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SCINTILLATION SPECTROMETRY WITH HgI_2 AS THE PHOTODETECTOR*

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ABSTRACT

A mercuric iodide (HgI_2) photodetector has been used to detect light pulses from gamma-ray and alpha-particle interactions in scintillators. The photocurrent response of an HgI_2 photodetector to light has been measured and found to be favorable for detecting light from most scintillators, which have their maximum emission between 300 and 500 nm. Energy spectra for alpha particles or gamma-rays from combinations of an HgI_2 photodetector with various scintillators are presented. The energy resolution of the photopeak from annihilation gamma-rays is 19% with a CsI(Tℓ) crystal and 24% with a BGO crystal. Fabrication of HgI_2 photodetectors and their optical coupling to a scintillator crystal will be described. The advantages of this new solid-state radiation detector compared to the combination of scintillator and PMT, and some proposed applications, are discussed.

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1. INTRODUCTION

A mercuric iodide (HgI_2) photodetector has been used to detect light pulses from scintillators exposed to gamma-rays and alpha particles. Previous attempts to exploit solid state photodetectors to detect the light pulses from scintillators have not resulted in very practical devices for detecting ionizing radiation, except for very high energy charged particles.[1] Devices have been made (and used, for example, in computer tomography scanners) which operate in the current mode, responding to the integration of many individual ionization events, but not to individual events. The main problem has been noise associated with the solid state photodetector and its associated preamplification electronics. In order to keep the noise low, Si photodiodes have been utilized with special guard ring structures[2] or with cryogenic cooling.[3] Because of noise considerations the active areas in these prototype photodetectors for scintillation light have been very small, at most a few square mm. Such small active areas limit the size of the scintillator that can be optically coupled to the photodetector, and the small active volume of the scintillator severely limits the detection efficiency for ionizing radiation that can be achieved practicably. The problem is in coupling a large enough scintillator to such a small photodetector area and still managing to get sufficient light out of the crystal and into the photodetector. Photodetectors with internal gain, such as avalanche photodiodes, require less light to produce a signal which can be distinguished above the noise, but avalanche photodiodes with relatively large active areas and reasonable gain uniformity over the active region did not appear until fairly recently.[4] We have made preliminary experiments on the detection of individual scintillation light pulses with avalanche photodiodes, but the results will be reported elsewhere.

2. PRINCIPLE OF OPERATION

In conventional scintillation spectrometry the interaction of ionizing radiation with a scintillation material gives rise to light which is detected by a photomultiplier tube (PMT). In the proposed concept an HGI_2 solid-state photodetector is used to replace the PMT.

Light of sufficient energy produced in a scintillator impinges on an HgI_2 photodetector and is transmitted through a semitransparent entrance electrode to produce electron-hole pairs in a very thin layer near the electrode. If the entrance electrode is negatively biased the resulting signal pulse is due entirely to the motion of electrons in the detector. Two factors which favor HgI_2 as a room-temperature detector material are its energy bandgap of 2.13 eV, which ensures a very low dark current and determines the long-wavelength limit of the spectral response to be about 600 nm, and the good electron transport characteristics of single crystals it has been possible to grow, which allow the construction of devices thick enough to have small capacitance. The usefulness of HgI_2 in the detection of x-rays has been demonstrated, and detectors based on this material have undergone considerable development in the last few years.[5-8] The charge carrier collection process in an HgI_2 photodetector is very similar to that in a low-energy x-ray detector. The ultralow-noise preamplification electronics which have been developed for HgI_2 x-ray detectors operating at room temperature[9] will be an important element in being able to detect scintillation pulses above the noise.

Solid state light-sensitive devices do not suffer the basic limitations which photomultipliers possess. There is no obvious minimum achievable size dictated by the physical mechanisms involved in their operation. Because of the spacing requirement between dynodes with large potential differences between them, there is some irreducible minimum in the size of PMTs which will eventually be reached. In addition they draw relatively large currents (mA) at high voltages (>1 kV). Solid-state photodetectors, on the other hand, offer the possibilities of more compact construction and lower-power operation. The highest quantum efficiency for PMT is usually less than 30%, often considerably less. Solid-state photodetectors have the potential for having a quantum efficiency close to 100% at wavelengths for which scintillation light output is maximum. Because of this, a solid-state photodetector presents the possibility of achieving better energy resolution than can be gotten with a PMT. Furthermore, solid-state light-sensitive elements are by their nature low-current, low-voltage devices which are compact and rugged. In addition, unlike the PMT, they need not be shielded from magnetic fields.

3. EXPERIMENTAL RESULTS

This paper reports the use of HgI_2 photodetectors, operating at room temperature to detect scintillation light pulses arising from the interaction of gamma-rays and alpha particles in scintillators.

Photodetectors were fabricated from HgI_2 with a semi-transparent entrance electrode of evaporated palladium. The area of the electrode was typically 16 to 100 mm^2. The spectral response characteristics were studied in the wavelength region from 300 to 600 nm by measuring the detector photocurrent arising from monochromator light which was allowed to impinge on the entrance electrode. Figure 1 gives the photocurrent as a function of wavelength for a typical HgI_2 photodetector. Somewhat similar results have been reported in the literature,[10-12] although previous investigators have used opaque carbon contacts, so that charge collection was from regions of the detector surrounding the entrance contact. The maximum photocurrent occurs at a wavelength of about 570 nm, and the long-wavelength cutoff is at roughly 600 nm. The majority of scintillators emit their maximum light in the region from 400 to 560 nm, so that the spectral response characteristics of HgI_2 are quite favorable for the detection of scintillation light.

Figure 2 is an alpha-particle spectrum from ^{244}Cm (5.8 MeV) measured at room temperature with an HgI_2 photodetector coupled to a bismuth germanate (BGO) scintillator. Figure 3 presents the annihilation radiation from a ^{68}Ga positron source (0.511 MeV), measured with a room-temperature HgI_2 detector coupled to a CsI scintillator crystal. Resolution (FWHM) is 19%. Similarly, we have obtained annihilation gamma-ray spectra using a room-temperature HgI_2 photodetector to detect the light from a BGO scintillator crystal. Figure 4 is a spectrum measured with a 4 mm x 4 mm HgI_2 photodetector coupled to a 4 mm cube BGO scintillator. The energy resolution of the 511 keV photopeak is 24%. It should be noted that the light output from BGO is only about one-tenth of the light output from NaI (Tℓ); the ability to show a photopeak energy resolution this good is indicative of the sensitivity of the HgI_2 photodetector.

4. CONCLUSIONS

It has been shown that scintillation light pulses produced by alpha particles and gamma-rays can be detected with HgI_2 photodetectors. The energy resolution of the photopeaks in the pulse height spectra which were obtained is comparable to that obtained with the combination of photomultiplier and scintillator, and improvements are expected to follow from optimization of HgI_2 photodetector design and fabrication.

The possible applications for an all solid-state room-temperature device combining the use of a scintillator and an HgI_2 photodetector for the detection of ionizing radiation are manifold, including most present applications in which photomultiplier tubes are used in combination with scintillators. Among the several significant advantages over photomultiplier tubes mentioned above, the great reduction in the size of the detector will permit changes in the design and construction of many types of present-day instruments, as, for example, in positron emission tomography, where a more compact detector arrangement may allow the attainment of improved spatial resolution. The low power consumption of HgI_2 photodetectors will allow the design of battery-operated scintillation spectrometry devices. Other applications in which detector size is a critical factor might include personnel radiation dosimetry and various types of probe-like detection arrangements in nuclear medicine.

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FIGURE CAPTIONS

Figure 1. Photoresponse versus wavelength of HgI_2 photodetector measured at a bias of 900 V.

Figure 2. Spectrum of alpha particles from ^{244}Cm taken with a bismuth germanate (BGO) scintillator coupled to an HgI_2 photodetector. Peak energy is 5.8 MeV.

Figure 3. Spectrum of 511 keV annihilation radiation from a ^{68}Ga positron source, taken with a CsI scintillator coupled to an HgI_2 photodetector. Resolution of the photopeak is 19%.

Figure 4. Energy spectrum of 511 keV annihilation radiation from a positron source detected with a 4 mm x 4 mm x 4 mm BGO crystal optically coupled to an HgI_2 photodetector fabricated with a thin semitransparent entrance contact of 4 mm x 4 mm. Detector bias voltage was 1000 V. Energy resolution of 24% is not substantially worse than typical value obtained with BGO and a photomultiplier tube, namely about 20%.

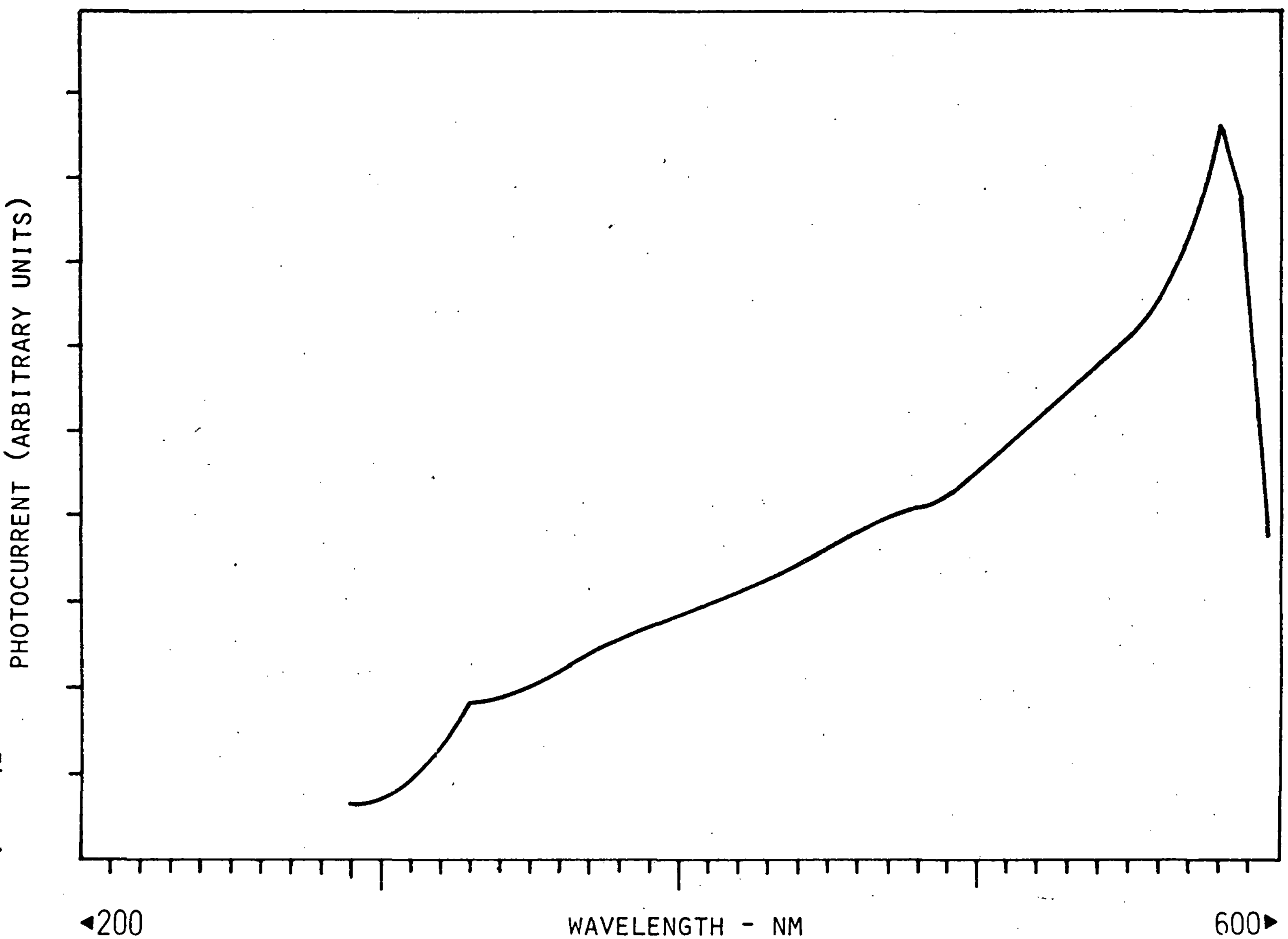

Figure 1

S-210-TP

FIG 1

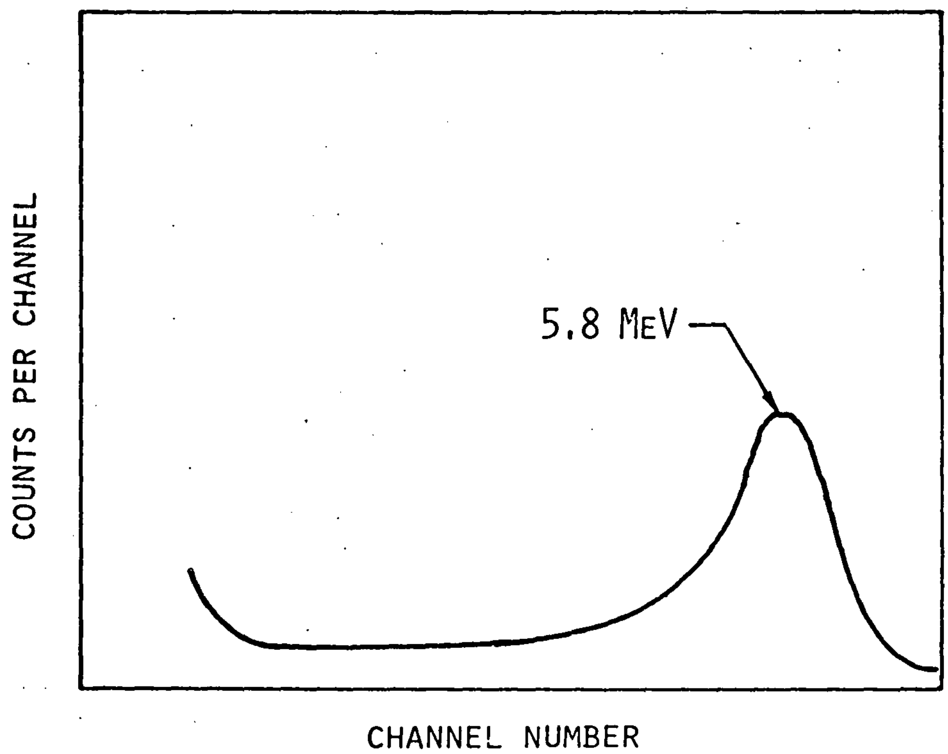

Figure 2

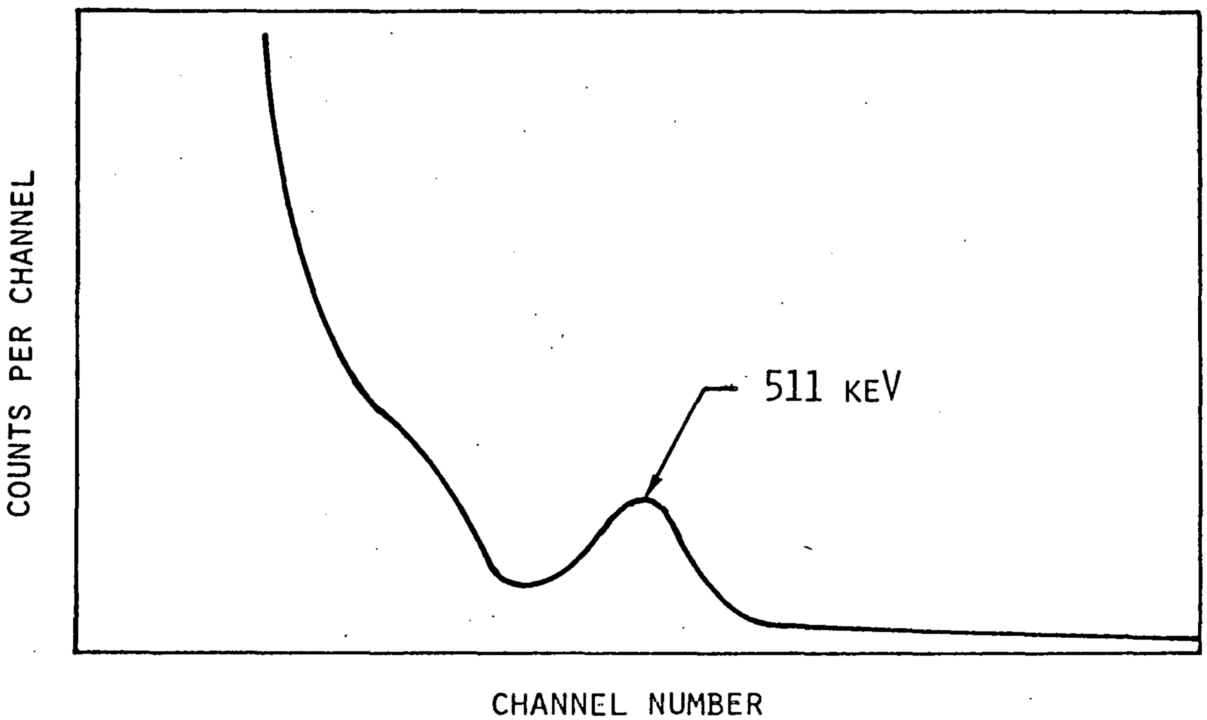

Figure 3

S-210-TP

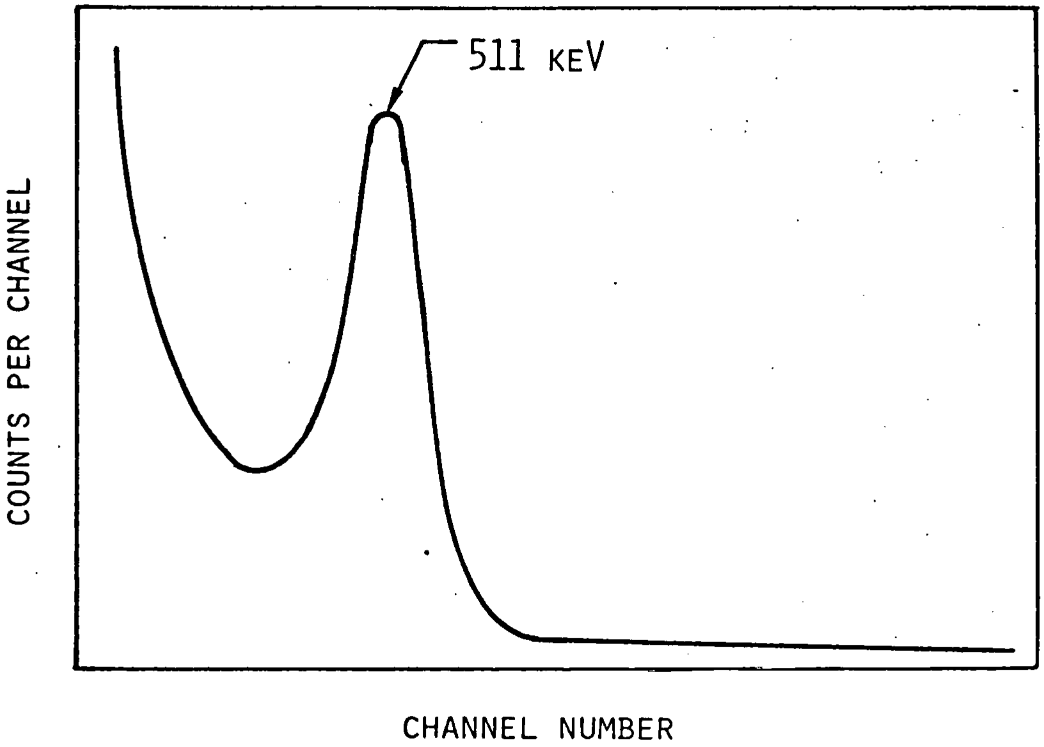

Figure 4

S-210-TP