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EFFECTS OF A HIGH-ENERGY PARTICLE ENVIRONMENT ON THE QUANTUM EFFICIENCY OF SPECTRALLY SELECTIVE PHOTOCATHODES FOR THE MIDDLE AND VACUUM ULTRAVIOLET

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ABSTRACT

The quantum efficiencies of spectrally selective photocathodes for the middle and vacuum ultraviolet were measured. The photocathode materials which were investigated are semitransparent depositions of CsI, CuI, and CsTe on Al_2O_3 windows, and a solid tungsten photocathode located behind a MgF_2 window. The quantum efficiencies of these photocathodes were measured before their use as detectors in an Aerobee 150 rocket experiment, and again one year later. There was no observable change in their quantum efficiencies in this interval.

These photodiodes were then irradiated with a dose of 5×10^{13} electrons/cm^2 at 1.0 MeV, and 5×10^{13} electrons/cm^2 at 2.0 MeV. This electron energy and dose represent what might be encountered in the artificial radiation belt in a circular, near polar orbit at 1400 km in the course of a year. The quantum efficiencies of the photodiodes were again measured. Only the CsI photodiode showed a change, an increase by almost two and one-half times in its quantum efficiency.

To examine further the increase in the quantum efficiency noted in the CsI photodiode after irradiation, two other CsI diodes were irradiated. One was subjected to a total dose of 10^{15} electrons/cm^2 at 1.5 MeV, and the other to a dose of 10^5 rads from a Co^{60} gamma source. Neither of these CsI diodes showed any observable change in quantum efficiency.

From these measurements it appears that the CuI and CsTe photocathodes are characterized by quantum efficiencies which remain stable under a high energy particle enviornment, while a CsI diode might exhibit a large increase in its quantum efficiency. All the photodiodes appear to be stable with time.

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EFFECTS OF A HIGH-ENERGY PARTICLE ENVIRONMENT ON THE QUANTUM EFFICIENCY OF SPECTRALLY SELECTIVE PHOTOCATHODES FOR THE MIDDLE AND VACUUM ULTRAVIOLET

INTRODUCTION

During the past ten years a considerable amount of time and effort has been expended in the development of photodetectors which possess high quantum efficiencies in the far and extreme ultraviolet.[1,2,3] These detectors are also described as "solar blind" because they are generally insensitive to light of wavelengths greater than 3000 Å, the short wavelength transmission limit of the terrestrial atmosphere. These detectors when first used were subjected to a space environment for only short periods of time, the few minutes during which sounding rockets are operational. Later, with the advent of earth satellites, these detectors have been used in experimental payloads which are expected to remain operational for a year or more. Generally the orbital elements of the satellites are such that the satellites spend a considerable portion of their lifetimes in the Van Allen radiation belts where they are subjected to the bombardment of high energy electrons, protons, and the resultant brehmstrahlung produced by the particles colliding with the spacecraft.

This work is concerned with the investigation of the effects of a high energy (1 MeV to 2 MeV) electron environment on the quantum efficiency of some representative photocathode materials which are commonly used in space research. Previous research on the effect of high energy electrons, Heath and Sacher,[4] and high energy protons, Sacher and Heath,[5] on the ultraviolet transmission of materials has shown that effects due to radiation on the window materials, Al_2O_3 and MgF_2, should be negligible in this investigation. Observable effects may therefore be attributed to the irradiation of the photocathode materials.

It is well known that the alkali halides are highly susceptible to the formation of F or color centers, the trapping of an electron at the site of a crystal lattice vacancy, when subjected to high energy radiation. This radiation may be electromagnetic, or that due to high energy particles. These trapped electrons may then indicate a wavelength-dependent increase in quantum efficiency. Presumably the wavelength dependence would be characteristic of the crystal structure.

The photocathode materials which were investigated are semitransparent depositions of CsI, CuI, and CsTe which were deposited on Al_2O_3 windows which are 0.5 mm thick, and a solid tungsten photocathode which is located behind a MgF_2 window. The MgF_2 window served only as a control of the total electron irradiation. These are sensors which are scheduled to be flown on a Nimbus spacecraft in an experiment designed to monitor the ultraviolet flux from 1100–3000 Å. The long wavelength response of the sensors is used in conjunction with the short wavelength transmission limit of various optical materials to separate the solar spectrum into relatively broad spectral intervals.

EXPERIMENTAL PROCEDURE

A set of five vacuum photodiodes* was first investigated. This set was comprised of the four semitransparent photocathodes (two CuI, one CsI, one CsTe) deposited on sapphire, and one opaque tungsten photocathode behind a MgF_2 window. The quantum efficiencies of the five sensors were calibrated before they were flown aboard an Aerobee 150 rocket from White Sands, New Mexico on August 29, 1966. They were subsequently recovered intact and fully operational. One year later, June 1967, they were recalibrated.

These photodiodes were then irradiated together at 1.0 MeV for a dose of 5×10^{13} electrons/cm^2 over a period of 35 minutes, and at 2.0 MeV for a dose of 5×10^{13} electrons/cm^2 for the same length of time. This irradiation is an approximation of the flux, predicted for January 1966, in a circular polar orbit at 1400 km over a period of one year, assuming no decay. The four sensors with semitransparent photocathodes were recalibrated within four days, and the opaque cathode within eleven days, after the irradiation. The absolute calibration was made using the standard technique of calibrating a freshly deposited film of sodium salicylate in front of a photomultiplier at H-Lyman α against a calibrated nitric oxide ionization cell, and at 2537 Å against a calibrated thermopile. It was assumed that the response of sodium salicylate was uniform between 1216 Å and 2537 Å. The calibration obtained with the ionization cell and the thermopile agreed to better than 15%. The freshly prepared film of sodium salicylate was in turn used to calibrate a tungsten diode and a CsTe diode which were thereafter used as standard detectors. All calibrations used in this work were obtained by comparison measurements with these two standard detectors.

RESULTS

The results showing the two calibrations made before irradiation, and the calibration made after the irradiation are shown in Figures 1-4. In Figure 1 the lowering of the quantum efficiency after irradiation is due to a loss of transmission

*A product of the Princeton Division of Electro-Mechanical Research, Inc., Princeton, New Jersey by the MgF_2, which is consistent with the observations of Heath and Sacher.[4] There should be no observable change in the transmission of the Al_2O_3 windows. There were no significant changes observed except in the case of the CsI photodiode, Figure 3. This photodiode showed a definite increase in the quantum efficiency. This irradiated CsI diode was recalibrated again 10 days after the irradiation. (The points of this recalibration are indicated by □ in Figure 3.) There was no observable reduction of the increase noted in the quantum efficiency after the irradiation by the electrons.

To investigate this effect further two more CsI diodes, which were made from two separate processings, were irradiated. One of these diodes which has a design similar to the diode described in Figure 3, but processed prior to it, was subjected to irradiation by gamma-rays from a Co^{60} source with a dosage of 10^5 rads.* The results showing the quantum efficiency before and after the gamma-irradiation are shown in Figure 5. There was no observable change in the quantum efficiency. The second CsI diode, a newer and more rugged model, was irradiated with electrons. The same electron flux and energies were used as in the previous experiments. The results are shown in Figure 6. This diode was then subjected to an additional total does of 10^{15} electrons/cm^2 at 1.5 MeV. There was no observable change in the quantum efficiency of this photodiode. There is no doubt, however, that the induced radiation effect indicated in Figure 3 is a real increase in the quantum efficiency. Sets of measurements preceding and following the irradiation indicate this clearly.

DISCUSSION

While the increase in the quantum efficiency of one of the CsI diodes which was irradiated is a genuine increase, it is surprising that such an increase is not reproducible in other CsI diodes which have been irradiated. The reason may be that the processing of these photocathodes is an art which still contains some uncertainties in their manufacture, as far as reproducibility is concerned. The possibility exists that the crystal structure (i.e. the number of crystal defects and lattice site vacancies) is different in those diodes which change under irradiation and those which do not. Another possible explanation is that during the irradiation contaminents were released which reacted with the photocathode material in this one diode.

The ratio of the quantum efficiencies measured after and before irradiation is shown in Figure 7 for the diode which experienced a change in its quantum

*One rad represents an absorbed dose of 100 ergs/gram of material.

efficiency. The three peaks at 1600 Å, 1825 Å, and 2260 Å are to be noted. Each of the points represents the average of quantum efficiency measurements after irradiation to measurements before irradiation, and the ratios are derived from the actual data points and not the smoothed curves.

According to M. Rome,[6] the CsTe cathode is prepared by evaporating Cs and Te separately, whereas CuI and CsI are evaporated as molecules from ultra-high purity single crystals. Of the two compounds, CuI and CsI, only CsI is an alkali halide. Thus, of the photocathodes considered in this work only CsI would be expected to show a radiation induced change in the quantum efficiency. This change would be related to the formation of F or color centers at the sites of vacancies in the crystal lattice. The number of vacancies may be related to the deposition process, and could vary considerably in different processings. Conceivably the increased quantum efficiency could be due to the ejection of the trapped electrons. A test of this hypothesis would be to determine if the quantum efficiency may be reduced to its pre-irradiation value by annealing the diode for several hours at elevated temperatures which are not high enough to decompose the crystal structure of the photocathode. This method of annealing the alkali halides to remove color centers is a well established technique. An attempt to bleach, at 100° C, the CsI photodiode which showed an increase in quantum efficiency after irradiation was not successful, due to a failure of the diode after baking. This failure was probably due to an excessive expansion of the potting material at this elevated temperature.

From these measurements it appears that the spectrally selective photocathodes for the middle and vacuum ultraviolet are characterized by quantum efficiencies which are very stable in a high energy particle environment, and over extended time intervals. However, because of the effect observed in one of the CsI photodiodes, it might be advisable to irradiate and examine the CsI photodiodes before using them.

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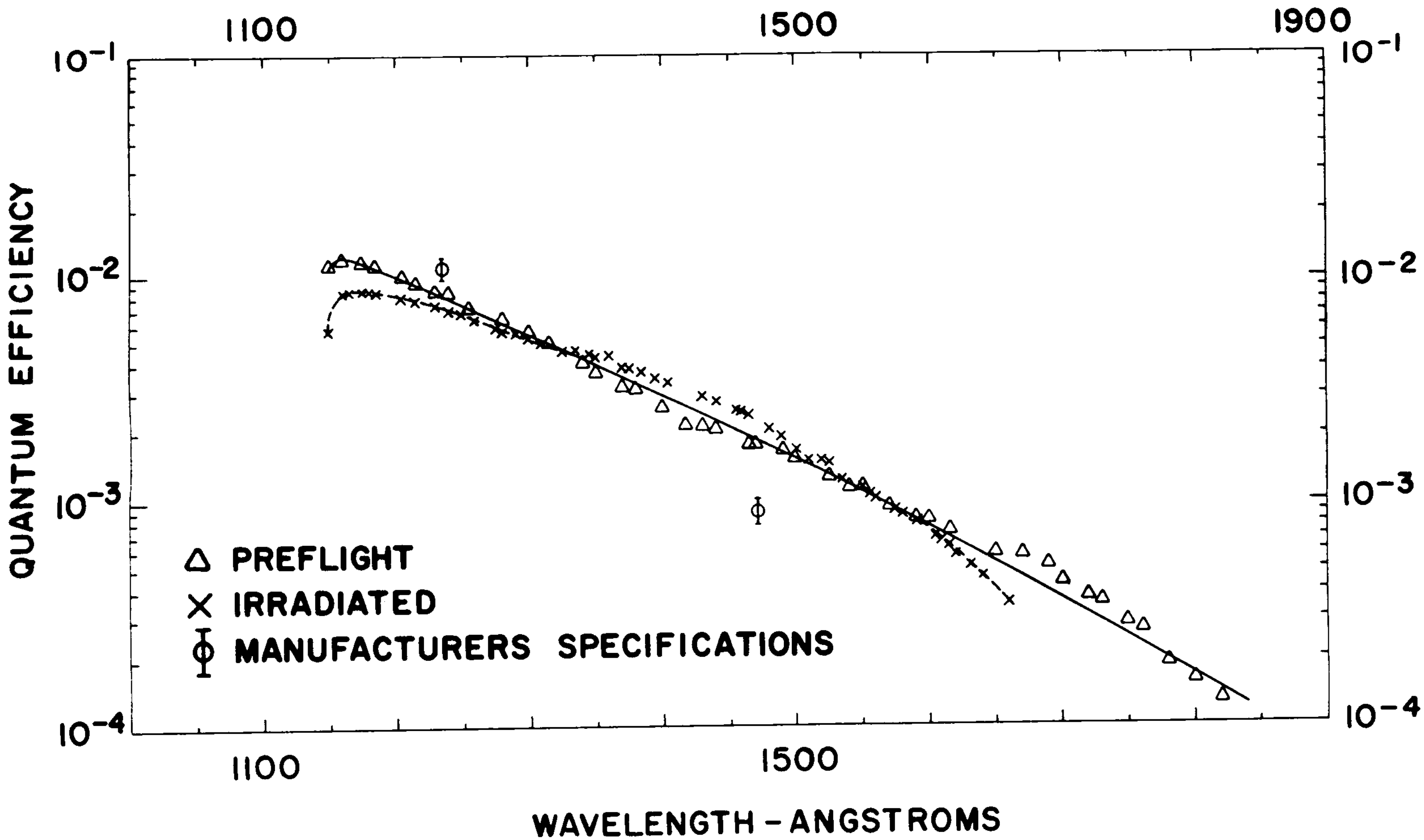

Figure 1. Quantum efficiency of tungsten photodiode before and after irradiation by 5×10^{13} electrons/cm^2 at 1.0 MeV and at 2.0 MeV.

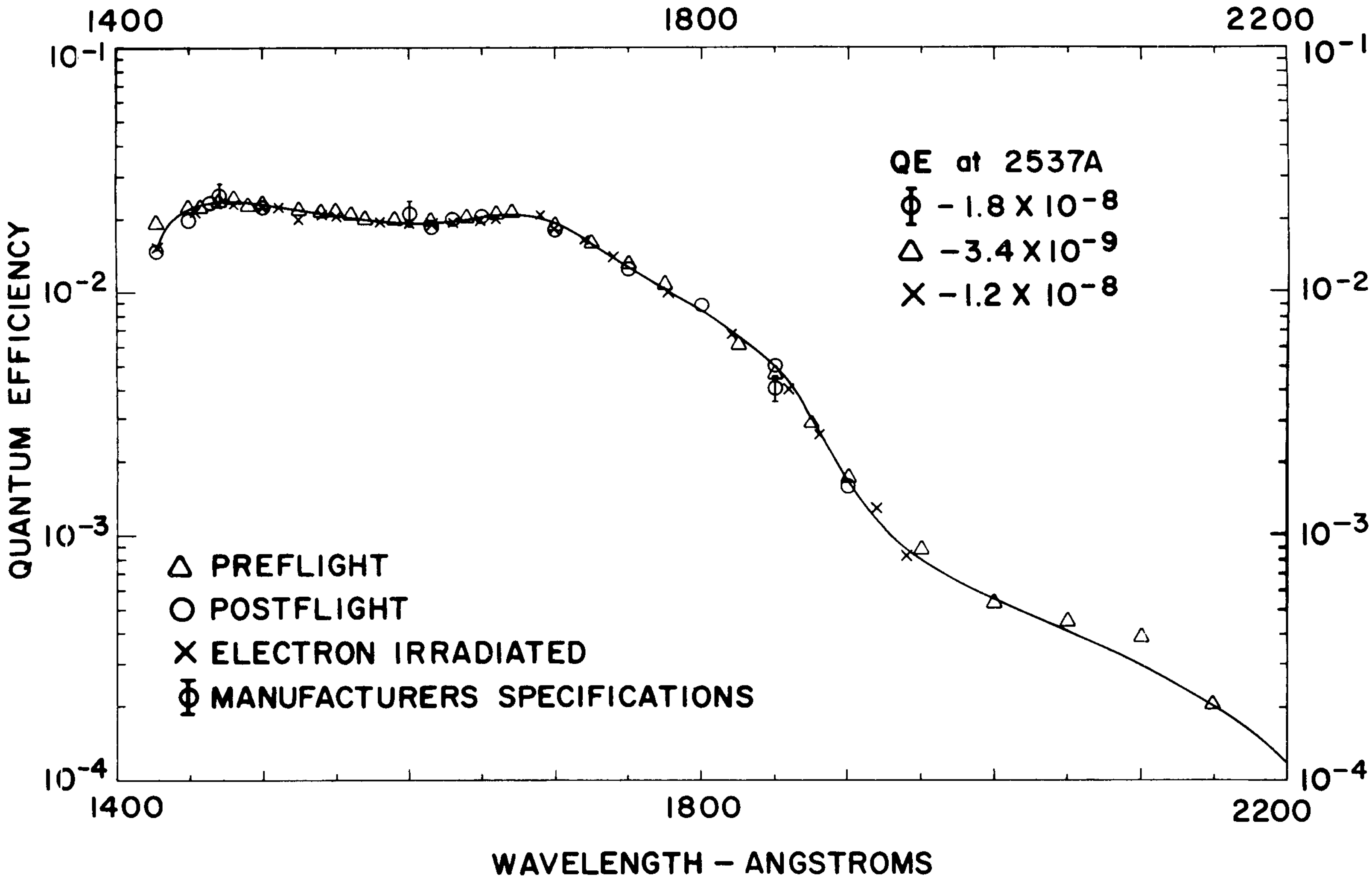

Figure 2. Quantum efficiency of CuI photodiode before and after irradiation by 5×10^{13} electrons/cm^2 at 1.0 MeV and at 2.0 MeV.

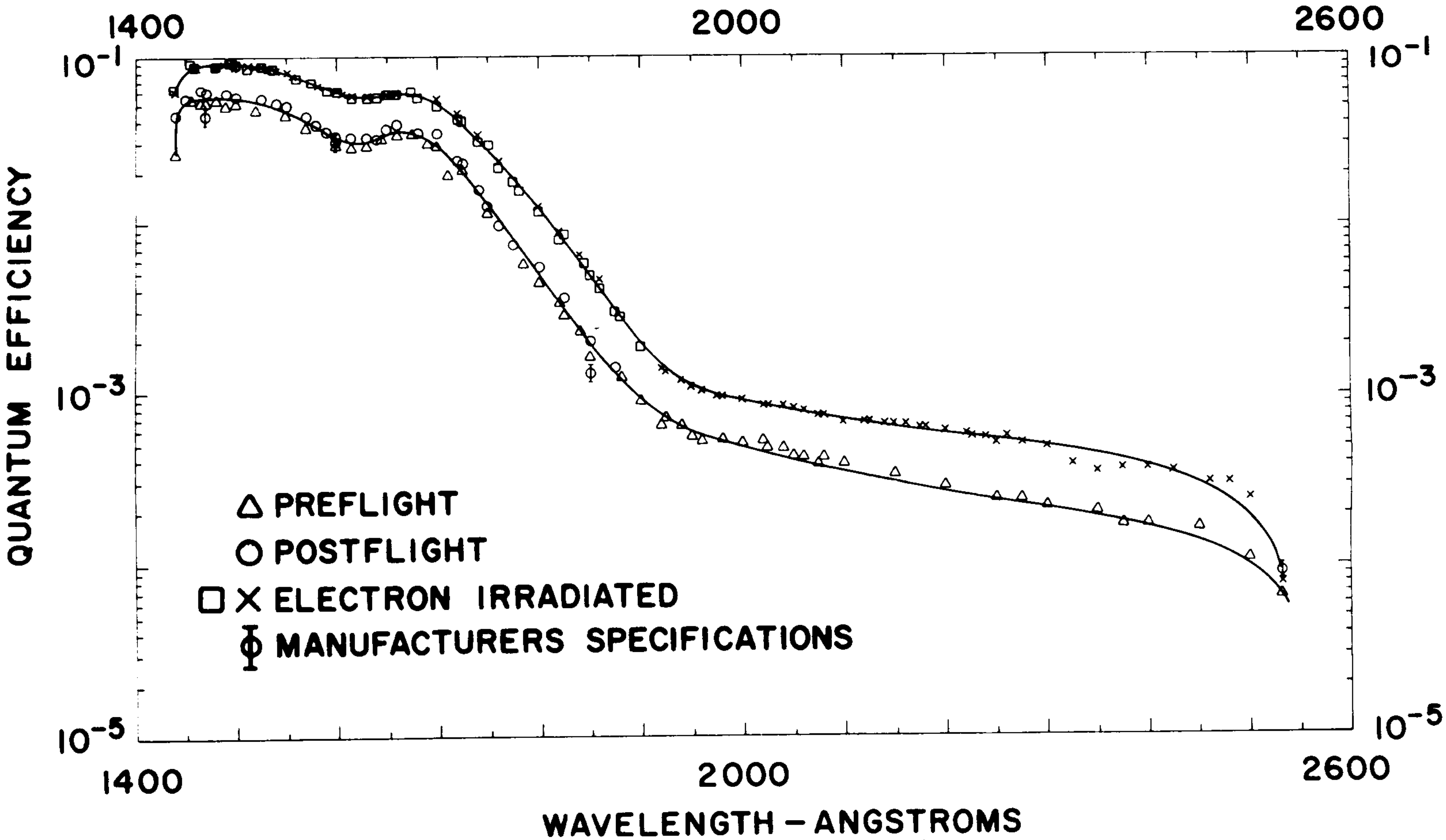

Figure 3. Quantum efficiency of one of the CsI photodiodes before and after irradiation by 5×10^{13} electrons/cm^2 at 1.0 MeV and at 2.0 MeV.

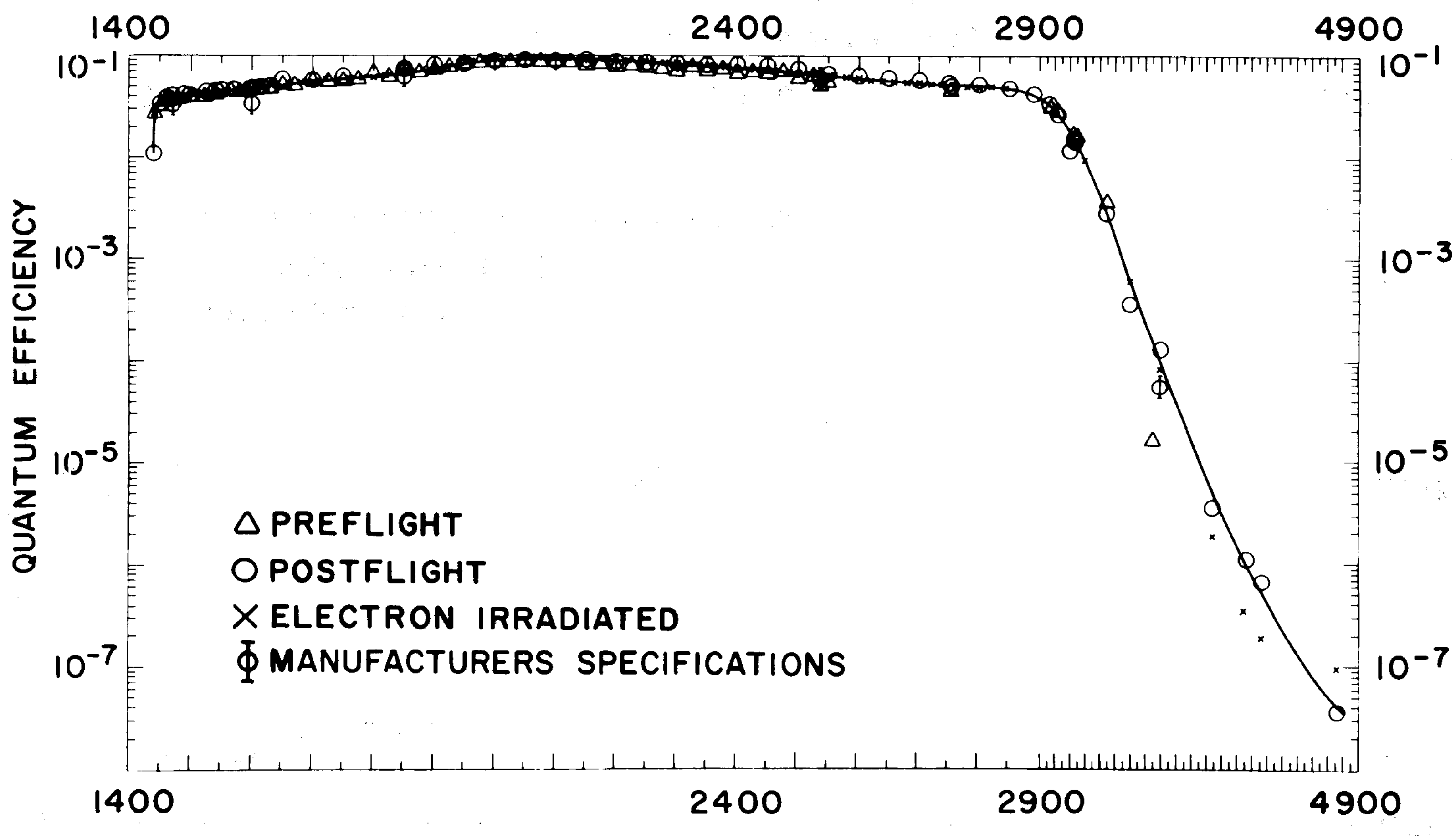

Figure 4. Quantum efficiency of CsTe photodiode before and after irradiation by 5×10^{13} electrons/cm^2 at 1.0 MeV and at 2.0 MeV.

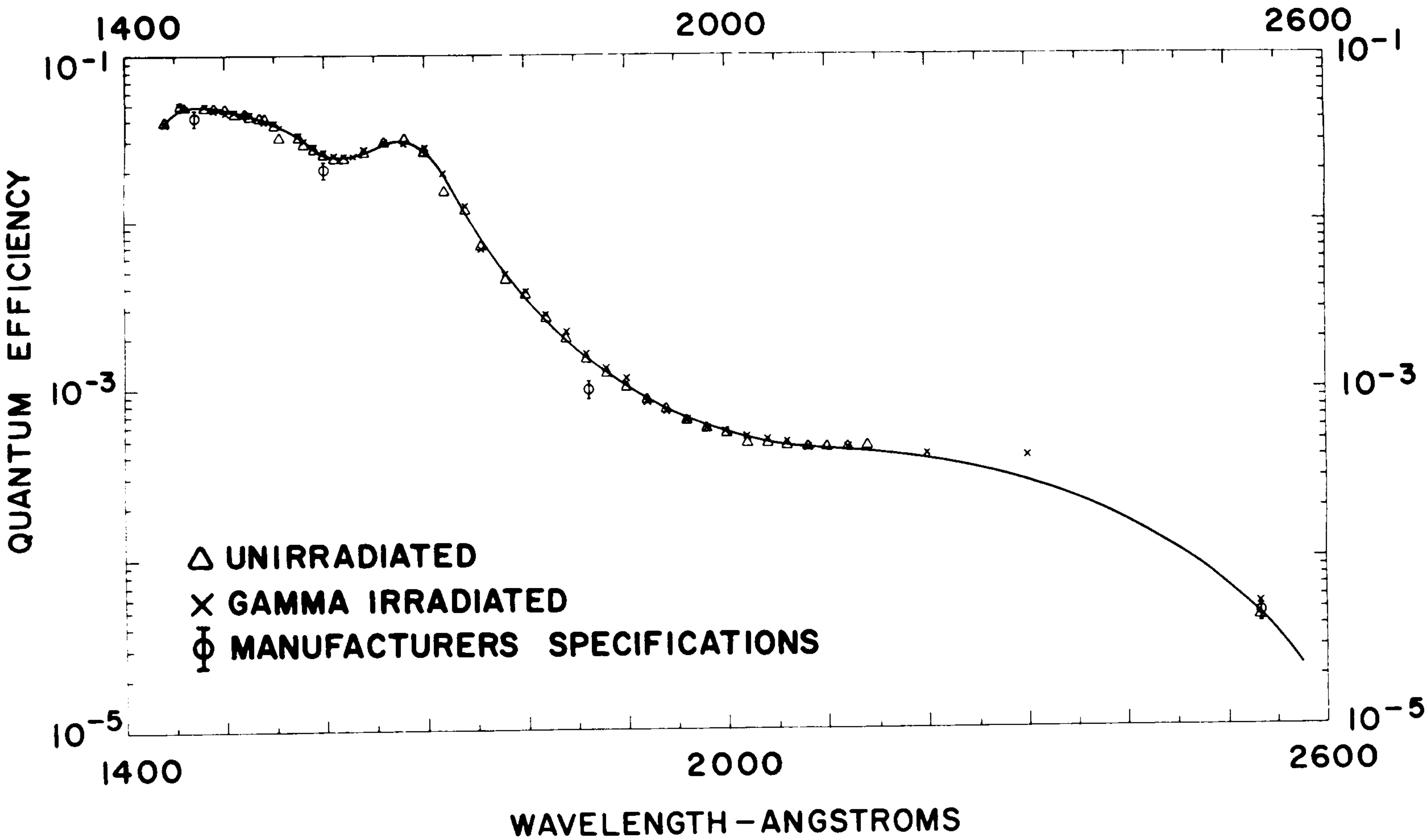

Figure 5. Quantum efficiency of one of the CsI photodiodes before and after gamma irradiation with a dosage of 10^5 rads.

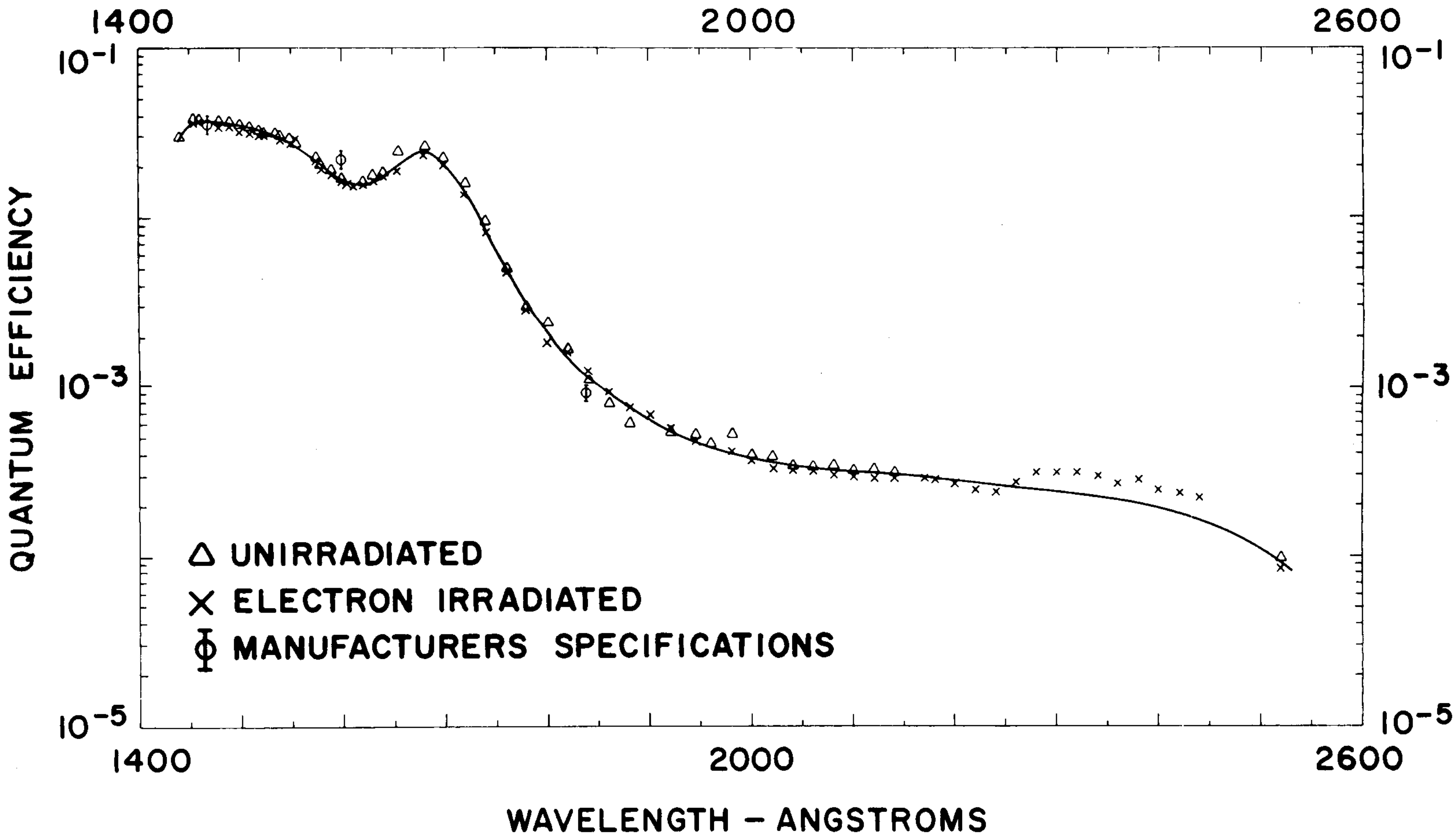

Figure 6. Quantum efficiency of one of the CsI photodiodes before and after irradiation by 5×10^{13} electrons/cm^2 at 1.0 MeV and at 2.0 MeV.

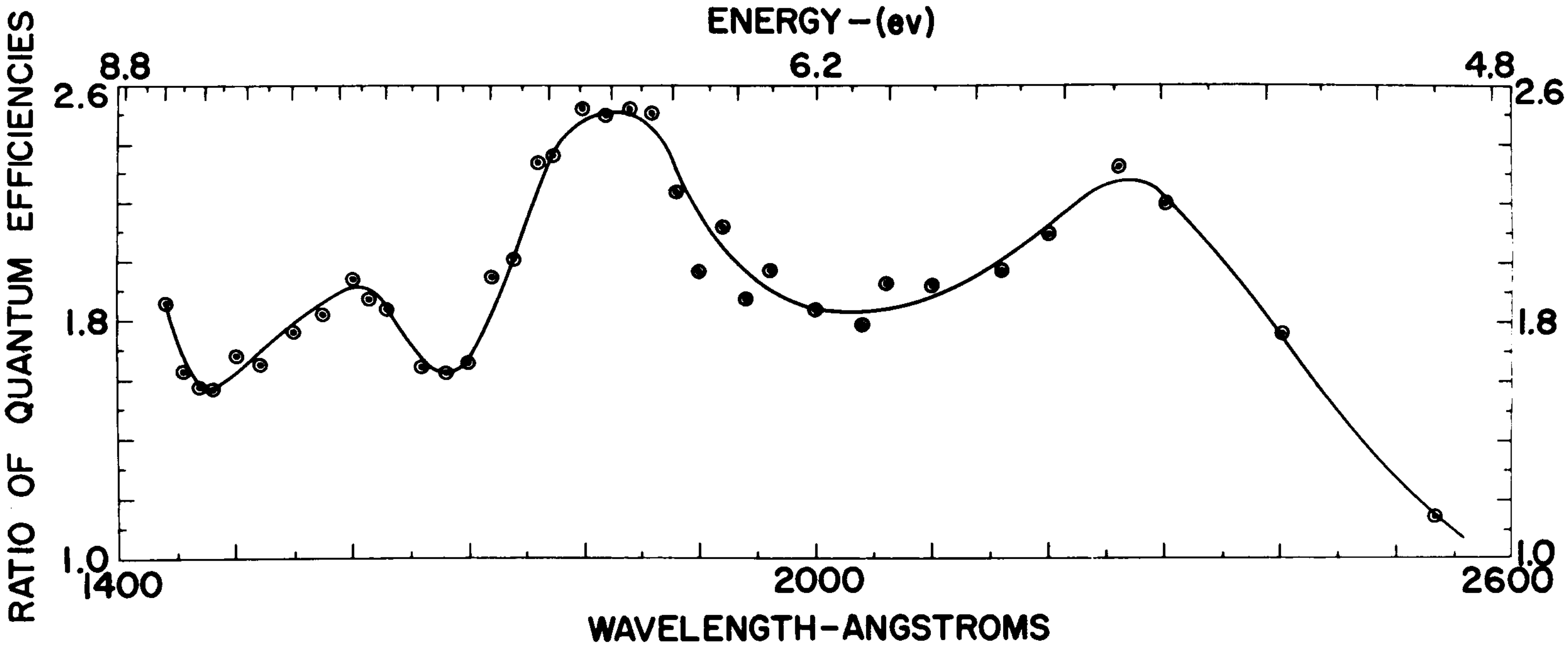

Figure 7. Ratio of the quantum efficiency after irradiation to that before irradiation by 5×10^{13} electrons/cm^2 at 1.0 MeV and at 2.0 MeV, of the CsI photodiode illustrated in Figure 3.