Silicon PIN-photodiode and CsI(TI) scintillator in application to a portable dosimeter

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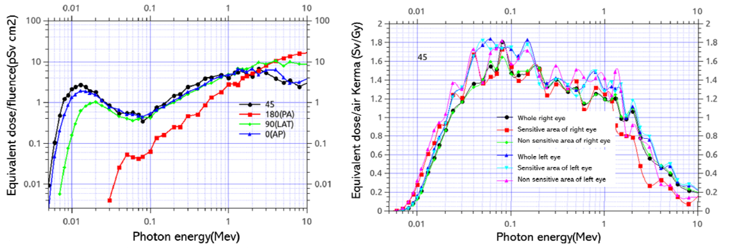
1. Background

ICRP has recommended an equivalent dose limit for the eye-lens be 20mSv per year, averaged over defined periods of 5 years, with no single year exceeding 50mSv. The reduction of the limit for occupational exposure for the eye-lens has significant implication in view of the application to planned exposure situations for the different areas of occupational exposure and needs adequate approaches for eye protection and eye dose monitoring. The electronic dosimeter can give an alarm in time when personnel are accidentally exposed, which is irreplaceable by TLD or other passive dosimeters.

2. Eye-lens dose simulation

Based on the ocular lens anatomy data of Behrens et al., the trunk and head models including the fine structure of the ocular lens were established in the geent4 program, and the calculation of the ocular lens dose conversion coefficient under different scale models was completed. The calculation results were close to those of Behrens. The current Chinese standard does not specify the calibration model of $H_p(3)$ dosimeter. Although the ISO standard plate model is different from the real head in shape and size, the simulation results show that it is appropriate and conservative to use $H_p(3)$slab to evaluate the ocular lens dose. Therefore, the ISO plate model is used to calibrate the dosimeter in this test.

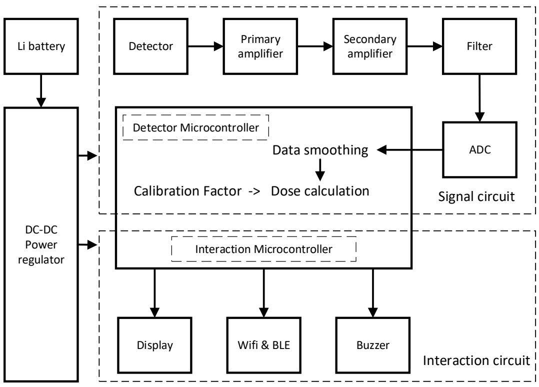


Simulation results of dose equivalent conversion coefficient, based on Behrens' research

3. Development of $H_p(3)$ dosimeter

3.1. Integrated Design

- The composition of the dosimeter is shown in the following figure. Silicon semiconductor detectors usually operate in current or pulse mode to collect the charge generated by the radiation, and the dosimeter uses current mode. The detector is a cesium iodide silicon semiconductor composite detector. When the incident ray deposits energy in the sensitive volume of the detector, the silicon semiconductor outputs the current signal. The small current output by the detector is converted into a voltage signal by an amplification circuit, and then the high-frequency noise is filtered by a low-pass filter. The voltage signal passes through the comparator / AD converter integrated in MCU, and the amplitude of the voltage signal is continuously collected, counted and analog-to-digital converted in each calculation cycle, and the average value of the voltage amplitude in the calculation cycle is counted to complete the original measurement. The average value of the average value of voltage amplitude in unit time reflects the current exposure dose rate.



Integrated Design of HP (3) dosimeter

3.2. hardware development

- The scintillator used in this paper is CsI(TI) scintillator. The most suitable characteristic for matching with silicon semiconductor is the emission wavelength. The light output wavelength of CsI material is about 560nm, which can be well coupled with Si pin type semiconductor. In addition, CsI is not as easy to deliquesce as Nai, nor easy to oxidize, and is easy to be processed into various shapes, so it is very suitable for the use of small detectors.
- The silicon semiconductor used in this paper is Hamamatsu S8559 silicon PIN photodiode. Its effective detection area is 10*10mm, the photoelectric sensitivity is 0.66a/w at 960nm, and the dark current is 6na at 70V bias. The main characteristic of this semiconductor is that the output signal strength is larger than that of other silicon semiconductors. It can be directly used as a radiation detector or combined with scintillators such as CsI(TI).
- Since the semiconductor operates in the current mode, the output current amplitude of the semiconductor is low for a low radiation level, and the lowest value is only ten to several hundred PA, which requires an amplification circuit with high gain and low noise. In this paper, a two-stage amplifier circuit is designed and fabricated. The preamplifier is a transimpedance and non-polarized current voltage amplifier, which is used to amplify the output signal of PIN diode and provide 10^8 closed-loop gain at zero frequency. The output voltage is proportional to the photocurrent generated in the photodiode. The post amplifier is a voltage amplifier with a gain of 10^2. The input bias current of the operational amplifier shall be as low as possible. The main circuit schematic diagram and circuit response curve are shown in the following figure.

3.3. low power design

In this paper, MSP430 single-chip microcomputer is used, and the program of single-chip microcomputer is compiled by C language. It is a 16-bit single-chip microcomputer with low power consumption and has many low power consumption modes. After the startup of the dosimeter and the completion of system initialization, the working state of the dosimeter is in LPM0 sleep state for most of the time, i.e. low power consumption state. The functions that may occur at any time, such as pulse capture and keys, are detected by the system through the I/O port interrupt mode, which saves the power consumption of timing query related module States, and uses the auxiliary clock to maintain the basic timing.

Whenever the data acquisition timing is 2s full (corresponding interrupt is generated), the system wakes up from the LPM0 mode to the active mode for data acquisition, i.e. reads the count value and clears it to start accumulation again; The data processing includes updating the just acquired count to the smoothed data set, using the long and short switching algorithm for smoothing, substituting the smoothed result into the dose and dose rate calculation, and finally displaying the data, that is, displaying the calculated dose or dose rate on the screen. The execution of these functions can be completed in a relatively short time, and then the system enters the LPM0 mode again, and circulates the above-mentioned working state with a period of slightly more than 2s.

3.4. Prototype processing

The dosimeter prototype is shown in the figure below. The shell is made of 3D printing and can be made into a shape similar to goggles or can be worn alone.

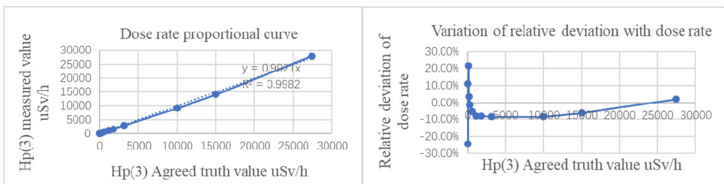
Pictures of dosimeter prototype and core measurement module

4. Prototype trial

The $H_p(3)$ dosimeter was tested in a reference radiation field of narrow spectrum X-ray and ^{137}Cs nuclide sources with an ISO standard plate phantom. The conventional values $H_p(3)$ on the test point of the reference radiation fields were calculated using the air kerma K_{air} and the conversion coefficients $H_p(3,α)$ recommended by ICRP 116 recommendation. The K_{air} can be measured by standard ionization chamber dosimeter. Then the conventional true value $H_p(3)$ on test point was provided and compared with dosimeter measured values. Dose rate measurement accuracy is better than 40% in range 10μSv/h-10mSv/h due to the special preamplifier circuit with low input bias current.

The batch-to-batch reproducibility of different batches of diodes and scintillators was also experimentally investigated, showing a linear correlation between PIN-photodiode readout and the conventional true value $H_p(3)$ of the reference radiation field. Therefore, this portable dosimeter based on silicon PIN-photodiode and CsI(TI) scintillator appears promising for the eye-lens dose monitoring.

The relative deviation of the dose rate decreases with the increase of the agreed true value of the dose rate. The measurement is sensitive and stable at a high dose rate. The main reason is that the output current of the low dose rate semiconductor is very small and is greatly affected by noise.



Main test results of dosimeter

5. Conclusions and Acknowledgements

In this paper, a portable $H_p(3)$personal dosimeter based on the coupling of silicon PIN photodiode and CsI(TI) scintillator is designed and tested. It can display the crystal dose of human eyes in real time, and directly read the dose rate and cumulative dose value through the display screen. The dosimeter is low in power consumption, small in size, easy to carry and easy to use. It has the function of over threshold alarm and can prevent accidental irradiation events. It is feasible to use silicon semiconductor for real-time monitoring of personal dose of $H_p(3)$. In the future, the energy response and angle response of weak penetrating radiation will be further optimized.