e^- bombardment with only a small loss in the maximum yield each time.

By biasing lens 1 (see figure 1) to about +1 kV during the period in which the filament was being used, it was possible to positively charge the moderator, probably as a result of secondary electron emission following positive ion impact. Here the moderated e^+ yield was reduced to near zero, while the secondary electron yield was enhanced by a factor of three. Such effects may be expected following the work of Gullikson and Henke (1989) on solid Xe and that of Koshida and Yoshida (1978) who observed enhancement of secondary electron emission as a result of positive ion bombardment of a porous MgO–Ag layer.

In conclusion, the present study has demonstrated that field assisted moderation of e^+ in RGS can be achieved by charge trapping on molecular impurity overlayers. Further studies of this phenomenon can be performed by implanting variable energy e^+ into these charged samples and these should shed light on the role of drift in the bulk and surface interactions. In addition the application of a DC bias to clean RGS films should yield moderation enhancements. Finally, it is feasible that the efficiency of solid neon moderators may be increased using the method described herein (Mills and Gullikson 1986, Khatri *et al* 1990).

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References

Beling C D, Simpson R I, Charlton M, Jacobsen F M, Griffith T C, Moriarty P and Fung S 1987 *Appl. Phys.* A **42** 111

Brandes G, Mills A P Jr, Voris S S Jr and Zuckerman D M 1992 *Proc. 9th Int. Conf. on Positron Annihilation (Szombathely, Hungary 1991)* (Aedermannsdorf, Switzerland: Trans Tech Publications)

Canter K F, Coleman P G, Griffith T C and Heyland G R 1972 *J. Phys. B: At. Mol. Phys.* **5** L167

Charlton M 1985 *Rep. Prog. Phys.* **48** 737

Gullikson E M and Henke B L 1989 *Phys. Rev.* B **39** 1

Gullikson E M and Mills A P Jr 1986 *Phys. Rev. Lett.* **57** 376

Khatri R, Charlton M, Sferlazzo P, Lynn K G, Mills A P Jr and Roellig L O 1990 *Appl. Phys. Lett.* **57** 2374

Koshida N and Yoshida S 1978 *Appl. Phys. Lett.* **32** 708

Lynn K G and McKee B A T 1979 *Appl. Phys.* **19** 247

Marsolais R M and Sanche L 1988 *Phys. Rev.* B **38** 11118

Michaud M and Sanche L 1990 *J. Electron. Spectrosc. Relat. Phenom.* **51** 237

Mills A P Jr and Gullikson E M 1986 *Appl. Phys. Lett.* **49** 1121

Sambe H, Ramaker D E, Deschenes M, Bass A D and Sanche L 1990 *Phys. Rev. Lett.* **64** 523
Sanche L and Deschenes M 1988 *Phys. Rev. Lett.* **61** 2096
Schultz P J and Lynn K G 1988 *Rev. Mod. Phys.* **60** 701
Spear W E and Le Comber P G 1977 *Rare Gas Solids* vol 2, ed M L Klein and J A Venables (London: Academic) ch 18