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A SILICON STRIP DETECTOR WITH 12 μ RESOLUTION

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ABSTRACT

We have demonstrated the use of capacitative charge division with 40 μ m pitch strips on a 350 μ m thick Silicon surface barrier detector. With this detector we have achieved a resolution of 12 μ m with α -particles. For minimum ionizing particles this technique is calculated to give $\sigma \sim 6$ μ m resolution with readout every 180 μ m.

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1. INTRODUCTION

We describe a silicon strip counter capable of measuring tracks with a precision of $\sigma \sim 12 \mu\text{m}$ and of giving a fast timing signal. It uses a novel method of charge division by capacitive coupling. This device was initially designed to measure the vertices of short-lived "charmed" particles produced in high-energy interactions.

Silicon surface barrier strip counters have been used for many years¹⁾, but have not until now achieved micron resolution. Counters with read-out strips with $\lesssim 30 \mu\text{m}$ pitch are costly, and connections to amplifiers are inconvenient for many channels at this density.

Charge division read-out can greatly reduce these difficulties. Resistive charge division involves a number of problems, including a compromise between introducing "parallel" noise and increasing the signal rise-time. To avoid these, we have investigated the method of charge division by capacitive coupling. The geometry of fig.1 illustrates the principle. The "floating" strips (a, b, c, d) charge up by surface leakage current to the applied bias voltage V_B . If a particle traverses strip 2a perpendicular to the counter, the charge liberated is collected on this strip in $\sim 20 \text{ ns}$ and decays away slowly. Thus image charges of $\sim \frac{1}{5} q$ and $\sim \frac{1}{5} q$ are induced on read-out strips 2 and 3, respectively, by capacitive coupling. The charge division is given purely by the geometry, provided that the bias voltage depletes the full thickness of the detector. We demonstrate that the resolution is determined by the strip pitch. This is $40 \mu\text{m}$, leading to a standard deviation of $40/\sqrt{12} \mu\text{m}$.

2. COUNTER AND MEASURING APPARATUS

The counter is a $350 \mu\text{m}$ thick silicon surface barrier detector, $20 \times 30 \text{ mm}^2$ in area. Surface barrier-type junctions were prepared on both sides of the silicon crystal by evaporating a $30 \mu\text{g}/\text{cm}^2$ layer of germanium onto the silicon, using the technique described by England and Hammer²⁾. This England-Hammer contact effectively seals the device from the influence of the ambient atmosphere and thus provides stable characteristics in addition to good junction characteristics. A uniform aluminium electrode is evaporated on the lower side of the detector.

The detector is mounted on a machinable glass support. A printed-circuit fan-out is glued to the glass, coplanar with the top surface of the detector. The silicon, printed board, and glue form a smooth surface on which a number of different strip patterns have been evaporated. One pattern, A, was that shown in fig.1, except that owing to a masking alignment error, strips d and 3, d and 4, etc., made electrical contact, thus giving three instead of four floating strips. (Three successive evaporations of layers, each $\sim 2000 \text{ \AA}$ thick, were used for this pattern.)

The counter has been tested using a 7 mm diameter, 13 μCi , ^{241}Am α -particle source ($E_{\alpha} = 5.5 \text{ MeV}$), collimated with a slit $\sim 20 \mu\text{m}$ wide, 4 mm deep, and 15 mm long. The source and slit were mounted on a goniometer table and on a trolley system, giving x, y, z displacements reproducible to $\sim 2 \mu\text{m}$. The slit was aligned parallel to the strips and about 1 mm above them. The α -particles were used so as to give a conveniently large charge, localized to a few tens of microns.

The signals from the read-out strips were amplified by conventional charge-sensitive amplifiers, followed by integration and differentiation time constants of 180 ns, and an output signal channel with fast rise-time.

3. MEASUREMENTS AND DISCUSSION

The device described above acts as a diode counter with either polarity of applied voltage. With a negative voltage applied to the strips, the resistance between them was a few megohms. It was used with this polarity, was fully depleted at 25 V, and was operated at 40 V.

Using the unshaped fast output channel, we measured the signal rise-time to be 40 ns with the floating strip pattern. The rise-time was mainly determined by the resistance of strips 2 and 3, which was around 5000Ω . With strips with $1 \mu\text{m}$ thickness of evaporated Al, the rise-time should drop to $\sim 20 \text{ ns}$, the collection time of the charges.

Figure 2 shows spectra of the quantity $S_2/(S_2+S_3)$ for successive x coordinate positions of the α -source over pattern A; S_2, S_3 are the amplitudes of the signals from strips 2 and 3, respectively. One sees clearly the quantization of this ratio as the source irradiates successive strips.

These plots include only events with, at most, small signals from strips 1 and 4 to select α -particles on or between strips 2 and 3. A small fraction of counts with values of S_2+S_3 much less than the α -line peak, presumably due to scattered α 's, were also rejected.

Figure 3 shows the peak value of S_2+S_3 , the sum of the charges collected, as a function of the source position between two read-out strips.

Some further measurements and observations made with this counter are described in an article³⁾ by us to appear soon in Nuclear Instruments and Methods.

We now discuss briefly factors affecting the ultimate spatial resolution of this type of counter for high energy particles.

The minimum fraction of the read-out pitch which can be measured is limited by the signal-to-noise ratio. For minimum ionizing particles, $1 \times 10^5 t$ charges are liberated (t , the detector thickness in millimetres). A typical noise at room temperature for a charge-sensitive amplifier connected to our strips, with a capacity of ~ 10 pF, is $< 10^3$ electrons r.m.s. Thus, in principle, interpolations can be made to $< 1/(100t)$ of the read-out pitch.

For a 300 μm thick counter this leads to a 180 μm read-out pitch for $\sigma = 6$ m. We have found, by Monte Carlo calculation that for detectors close to 200 GeV hadronic interactions a smaller pitch ($\sim 50 \mu\text{m}$) is needed to resolve the coordinates of most adjacent particles. Here the ability of strip counters to resolve nearby trajectories is invaluable.

We have calculated the projected lateral fluctuation of the centre of gravity of charge around the trajectory of a relativistic particle due to energetic knock-on electrons. The distribution has a long, non-gaussian tail due to occasional single large energy transfers. These cause the variance of the distribution to increase with the maximum energy transfer accepted. Excluding events with a total ionization $> 1.5 E_p$ ($2.0 E_p$) leads to $\sigma \sim 2 \mu\text{m}$ ($\sigma \sim 7 \mu\text{m}$), where E_p is the most probable energy loss.

While charge division will find the exact centre of a uniformly ionizing inclined track, energy loss fluctuations introduce a further measurement error due to uneven deposition of ionization. For relativistic particles incident at 45° , this error is calculated to be roughly $t/30$.

There does not appear to be any fundamental technological barrier to achieving coordinate measurements limited only by the above physical processes. We are starting to fabricate diodes with conventional photo-resist technique with a pitch of 20 μm .

We are optimistic that it will soon be possible to manufacture devices on 3" Silicon wafers giving a few microns resolution.

REFERENCES

- 1) E.H.M. Heijne et al., NIM 178 (1980) 331, gives references to earlier work.
- 2) J.B.A. England and V.W. Hammer, NIM 96 (1971) 81.
- 3) J.B.A. England et al., Capacitative Charge Division Read-Out with a Silicon Strip Detector, NIM, in press.

Figure captions

- Fig. 1 : Plan view and side section of counter, showing part of the repetitive pattern.
- Fig. 2 : Distributions of $R = S_2/(S_2+S_3)$ for different source positions. Channels 0 and 100 correspond to $R = 0$ and 1 respectively. Strip pattern A.
- Fig. 3 : Variation of mean value of S_2+S_3 with x coordinate. Strip pattern A.

Fig. 1

Fig. 2

Fig. 3