The Argonne Silicon Strip-Detector Array

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Many nuclear physics experiments require the ability to analyze events in which large numbers of charged particles are detected and identified simultaneously with good resolution and high efficiency, either alone, or in coincidence with γ rays. Such experiments cover a wide range of topics. These include breakup reactions, which have attracted some attention recently due to their potential astrophysical significance, inelastic scattering and transfer reactions leading to particle-unbound final states, and the detection of particle-unstable reaction products such as ^8Be nuclei. In the case of fusion-evaporation reactions where charged particles are emitted, it is useful to detect these charged particles in coincidence with photons, for instance, in conjunction with a large array of gamma-ray detectors. Such an arrangement could permit high-efficiency reaction-channel selection, measurement of the energy spectra of evaporated particles, the reconstruction of compound-nucleus excitation energies and, through the reconstruction of the velocity of the heavy reaction product, facilitate better Doppler-broadening corrections¹.

To study these processes, it is frequently necessary to detect the emitted particles with both good energy and spatial resolution. To perform these measurements, we encounter a number of technical requirements which apply to any kind of particle-detector array dedicated to study these types of reactions. The detector-device should be compact, especially if it is to operate in conjunction with a large gamma-ray detector array. It should be highly segmented, in order to be able to detect simultaneously several charged particles. The device should also provide good energy resolution. Finally, to provide high efficiency for the reconstruction of many-particle final states, the detector system should have a rather large solid angle.

Some solid-state detector devices which very nicely satisfy all of these criteria are double-sided silicon strip detectors (DSSDs)². The detectors used in this work are fabricated from 5 cm $\times$ 5 cm square silicon wafers, with the front and back diode junctions divided into two orthogonal sets of 16 strips, thus effectively segmenting the detector into 256 pixel regions within the 5 cm $\times$ 5 cm square. In addition to this high degree of segmentation, these devices provide excellent energy and time resolution, and their 2500 mm² area does indeed yield a large solid angle. The unique capability of these devices, which makes them particularly useful for the kinds of studies described above, is that when properly instrumented, they can provide $X - Y$ position sensitivity for events in which more than one particle strikes the detector at once.

In order to take advantage of this capability, each of the 32 separate segments of the DSSD must be read out independently. For an array consisting of several DSSDs,

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many channels of electronics must be used. With conventional NIM electronics, this requirement leads to an bulky, complicated and expensive setup. We have developed a readout system for several DSSDs designed to be modular, compact, and relatively inexpensive. The heart of this readout system is a high-density, preamplifier module that contains 16 channels of FET charge preamplification and fast time pick-off circuitry within one single-width NIM module. The charge preamplification is performed using two hybrid integrated circuits manufactured by LeCroy, called the HQV810. These circuits each contain 8 channels of FET preamplifier and feedback circuitry within a single chip. The time pickoff circuits were designed at ANL. Using these modules, the entire energy and time preamplification requirements for one DSSD are contained within a very compact package of two NIM modules³.

The remainder of the electronics relies upon commercially available high-density CAMAC units. The energy signals are sent directly into 16-channel charge-to-digital converters, and the time signals are fed to 16-channel constant-fraction or leading-edge discriminators which also reside in CAMAC. The outputs of these discriminators are used to trigger time-to-digital converters for time-of-flight information, as well as pattern registers which are used to control the event readout. The hit multiplicity information from these discriminators is also used to develop the logic required for event triggering.

To demonstrate the performance of the strip detectors and readout systems, we have performed tests with radioactive sources. These data were obtained using a detector with a thickness of 300 μm , and a leakage current of $\approx 15\text{--}20\text{ nA/cm}^2$ at a bias voltage of 35 V, corresponding to 1.5 times the full depletion voltage⁴. Figure 1 shows an energy spectrum for alpha particles emitted by a ^{252}Cf source, with a strong peak at an energy of $E_\alpha = 5.812\text{ MeV}$, obtained from a single pixel region of the detector. The observed resolution is approximately 40 keV (FWHM), and is dominated by the leakage current, the detector dead layer and the electronic noise contribution of the preamplifier.

Figure 1. α -particle energy spectrum for one pixel region of the DSSD.

In order to take advantage of the multi-particle $X - Y$ position sensitivity of the DSSDs, certain ambiguities inherent to these devices must be resolved. Since the signals from the two sides of the DSSD are independent from each other, a multi-particle

event yields a set of X coordinates from one side of the detector, which must be correctly associated with a set of Y coordinates obtained from the other side of the device. To do this, we take advantage of the property of the DSSD that from the front and back of the device, we obtain two independent measurements of the energy of each particle striking the detector, and by correlating these energy signals we can readily assign the correct X and Y coordinates for each particle. The ability to perform this correlation depends upon the combined energy resolution of both sides of the detector. As a measure of this combined resolution, a spectrum of the measured difference between the alpha-particle energy signals obtained from the front and back of the DSSD for one pixel region appears in Fig. 2. The resolution of this difference spectrum is ≈ 55 keV (FWHM). Therefore, in a multi-particle event, if the particles have energies that differ by more than 60 to 100 keV, we can very efficiently assign them their correct X and Y coordinates.

Figure 2. Spectrum of the front-back energy difference for 5.812 MeV alpha particles obtained for one pixel region of the DSSD.

To demonstrate the powerful capabilities of the DSSD for studying multi-particle final states, we present some data obtained from a measurement in which we studied $^{12}\text{C}+^{12}\text{C}$ inelastic scattering and transfer leading to several different particle-unbound final states⁵. The experimental setup for this measurement included two DSSDs positioned at 35° on either side of the beam, 15 cm from the target. Here, the vast majority of many-particle final states involve several alpha particles. For events in which two or more of these alpha particles strike one DSSD, assuming the alpha particles come from the decay of a composite object, the measured angles and energies of those alpha particles can be used to reconstruct a number of quantities which describe that composite object, including its kinetic energy, scattering angle, and excitation energy. For example, if N alpha particles hit the detector, the composite excitation energy is given by the simple expression $E_X = \sum_{i=1}^N E(\alpha)_i - E_K + E_{sep}$, where $E(\alpha)_i$ are the alpha particle kinetic energies, E_K the reconstructed kinetic energy, and E_{sep} a separation energy constant.

Figure 3a shows the resulting excitation-energy spectrum for events where two alpha-particles are detected in the DSSD. The ^8Be ground state is cleanly reconstructed with

a resolution better than 50 keV (FWHM). The corresponding spectrum for events in which three alpha particles are detected appears in Fig. 3b. Here, the first excited 0^+ state in ^{12}C is easily identified at $E_x(^{12}\text{C})=7.65$ MeV, just 379 keV above the threshold for decay of ^{12}C into three alpha particles. This level is reconstructed with a resolution of ≈ 65 to 70 keV (FWHM). The 3^- level at 9.64 MeV is somewhat broader and weaker, due mainly to the effect of the much larger average opening angle for the three alpha particles on the excitation-energy resolution and detection efficiency, respectively.

Figure 3. Reconstructed (a) ^8Be and (b) ^{12}C excitation energy for events with two and three alpha particles, respectively, detected in one DSSD.

Using this setup, we are also able to identify more complicated final states. For events in which both ^{12}C nuclei are dissociated into three alpha particles, we can, in some cases detect and identify all 6 alpha particles, three in each DSSD. In this case, the excitation-energy calculation shown in Fig. 3b can be performed for each set of alpha particles, and the sum of those two excitation energies yields the total excitation energy in the final state. Figure 4 shows the resulting total excitation-energy thus spectrum obtained at a beam energy of 64 MeV. The peak at a total excitation energy of 15.30 MeV corresponds to the final state where both ^{12}C nuclei are left in their excited 0^+ levels. Despite the fact these events represent 6 charged-particle final states, the rather powerful capabilities of the DSSD allow us to kinematically reconstruct and fully characterize this reaction process.

Figure 4. Total excitation-energy spectrum for 6 alpha-particle coincidence events in $^{12}\text{C}+^{12}\text{C}$ inelastic scattering.

We have begun implementation of a number of improvements and additions to our strip-detector array. One modification is to add a second large-area detector to each array element, thereby making each element a two-detector sandwich. The front element is a DSSD, and the second, backing, element a $5\text{ cm} \times 5\text{ cm}$ wafer divided into 4 quadrants. Such an arrangement can serve two purposes. For instance, for events in which particles with high energy penetrate the front DSSD, if those events are uninteresting, the quadrant detector provides a very effective veto. Also, for events with moderate charged-particle multiplicity, a thin DSSD combined with a thick backing detector could be used as a highly segmented, large-area silicon $E - \Delta E$ counter. A box configuration with several of these units packed closely around the target could easily serve as a large solid angle, high segmentation detector for studies of charged-particle fusion-evaporation reactions.

In conclusion, the present results demonstrate that the highly segmented, high resolution double-sided silicon strip detectors are very powerful tools for studying nuclear reactions resulting in many-charged-particle final states. A readout system for these detectors has been constructed that is compact, modular, and inexpensive. The flexibility of these detectors, combined with the modularity of the readout system, suggest many further applications for arrays of these devices, both alone, or in conjunction with other detector systems.

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¹J. Nyberg, Talk presented at this workshop.

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⁴Detectors manufactured by Micron Semiconductor, Lancing, UK.

⁵A. H. Wuosmaa, *et al.*, Phys. Rev. Lett. 68 1295 (1992).

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