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A PULSE SHAPE DISCRIMINATION CIRCUIT FOR LITHIUM-DRIFTED GERMANIUM DIODES

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A pulse-shape discrimination circuit has been developed which is sensitive to a slow time-constant component in the charge carrier collection of lithium-drifted germanium detectors. Preamplifier output pulses containing such a component are rejected. By this method the spectrum shapes can be improved considerably. In high-energy gamma-ray spectra the background under the peaks is reduced by a factor of up to 3. The resolution of the spectra is not affected. The attenuation of the peaks is certainly less than 10%.

1. Introduction

In neutron capture gamma-ray spectroscopy lithium-drifted germanium detectors are applied with the most promising results in the high-energy region above about 3 MeV, ref.[1]). In this region the diodes are used as double-escape spectrometers. The double-escape peaks are superimposed on a background which arises from Compton scattering, electron and bremsstrahlung escape. For making full use of the detector resolution and for detecting weak lines, a considerable reduction of the background is desirable. In this paper a circuit is described which discriminates against detector pulses with slow time-constant components. Such pulses obviously make an important contribution to the back-

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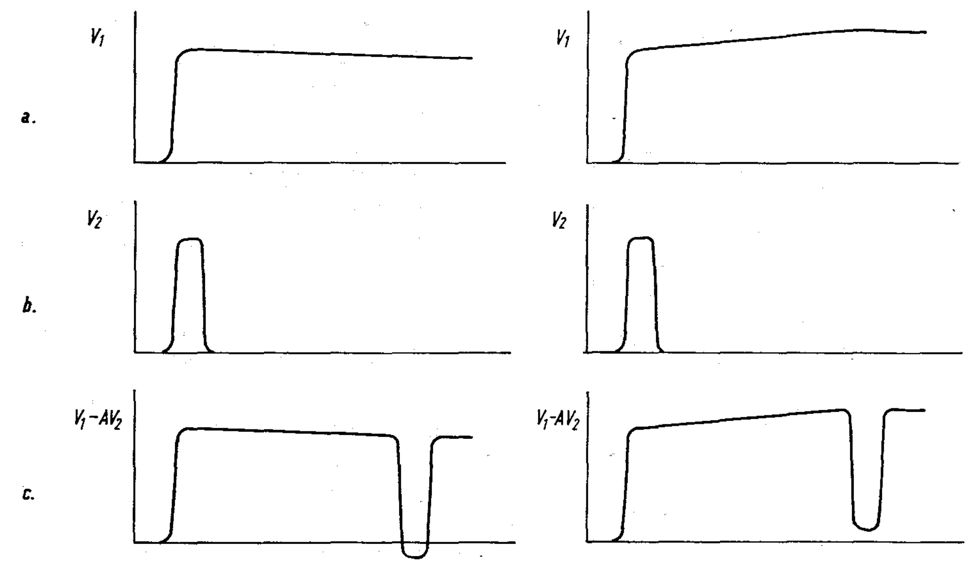

Fig. 1. Simplified pulse shapes for type I pulses on the left and type II pulses on the right.

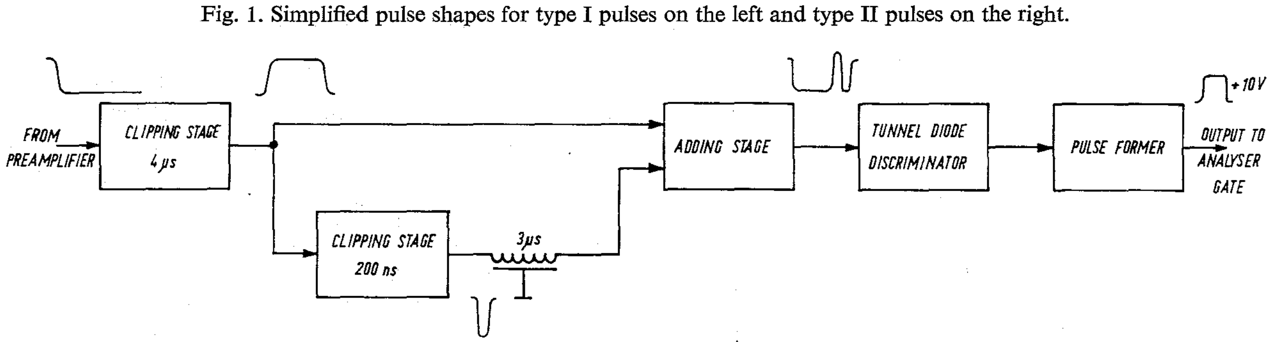

Fig. 2. Block diagram of the pulse-shape discriminator.

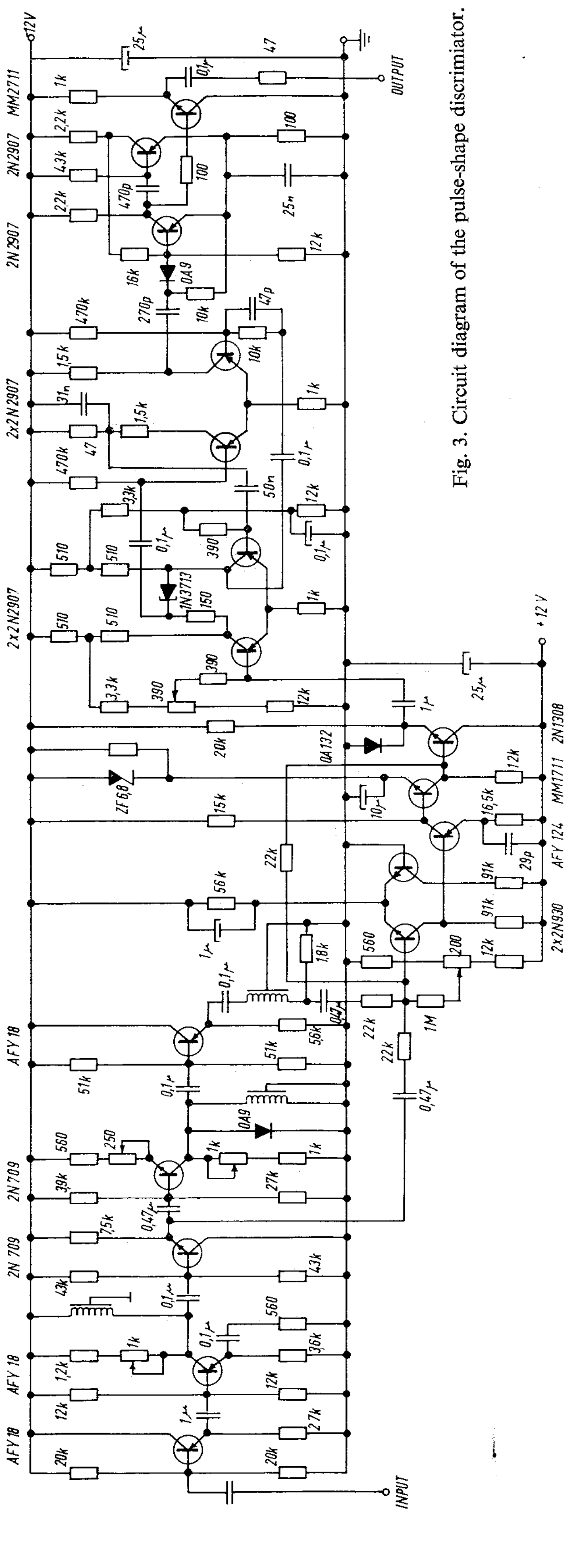

Fig. 3. Circuit diagram of the pulse-shape discriminator.

ground under the peaks. In contrast to other methods[2-4]), this circuit is applicable over a wide range of energy (100:1). Of course the technique is not limited to neutron capture spectroscopy, but can also be applied to other kinds of gamma ray spectra.

2. Some properties of p-i-n diodes

As the principle of pulse-shape discrimination is depending on some properties of semiconductor detectors, these properties will be briefly discussed here. It should be noted that the reason for the occurrence of slow time-constant components and for the observed different effects on peaks and background is not yet entirely clear. However, the following discussion may give a reasonable explanation.

The sensitive zone of a p-i-n diode is the intrinsic region which is free from charge carriers. A particle penetrating this region looses its energy by ionisation and creates a number of hole electron pairs which is proportional to the particle energy. The hole-electron pairs are collected at the electrodes by the electric field applied to the junction. The time in which all carriers have reached the electrodes depends on the depth of the intrinsic region, the electric field strength and the mobility of holes and electrons. In most cases this time is in the order of some nsec.

If the particle range is greater than the intrinsic region depth, the particles penetrate into the undepleted n or p region or escape from the detector. In the undepleted region hole-electron pairs are created in the same manner as in the intrinsic region. Before being collected at the electrodes they must diffuse into the electric field of the intrinsic region. The mean diffusion time depends on the diffusion coefficient, the depth of the undepleted region and the charge carrier life time. Values of this time are in the order of some μsec. Because of loss of hole-electron pairs by recombination during the diffusion process the charge collected at the electrodes is no more proportional to the energy of the penetrating particle. Thus these events in any case contribute to the background in the spectra.

The results given in section 5 were obtained using a detector with 2 mm intrinsic region, the depths of the diffused layer and of the undepleted region were 0.5 mm and 1 mm, respectively. An electric field of 1000 V/cm was applied to the junction. The calculated maximum collection time for charge carriers created within the intrinsic region is 20 ns, which should be equal to the pulse risetime at the output of the charge-sensitive preamplifier. However, due to the bandwidth of the preamplifier, the risetime was 50 ns. The maximum diffu-

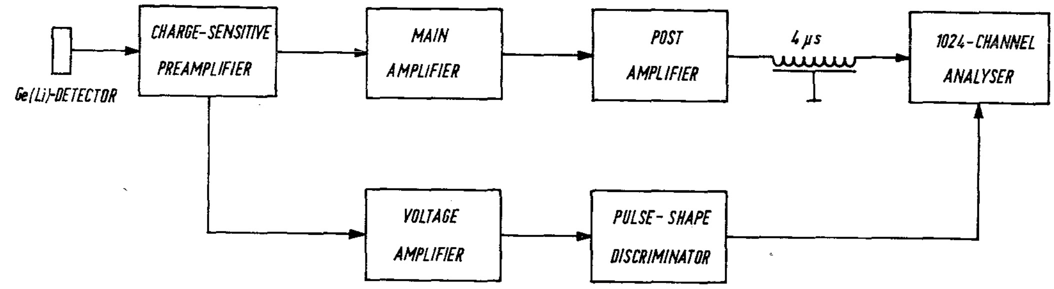

Fig. 4. Electronic arrangement for gamma-ray measurements.

sion time for charge carriers created in the undepleted region was measured to be about 3 μs.

Thus the signals arising from particles not completely stopped within the intrinsic region have two components, a fast component of the order of nsec and a slow diffusion component of the order of μsec.

These pulses will be labelled type II pulses in contrast to the pulses due to particles completely stopped within the depletion region which are labelled type I pulses.

3. Principle of discrimination

Fig. 1 shows the shape of the two pulse types, on the left a type I pulse and on the right a type II pulse. By means of this figure the principle of pulse-shape discrimination can be easily explained. At the end of the fast-rising component there is not yet a marked influence of slow time-constants components. After some μsec, however, all diffusion components, if present, contribute to the pulse shape. By comparing the pulse heights after these time intervals, information can be obtained whether a diffusion component exists or not.

By clipping the input pulse, the pulse shape shown in fig. 1b is obtained. After amplifying this signal by a factor somewhat greater than one the signal is delayed and subtracted from the unshaped pulse (fig. 1c). Type I pulses are crossing the zero level, whereas for type II pulses there is no zero crossing. In a following low-threshold discriminator stage this zero crossing is used as a criterium, whether a type II pulse with diffusion component is produced.

4. Description of electronic design

The block diagram of the pulse-shape discriminator is shown in fig. 2. The input pulses coming from the preamplifier have a risetime of 50 ns and an exponential decay of 60 μs. In the first clipping stage consisting of a short-circuited delay line and an inverting amplifier the pulses are limited to a width of 4 μs in order to avoid baseline shifts and pile-up effects. Then the shaped pulse is fed into two channels. In one channel the pulse is inverted and clipped again after the first rise by a short-circuited delay line. The pulse width is now 200 ns. To the first approximation the shape is equal for both types of pulses as shown in fig. 1b. In the clipping stage the amplification factor can be adjusted. After a delay of 3 μs equal to the maximum diffusion time the signal is fed into an adding circuit and is added to the undelayed 4 μs pulse from the first clipping stage. For a type I pulse without diffusion component the signal crosses the zero level and produces a positive overshoot. This overshoot should be as small as possible for making the discrimination independent of the input pulse height over a wide range and for discriminating against small diffusion components. The lower limit for the positive overshoot, however, is set by the noise of the preamplifier which is in the order of some millivolts. For a type II pulse the signal remains below the zero level and thus does not trigger the following discriminator.

The required discriminator must have a very small threshold. We used a tunnel diode circuit[5]) with a maximum sensitivity of 3 mV. The discriminator output pulses are fed into a pulse former which gives a ten volt pulse for gating the analyser.

The circuit diagram of the pulse-shape discrimination is shown in fig. 3.

5. Experimental results

The electronic arrangement for obtaining the gamma-ray spectra is given in fig. 4. The detector used for the measurements was a 2 mm deep diode with 2.8 cm^2 sensitive area. Fig. 5 shows two high-energy neutron capture gamma-ray spectra from natural strontium in the energy range from 6264 keV to 7527 keV. The upper spectrum was taken under normal conditions without discriminator whereas the lower spectrum was recorded by coincidence gating with the discriminator pulses. As can be seen, the background is reduced by a factor which increases with decreasing energy. At 7.5 MeV it is 2.3, at 6.2 MeV a value of 3.0 is observed. The attenuation of the double-escape peaks is less than 10%. In a 13 h run a fwhm of 9.1 keV at 7 MeV was

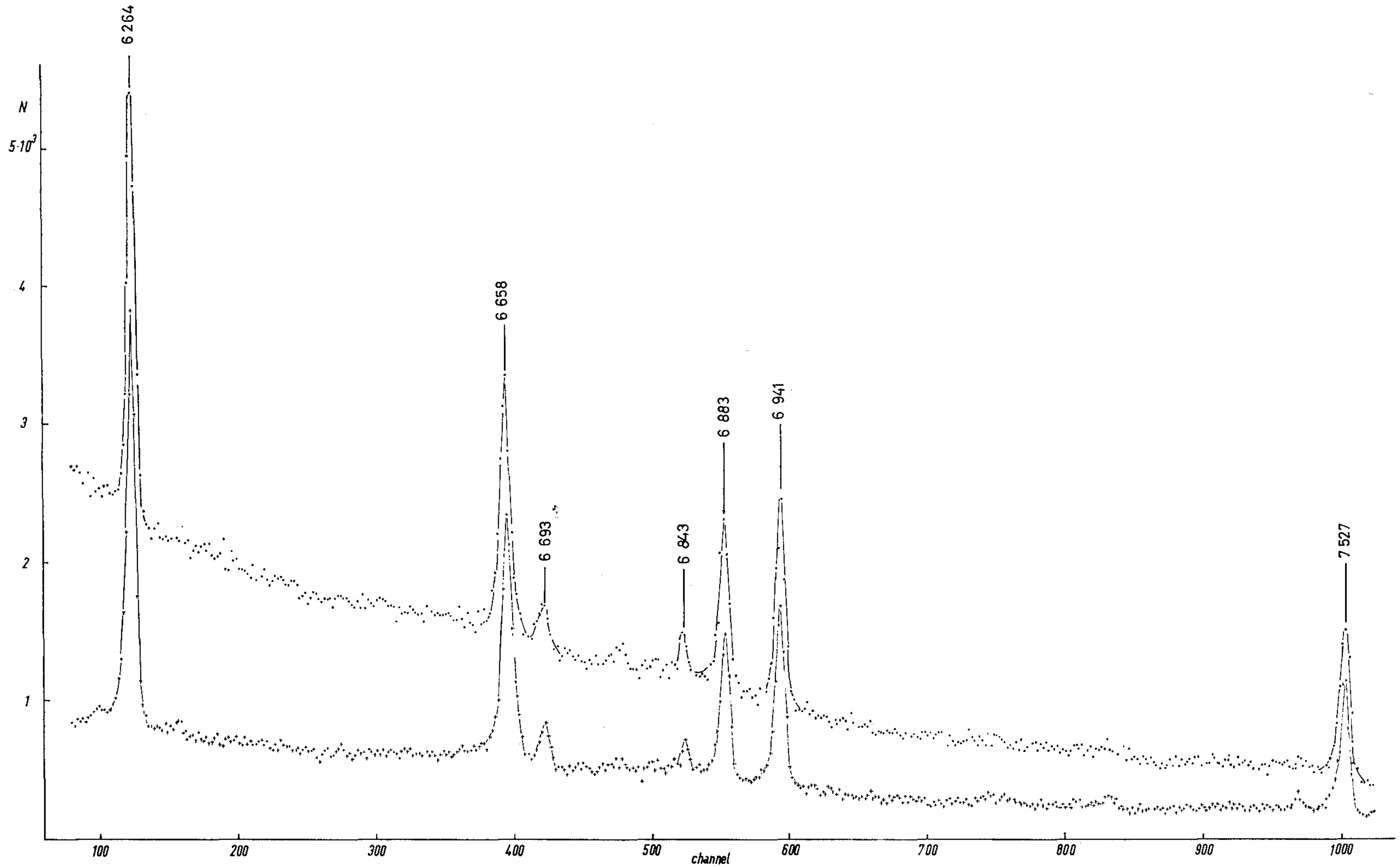

Fig. 5. Gamma-ray spectrum from thermal neutron capture in natural strontium. The lower curve was taken by coincidence gating with the discriminator pulses, the upper curve gives the ungated spectrum.

measured for both spectra. Thus the resolution is not affected by the pulse-shape discrimination. This is as expected from the circuit design. The resulting improvement of the spectra is particularly important when studying weak gamma-rays in the presence of intense lines.

For spectra of low-energy gamma-rays the reduction of the background by the pulse-shape discriminator is smaller than in the high-energy region. In the Compton distribution of ^{60}Co up to 25% of the pulses are rejected while the full-energy peaks remain unaffected. Since the improvement of the spectrum shape increases towards lower energy losses, the technique is particularly recommended when investigating low-energy gamma-rays in the presence of intense high-energy radiation. This is, for instance, always true of neutron capture spectroscopy.

The above measurements were also performed with a 2 cm^3 diode. In this case the intrinsic region had a depth of 5 mm and the sensitive area was 4 cm^2. The results obtained were very similar to those observed with the small detector. Thus it is reasonable to assume that the pulse-shape discrimination method is very useful also for larger diodes, at least when the sensitive volume is in the region of a few cm^2. The same may be true for coaxially drifted diodes with an uncompensated core.

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