A small dimension intraoperative probe

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Abstract This article introduces the usage of the intraoperative probe in surgical based on RGS and proposes one method to design the probe. Also, a charge-sensitive preamplifier used in semiconductor detector was constructed which can reduce the dimension of the probe. At last the probe is tested by some animal experiments. Results showed that the property of this system are reliable.

Keywords RGS, Preamplifier, Nuclear detector, Lymph node

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1 INTRODUCTION

Every year many people die from cancer. The task of predicting which patient can survive their disease is difficult and depends on numerous factors including stage, tumor grade, DNA studies, and the presence of lymphatic or vascular invasion. One of the most important factors in determining survival is the presence of regional lymph node metastases. The clinical significance of occult micrometastatic extrahepatic disease has not been determined. The ability of the surgeon to identify subclinical micrometastatic disease is limited to visual and tactile senses, in addition to surgical instincts. These traditional methods are crude, and may be augmented with a newly evolving modality known as radioguided surgery (RGS). This technique has developed over the past two decades both in the laboratory and clinical settings.[1]

By taking advantage of the proximity to radioactive sentinel nodes and occult tumors achievable in an operative setting, intraoperative probes are becoming increasingly important in the surgical management of cancer, detection and localization of tumors, especially small tumors.[2]

In this article we describe the design and testing of a CdTe semiconductor detector. Because the key to reduce the dimension of the probe is to reduce the dimension of the preamplifier,[3] we give an instance of a micro-charge sensitive preamplifier. The animal experiments, which were conducted to evaluate the property of the designed probe, were also studied.

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2 DETECTORS

Radiation detectors can generally be characterized as either scintillation or ionization detectors in terms of their operation. In scintillation detectors, visible light, produced as radiation-excited atoms of a stopping medium (crystal), is converted into an electrical pulse. In ionization detectors free electrons produced as radiation ionizing a stopping medium are collected as an electrical pulse. Because the scintillation detector is larger and its energy resolution is worse than the semiconductor detector, we adopt the semiconductor. Semiconductor is one type of ionization detector.[4]

This detector contains a parallelepiped CdTe crystal 1 cm×1 cm×1 cm and a small dimension charge-sensitive preamplifier. The key to reduce the dimension of the detector is to reduce the size of the preamplifier.

So a small charge-sensitive preamplifier is designed to satisfy the request, the main circuit is composed of Silicon Junction Field Effect Transistor (JFET) and integrated operational amplifier. All components are S.M.D except JFET, feedback resistor and feedback capacitor. The total size of the preamplifier is 10 mm×100 mm×5 mm. The basic circuit of the charge sensitive of the preamplifier is shown in Fig.1.

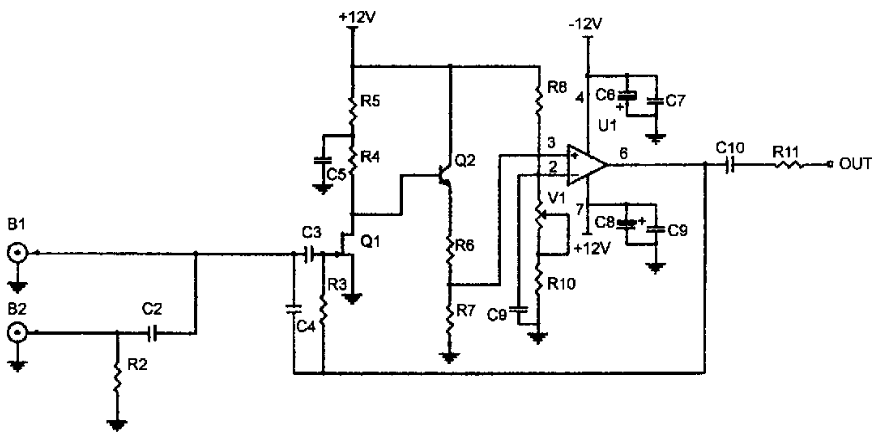

Fig.1 Basic circuit of the charge sensitive preamplifier

The JFET adopts CS (Common-Source) connection, the feedback resistor connecting its Grid is used to stabilize the quiescent point and to discharge the feedback capacitor $C_{\rm f}(C_{\rm f} = C_4)$, the voltage of its grid will be around 0 V. In this station, noise of JFET becomes the lowest. Resistor R_5 and R_4 are used to limit the current of the Drain, it can be decided according to the transfer characteristic $I_{\rm D} - V_{\rm GS}$ $[i_{\rm d} = T_{\rm DSS}(1 - V_{\rm GS}/V_{\rm P})^2(0 \geq V_{\rm GS} \geq V_{\rm p})]$.

The transistor following the JFET can satisfy common-mode input of the operational amplifier. MAX437 is selected as an operational amplifier. Its open-loop gain is 100dB, which satisfies $(1+A_0)C_f >> C_i$ (C_i is the input capacitance of the detector), so the sensitivity of the preamplifier is $1/C_f$. Also, capacitor C_f between input terminal and output terminal realizes alternating current feedback, capacitor C_3 realizes alternating current coupling, and resistor R_{11} completes impedance matching.

The output voltage of the power supply is $\pm 12\,V$*. Its ripple voltage is reduced by* using RC filter circuit. Considering the power supply may also contain ripple that will not be completely reduced by the RC circuit, RC filters are added at the point close to MAX437 on both the positive and negative power supply lines. It is known that a little disturbance of I_D will bring high noise to the circuit, single-stage RC filter circuit is added in front of R_4 to reduce the disturbance of the power supply.

The total size of the preamplifier is $10\,\text{mm}\times 100\,\text{mm}\times 5\,\text{mm}$, the noise is 1.8 keV (Ge), the rise time is less than 30 ns, and the fall time is 1.5 ms. (Measured under the condition of no input capacitance, and using Gaussian shaping amplifier with time constant=$10^{-6}\,s$) *We use* ^{57}Co (122 keV) to evaluate this type of detector and compare to CsI detector. The energy resolution of the CdTe detector is 9.5%. The following Fig.2 and Fig.3 are the energy spectrum of the two detectors.

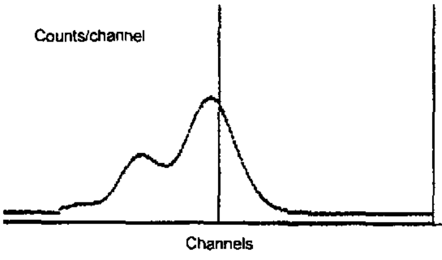

Fig.2 Pulse height spectra for CsI

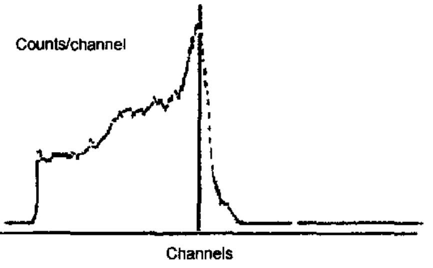

Fig.3 Pulse height spectra for CdTe

3 CONTROL UNIT

As shown in Fig.4, the signal from detector is amplified by main-amplifier, the gain of the amplifier can be adjusted through SCM, the threshold value of SCPA (single channel pulse analyzer) can be changed through two DAC0832, which are controlled by SCM. The spectrum can also be measured. The data can be processed on PC, thus we can evaluate the detector by this way.

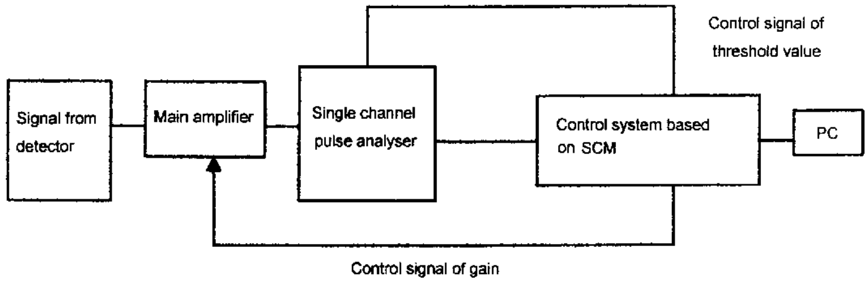

Fig.4 Simplified schematics of nuclear detector

4 DESIGN FEATURES

The intraoperative probe, as a clinical instrument, especially one to be used in a surgical setting, many factors besides the performance parameters of it should considered by a prospective user.

The probe has removable sideshielding, interchangeable collimators and detectors, and user-adjustable energy window. The real-time analog count-rate display and audible count rate tone are available to help the doctor detect cancer. The frequency of the tone is decided by the count rate. The system is also auto-ranged. When the detected count rate exceeds the maximum count rate for a particular range, the system automatically switches to a higher count-rate range. The probe is portable and light, so it can be used in operating system easily, which are usually rather crowed with instrumentation and personnel. The two type detectors themselves are small, light, and compact to simulate surgical instruments to which surgeons are accustomed and to provide easier detector access to certain internal tissues.

5 ANIMAL EXPERIMENTS

In order to evaluate the property of the designed probe, we conducted some animal experiments. In these experiments, we used the probe to detect the uptake of nanocolloids by rabbits' lymph nodes. We prepared the two different particle sizes of antimony sulfide nanocolloids and labeled by ^{188}Re. The mean diameters of them were 10.2 nm and 44.7 nm respectively.

White New Zealand rabbits were injected subcutaneously on the dorsum of the hind foot with two kinds of ^{188}Re-Sb_2S_3. The uptake of them by popliteal lymph node and inguinal lymph node were measured quantitatively. Results were shown in Fig.5 and Fig.6. From which we can see that the highest uptake of 10.2 nm and 44.7 nm nanocolloids by popliteal lymph node reached 17.4% and 19.4% of the total after 1.5 to 2 hr post injection respectively (which was similar to 18.2% as reported[5]). The highest uptake by inguinal lymph node reached 4.7% and 4.2% of the total about 2 h post injection respectively. At the same time, we can also see that though nanocolloids with a mean particle size 44.7 nm have a slower uptaking rate, they have a longer retention time in lymph nodes.

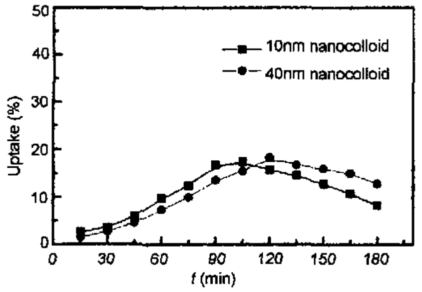

Fig.5 Uptake of nanocolloids with different particle sizes by popliteal lymph node

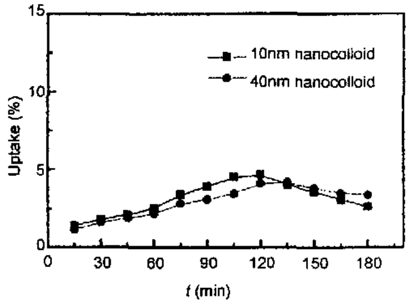

Fig.6 Uptake of nanocolloids with different particle sizes by inguinal lymph node

6 CONCLUSION

The probe is portable, and its energy resolution is excellent. The animal experiments show that the property of the designed probe was reliable, for the results of the experiments can reflect the biological properties of nanocolloids with different kinds of particle size.

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