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Letters to the Editor

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Optical properties of neutron and proton irradiated Kapton foil

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The optical transmission spectra of Kapton foils irradiated with ≥0.1-MeV neutrons and ~0.25-MeV protons have been recorded in the visible region using a photoacoustic spectrometer.

Kapton is a heat resistant, thermally and electrically insulating polymer. It has very good mechanical and optical properties with high radiation resistance. It can be operated up to 400°C in continuous use. This material is being used in nuclear technology as well as in space applications,[1] as a thermal control surface,[2] encapsulans for solar cells,[3] reflectors for concentrator arrays, and solar sail material.[4] The satellites in deep space face a considerable thermal, vacuum, and radiation threat which may damage the material properties and create failure to the system. Polymides (Kapton) are now being used as insulating material in the nuclear fusion experiments as a superconducting magnet coil insulation in a high radiation (neutron) environment.[5] The earlier reported result[6] that the effects of radiation on polymer depend only on the radiation energy, irrespective of the types of particle passing through it, has to be tested.

The present study was made, first, to see the differences in the extent and nature of the effect of charged and neutral particles and, second, to compare the results of Ar^+ implanted Kapton[3] foil with neutron and proton irradiated foils.

A 25-μm Kapton-H film was obtained from ISRO, India, and E. I. du Pont de Nemours & Co. Small pieces of appropriate sizes were cut from this sheet, cleaned in an ultrasonic cleaner with detergent, and then wrung with deionized water several times. These samples were irradiated with fast neutrons ($E \geq 0.1$ MeV) at the APSARA reactor of Bhabha Atomic Research Centre, India, with doses up to 1.2×10^{18} cm^{-2}.

The H^+ implantation at 0.25 MeV was done on Kapton foil using the AN-400 Van de Graaff accelerator in B.H.U. India with doses of 7×10^{15} cm^{-2}. The details of the techniques used for the H^+ implantation have been reported earlier.[7]

The transmission spectra of the irradiated and unirradiated samples were recorded using a photoacoustic spectrometer[8] in the visible region. A 600-W halogen lamp was used as a visible continuum source. A discrete frequency chopper obtained from EG & G PARC, model 125A, was used. Light from the source was focused onto the entrance slit of a monochromator from CEL, model HM401. The light coming out of the monochromator was focused into a photoacoustic cell having carbon black as a blackbody absorber. The microphone signal was processed using a lock-in amplifier from EMCO, model EE201.

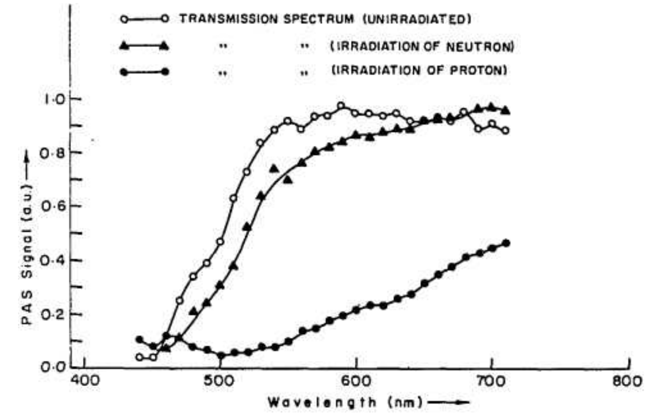

Fig. 1. Transmission spectra of ○, Virgin Kapton foil; ▲, neutron irradiated Kapton foil; ●, H^+ implanted Kapton foil.

Figure 1 shows the transmission spectra of the unirradiated and irradiated Kapton foils. The unirradiated foil shows an absorption peak at 450 nm. The peak of the neutron irradiated sample is broadened and shows an increased absorption (decreased transmission) at each wavelength below 700 nm. This effect is more pronounced in the case of the proton (H^+) irradiated sample, where the transmission signal becomes very low compared with the transmission in the unirradiated or neutron irradiated samples. The increase in transmission at 450 nm and development of a new peak at 510 nm show that the number of original molecules decrease due to dissociation and some other radicals are being formed in the effect of H^+ irradiation.

Along with the dissociation of molecules, the production of electrons due to ionization of the atoms is also probable. These electrons may be trapped and produce color centers. The trapping of electrons may also shift the absorption peak toward the higher wavelength side.[9] The observed darkening in Kapton after irradiation may be due to the same effect, which leads to the broadening of the transmission spectra. The broadening in neutron irradiation is very small because these are the neutral particles, and a large number of high energy neutrons can easily pass the Kapton thickness. The penetration depth of ~0.25-MeV protons in these polymers is ~1 μm. This shows that all the energy of protons and particles itself will be absorbed in the foil and create dissociation and ionization. In this case doses for neutron irradiation are 3 orders of magnitude higher; the energy is of the same order but has less effect, as observed experimentally. The transmission spectra of proton irradiated Kapton foil are in qualitative agreement with the earlier ~1-keV Ar^+ implanted Kapton foil spectra.[3] This confirms that all charged particles will have a greater effect than the neutral particle. The decrease in resistance[3] and increase in dielectric constant[7] of Kapton foil bombarded by charged particles have been reported. The values are in agreement with the following relation for polyimides[9]:

$$\rho_0 \epsilon_0 = \text{const.}$$

where ϵ_0 is the dielectric constant and ρ_0 is the resistivity of the foil. Mirtich and Sovey[3] have reported that the increase in conductivity and increase in absorption of Ar^+ implanted Kapton will solve many problems expected during space missions. The similarity of our results (after H^+ implantation) with Mirtich and Sovey[3] shows that the H^+ implantation on Kapton will be helpful for space missions. Cosmic rays (H^+ particles) will continue to modify the kapton properties during the space mission. Therefore, high energy Ar^+ implantation in Kapton is not necessary before the space mission in any of the above-mentioned systems, if the level of cosmic H^+ implantation is sufficient.

The main conclusions of the above results are the following:

(1) The proton does have a greater effect on kapton properties than do neutron doses, which shows that any charged particle will have more effect (due to small penetration length) than neutral particles. This makes it suitable for use as an insulator in high flux neutron environments, as in reactors.

(2) The effect of H^+ implantation increases the bandwidth and absorption in the visible region and also increases the conductivity. This makes the Kapton properties more suitable for space applications,[3] because in space cosmic rays (H^+) are present.

(3) The photoacoustic spectrometer can be used to study the radiation damage in transparent materials.

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Novel correlation radiometer: the length-modulated radiometer

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The operating principle of a new radiometer is described, which consists of length modulation in a static cell. This development retains the advantages of the pressure modulator but allows higher operating pressures.

The technique of correlation radiometry has been used for many years to measure composition and temperature in the middle and upper atmosphere. Such devices as the selective chopper radiometer (SCR) and pressure modulator radiometer (PMR) have been flown successfully on balloons, aircraft, and satellites.[1-6]

Correlation radiometers operate by switching the optical path between one which has a large gas path and one which has a smaller gas amount, or none at all, while making minimal changes to the rest of the optical system. The only change in optical properties is the change in the transmission at wavelengths near those of spectral lines of the gas sample. By alternating the paths and electronically detecting radiance changes at the alternating frequency, a filter is synthesized which only passes radiation at wavelengths near spectral lines of the gas sample. The sensitivity of the instrument to atmospheric emissions whose wavelength is close to, or coincident with, spectral lines of the gas sample is, therefore, greatly enhanced, and a lower detection limit may be achieved.[1]

There are a number of engineering problems associated with the technique which have been overcome in various ways. These are essentially concerned with the balance problem which is caused by disturbances to the optical path in excess of those due to the changing gas amount. These additional changes could be misinterpreted as signals if not properly treated in the calibration and data processing. A PMR has a minimal problem in this respect as only the gas itself is moved,[1] whereas the SCR has a larger problem as the entire gas cell, including the windows which are also vacuum

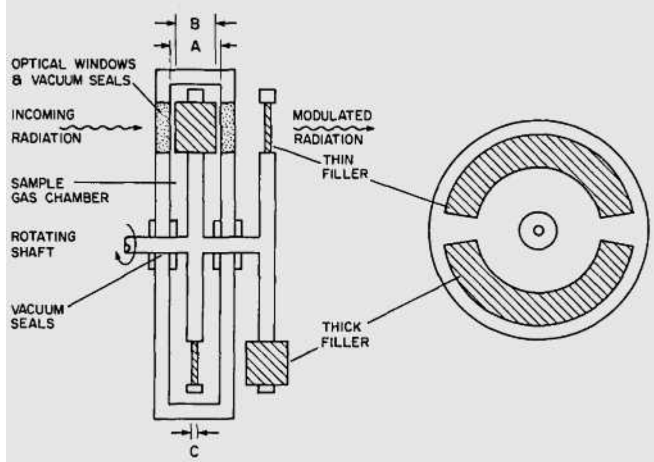

Fig. 1. Conceptual drawing of a length-modulated radiometer. One section of the rotor is shown end-on as well as in section. The gas path length is switched between $A - B$ and $A - C$.