Particle Identification using Digital Pulse Shape Analysis for new generation NTD Silicon detector arrays

V. V. Parkar¹, J. A. Dueñas¹, D. Mengoni², R. Berjillos¹, A. M. Sánchez-Benítez¹, I. Martel¹, M. Assie³, and D. Beaumel³

¹Departamento de Física Aplicada, Universidad de Huelva, E-21071 Huelva, Spain
²Dipartimento di Fisica, Universita di Padova, via F. Marzolo, 8 - 35131 Padova, Italy
³Institut de Physique Nucléaire, Université Paris-Sud-11-CNRS/IN2P3, 91406 Orsay, France

Particle identification from silicon detectors with analog electronics using the energy loss, rise-time or time of flight information is known from few decades. However, there is a limitation in the pulse shape analysis (PSA) due to the non-homogeneity of the silicon wafer. The recent advances in semiconductor detector technology brought the use of NTD (Neutron Transmutation Doped) silicon for making detectors. The higher resistivity and more homogeneity from NTD technique has provided the opportunity for better PSA. The high density, compact and efficient charged particle detector arrays namely HYDE, GASPAR, FAZIA and TRACE being built in Europe will use NTD silicon for making double sided silicon strip detectors (DSSSDs). At present, PAD detectors and few prototype of DSSSDs which belongs to HYDE-GASPARD collaboration are being used for doing some studies on Digital Pulse Shape Analysis (DPSA). The limits in the Z and A separation from DPSA as well as the lowest cutoff in energy are the main concerns of this study. The results from the recent experiments along with the future plans are discussed here.

1. Introduction

The upcoming radioactive ion beam (RIB) facilities at Germany (FAIR, GSI) and France (SPIRAL2, GANIL) will provide new exotic nuclear species with higher intensities. The nuclear reaction and spectroscopy studies with these nuclei also demand for highly efficient detector arrays with the modern technology. This has stimulated an interest in building the high density, compact and efficient charged particle detector arrays. The arrays namely HYDE (Hybrid Detector array) [1], GASPARD (Gamma Spectroscopy and Particle Detector) [2], FAZIA (Four π A and Z Identification Array) [3] and TRACE (Tracking Array for Light Charged Particle Ejectiles) [4] being built in Europe will use NTD silicon strip detectors along with the state-of-the-art electronics to process the signal directly from the preamplifier. These arrays will consist of NTD silicon strip detectors of various thicknesses (20 µm - 2000 µm) [5]. The NTD silicon is much more homogeneous than normal silicon which is advantageous for better PSA and hence clean particle identification. The basic philosophy of all these detector arrays is to digitize the charge and current signals from the preamplifier and store in the digitizer for further analysis. For better DPSA, it is well known that the detectors have to be mounted in low field injection mode [6, 7]. The high bandwidth charge sensitive preamplifier PACI [8] is already fabricated and tested. For the digitizer, currently the commercial available digitizers viz., CAEN [9] are being used. The recent experiments with these NTD-PAD and DSSSD (prototype of HYDE-GASPARD arrays), supplied by Micron Semiconductors Ltd. [10], PACI preamplifier and different digitizers are presented here in the following sections.

2. Experimental Details

This experiment was dedicated for finding the lowest energy thresholds for light charged particles (Z=1,2) and also isotopic separation

*Electronic address: parkarvivek@gmail.com

Available online at www.sympnp.org/proceedings
in DPSA [11]. The mono-energetic beams of deuterium at energies of 2, 2.5 and 10 MeV and proton at 2 MeV from TANDEM-ALTO accelerator facility at IPN-Orsay, France were bombarded on a thin (∼ 100 μg/cm²) ¹⁹⁷Au target. In addition to it, we have also performed ⁷Li + ¹²C reaction at 34 MeV. The resulting charged particles from the reaction were collected by a 500 μm NTD-Silicon (crystal orientation (111)) detector placed at 55° with respect to beam axis, and 8° out off reaction plane to avoid channeling effects. The detector (20×20 mm²) with a measured capacitance of 106 pF and resistivity of 4200 Ω·cm, was operated at a bias of 300 V in a low-field injection configuration. To avoid the influence of the resistivity non-uniformity on the PSA [12, 13] the detector was collimated (Ø 3 mm). It was connected to a PACI preamplifier that provided charge \( Q(t) \) and current \( I(t) \) outputs with gain of 32 mV/MeV and 7000 V/A respectively. The two signals were acquired using a four channel NIM-based card (N1728B from CAEN) with 14 bit, 100 MHz sampling rate, and a maximum input voltage of 1 V. It is important to mention that the preamplifier was kept in the chamber just a few centimetres away from the detector and had a water cooling system attached to ensure its stability along the experiment. Continued close monitoring of the detector leakage current showed values between 3 and 6 nA and thus there was no need for bias compensation. Moreover, the energy resolution in situ of the detector plus electronic chain before and after the experiment yields values of 18-22 keV using a triple α-source. The typical experimental setup is shown in Fig. 1.

3. Digital Pulse Shape Analysis

The off-line analysis of the data was performed on the two output signals of the preamplifier, which were digitized at a frequency of 100 MHz (see Fig. 2-top). We labeled them as \( I(t) \) for the current signal, and \( Q(t) \) for the charge. The digital signal processing flow diagram is shown in Fig. 2-bottom. Both signals were baselined by simple average algorithm that took the samples just before the rising/falling of the signals, yielding \( I_{th}(t) \) and \( Q_{th}(t) \). Then we separated pulses from non-pulses by setting a threshold discriminator, obtaining \( I_{th}(t) \) and \( Q_{th}(t) \), the current and the charge signals, which underwent different treatment. The energy information was obtained by \( Q_{th}(t) \) using a trapezoidal filter (for recursive shaping algorithm see for example [14]) with a risetime of 0.5 μs and a flat top of 1 μs. Its output \( Q_{tf}(t) \) passed through a “find-maximum” algorithm to yield the non-calibrated Energy value. We curve fitted \( I_{th}(t) \) to find its maximum \( (I_{max}) \), by applying a cubic interpolation algorithm (third degree polynomial equation). The number of interpolated points between two adjacent ADC samples (10 ns spaced) was 50, yielding a new interpolated sampling rate of 200 ps. We found that the Energy - \( I_{max} \) correlation improves (i.e. better particle identification) as the number of interpolated points increases, reaching a non-improvement situation for more than 50 points.

4. Results and discussion

Figure 3 shows the correlation between Energy and \( I_{max} \) for proton and deuterium at 2 MeV. Good separation is achieved by taking the maximum of the current signal after fitting \( I_{th}(t) \) (see Fig. 3-top). However, if one takes the maximum directly from the digitized signal without any fitting algorithm \( I_{th}(t) \) (just the ADC values), then the identification resolution is lost (see Fig. 3-middle). The projection histogram of the \( I_{max} \) for both the cases can be seen in Fig. 3-bottom, where the separation between the proton (right

Available online at www.sympnp.org/proceedings
side) and deuterium (left side) contributions are well established in the fitting case. It is apparent that the sampling rate of our digitizer (10 ns) cannot reproduce the real shape of the analog current signals, particularly its pointed part (see the lower peak of the current signal in Fig. 2-top). Therefore, the use of a fitting algorithm is mandatory. Nevertheless, interpolation can however not modify the shape of the measured signal: indeed it was shown by Hamrita et al. [8] that the current signal for low energy protons and deuterons (3 MeV) display a peculiar shape where one can recognize the parts due to the electrons and holes migrations. The signal-to-noise ratio SNR (been defined as the maximum of $I_{\text{max}}$ divided by the noise amplitude) for the 2 MeV runs yielded gaussian distributions (not shown here) center at 12.26 and 12.45 with standard deviations of 1.59 and 1.56 for proton and deuterium respectively.

FIG. 2: (Colour online) Top, preamplifier outputs for a given event after digitization (100 MHz). The digital values are marked with asterisks, while the solid lines correspond to the interpolated values. Bottom, digital signal processing flow diagram. The correlation of Energy vs $I_{\text{max}}$ is used for particle identification.

FIG. 3: (Colour online) Energy vs $I_{\text{max}}$ correlation for proton and deuterium at 2 MeV. Top, the values of $I_{\text{max}}$ taken from the fitting of signals. Middle, the values of $I_{\text{max}}$ taken from ADC samples. Bottom, $I_{\text{max}}$ projection of the above two cases.
Figure 4 (top and middle) shows the Energy vs $I_{\text{max}}$ correlation for the reaction products obtained from a 34 MeV $^7\text{Li}$ beam bombarding a thin $^{12}\text{C}$ target (information about this reaction can be found at [15, 16]). For identification purposes the data from the mono-energetic runs have been superimposed. The dynamic range, in our case dictated by the maximum voltage (1 Vpp) at the ADC input went from 1 to 18 MeV, which means we cannot see the elastically scattered $^7\text{Li}$ particles. The energy calibration was done using the mono-energetic deuterium beams plus a triple alpha source. The deuterium line (labelled as d in the figures) was identified using the mono-energetic beams, and the helium one (labelled as $\alpha$) using the data from the calibration alpha source. The data from the proton beam at 2 MeV also help us to identify the proton line (labelled as p), see Fig. 4-middle. Good particle separation is observed down to 3 MeV as shown in Fig. 4-bottom, where the projection of the $I_{\text{max}}$ for energies between 2950 and 3050 keV reveals the proton, deuterium, tritium and alpha contributions. This energy threshold corresponds to a range in silicon of about 92.05, 60.97, 49.51, and 12.04 $\mu$m respectively. Similar threshold was found by Schmid et al. [17] for proton-alpha separation using an electronic chain based on a time filter amplifier (TFA), leading edge discriminators (LED), and a time-to-digital converter (TDC). As the energy gets lower the alpha-tritium separation is lost, and then at even lower energies, particle identification cannot be resolved.

Previous publications from FAZIA collaboration [18–20] have also shown the Energy vs $I_{\text{max}}$ correlation under different experimental conditions, such as achieving Z (charge) identification down to $\alpha$ for particles fully stopped in a first layer of silicon. However, FAZIA thresholds for PSA correspond to particle identification obtained from different kind of reactions using relatively low gain preamplifier (due to their large dynamic range 2-5 GeV involved), and therefore in FAZIA data Z-separation is not obtained for the low energy values studied in the present paper. A factor that may contribute to the quality of the A/Z (Mass no./Atomic No.) separation obtained here is the absence of heavier ions. Other correlations such as Energy vs...
FIG. 5: (Colour online) Three prototype NTD Silicon strip detectors of thicknesses 100, 500 and 1500 µm, from left to right respectively. At the top one can see a dummy frame with the kaptons and Molex connectors.

Risetime of both charge signal and current signal were studied with our data and they did not show proton-deuterium separation, since the Risetime values (i.e. about 23 ns and 11 ns for charge and current signal respectively) are at the very limit of the preamplifier capability. From this observation, it would be advisable to lower the bias applied to the detector in order to reduce the drift velocity of the charges. This finding is consistent with the FAZIA collaboration which recommend the use of $I_{\text{max}}$ rather than Risetime for $Z < 10$.

5. DPSA with NTD silicon strip detectors

We have also received recently the prototype of NTD silicon strip detectors of various thicknesses (100, 500 and 1500 µm). The picture of these detectors along with the connectors can be seen in Fig. 5.

We have taken the data recently with these NTD silicon strip detectors. The same reaction of $^7\text{Li} + ^{12}\text{C}$ have been used in this experiment at IPN-Orsay. The typical experimental setup is shown in Fig. 6. We have used two telescopes in this experiment having the following configurations. The first layer ($\Delta E_1$) is the 16×16 normal DSSSD (thickness = 40 µm) from where the n-side strips have been electrically shorted together to be grounded, also the p-side strips have been electrically shorted to read only one signal. The second layer ($\Delta E_2$) of the telescope, for which the DPSA was applied (for particles stopping fully in this layer) was the NTD-DSSSD (64×64) (thicknesses = 100, 500 µm). In this case, we collected the data only from the four central pins of p and n-side. The n-side (backside mounting) was kept facing the reaction products for better PSA. The third layer (E3) was the 500 µm Si-PAD detector for stopping the reaction products leaving the second layer ($\Delta E_2$). The first and third layer signals were processed via the preamplifier-amplifier chain and sent it to peak sensing ADC. The 4×4 strips of the middle layer meant for DPSA studies were given to individual PACI preamplifiers (Fig. 6-top). The charge and current outputs from the PACI were given to MATACQ digitizer having 2.5 Gs/s sampling rate. A stainless steel collimator of size 3 mm×3 mm was kept in front of the telescope assembly. The dedicated data acquisition system (Narval) [21] from GANIL was used. In the present three element telescope assembly, particle identification can be performed by using energy loss information from different combinations ($\Delta E_1: \Delta E_2$, $\Delta E_2:E_3$ and $\Delta E_1+\Delta E_2:E_3$). For the particles stopped in the second layer, additional information of $\Delta E_2 I_{\text{max}}$ and $\Delta E_2: \Delta E_2 \text{Risetime}$ was also possible. The typical plots of charge and current outputs from p and n side from one of the strips are shown in Fig. 7. A good quality of signal can be seen with very low noise (noise level < 5 mV). The data analysis is in progress and will be reported shortly.

6. Summary

Thanks to both a high quality NTD-Si detector and a low noise electronic chain, isotopic separation for $Z=1$ at 3 MeV have been accomplished in a $^7\text{Li} + ^{12}\text{C}$ reaction.
making use of DPSA. This energy threshold went down to 2 MeV for proton-deuterium identification separation using mono-energetic beams. It has also been observed that the current signal of the charge sensitive preamplifier is needed for low energy particle identification, in particular the peak value rather than its Risetime, which is limited by the bandwidth of the preamplifier. A long sampling rate (in our case 10 ns, 100 MHz ADC) implies the use of interpolated algorithm to obtain a good fit of the current signal. Otherwise, faster ADC would be recommended when dealing with light particles at low energies. A trade-off between low threshold particle identification and energy dynamic range must be considered.

FIG. 6: (Colour online) Top, The schematic of the telescope consisting of $\Delta E_1$: Si1, $\Delta E_2$: NTD Silicon, E: si-PAD (see text for details). Bottom, the picture of experimental setup. The cooling system was also connected to all the PACIs for its better performance.

The NTD silicon strip prototype detectors of HYDE-GASPARD collaboration are now available with us. We have already carried out one experiment (reading only four central strips) to see the capabilities of DPSA on these detectors. In future, we will be investigating the DPSA method for all the X and Y strips of the detectors and decide the limits of identification of isotopes and lowest energy thresholds.

FIG. 7: (Colour online) The typical charge and current signals from n and p-side strips are shown.

Acknowledgments

This work has been partially supported by the Spanish Ministry of Science and Innovation (MICINN) under projects, FPA2010-22131-C02-01 (FINURA) and INGENIO-2010 (CPAN), and by the Italian Ministry of Education, University and Research (MIUR) under the project FIRB08. The research leading to these results has received funding from the European Union Seventh Framework Programme FP7/2007-2013 under Grant Agreement n. 262010 - ENSAR. The authors would like to extend appreciation to the technical staff of Tandem ALTO from Orsay for their assistance during the experiment.
References

[10] www.micronsemiconductor.co.uk