Development of novel neutron imaging technique with boron layer deposited on a Charge Coupled Device

Juan Jerónimo Blostein[1], Juan Estrada[2], Aureliano Tartaglione[1], Guillermo Fernández[3], Jorge Molina[4]

[1] CONICET, Centro Atómico Bariloche, Instituto Balseiro, Argentina
[2] Fermilab National Accelerador Laboratory, USA
[3] CONICET, Universidad Nacional del Sur, Bahía Blanca, Argentina
[4] Facultad de Ingeniería, Universidad Nacional de Asunción, Paraguay

jeronimo@cab.cnea.gov.ar

Abstract. We present the results obtained during the implementation of a novel high resolution 2D neutron detection technique. The proposed technique consists on a boron layer (enriched in ^{10}B) placed on a Charge Coupled Device (CCD). After the nuclear reaction $^{10}B(n,\alpha)^{7}Li$ the CCD detects the emitted charge particles thus obtaining information on the neutron absorption position. Plasma effects in the CCD exposed to the ionizing particles with energies in the range 0.5–5.5 MeV are analyzed. We present the first neutron images recently obtained with this technique. We also show numerical simulations which indicate that the resolution of this technique will be about 10 μm. We analyze the advantages and disadvantages of the proposed technique.

1. Introduction

Scientific CCDs have been used extensively in ground and space-based astronomy, X-ray imaging and other particle detection applications [1]. The combination of high detection efficiency, low noise, good spatial resolution, low dark current, and high charge transfer efficiency results in an excellent performance for detection of ionizing particles [2]. The purpose of this work is to show the advances in the implementation of a novel neutron detection technique based on a boron layer deposited on a CCD. This technique will be useful for neutron imaging applications as well as for neutron techniques for which high resolution in the detection position is required.

The CCD used in this work was developed for the DECam wide field imager that is currently under construction [3]. The CCD was built by the Lawrence Berkeley National Laboratory (LBNL) [4], and extensively characterized at Fermilab for the DECam project [5]. The CCD used in this work is 250 μm thick, fully depleted, back-illuminated devices fabricated on high-resistivity silicon. It has 8 million pixels 15 μm x 15 μm each.

2. Preliminary tests

As a preliminary test we expose the CCD to a ^{241}Am α source. Figure 1 shows the obtained image.

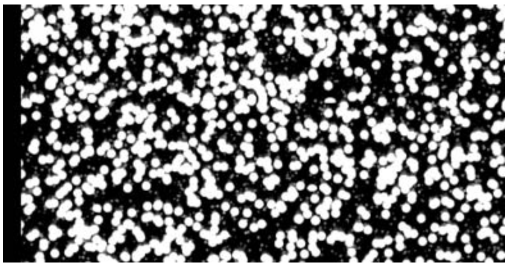


Figure 1. Image obtained with the CCD exposed to a ^{241}Am source.

The α events are clearly recorded as spots of about 10 pixels diameter. The gamma events are recorded as smaller spots and small tracks. Figure 2 shows the corresponding energy spectrum.

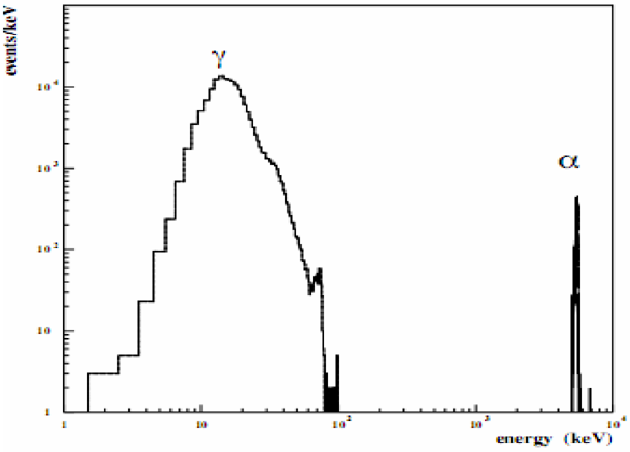


Figure 2. Energy measured by the CCD when is exposed to a ^{241}Am source.

It can be noted the two different ranges in the energy of the particles detected, making a clear distinction between α particles and photons.

The CCD was also tested exposing its active surface to different ionizing radiations; the results are shown in figure 3.

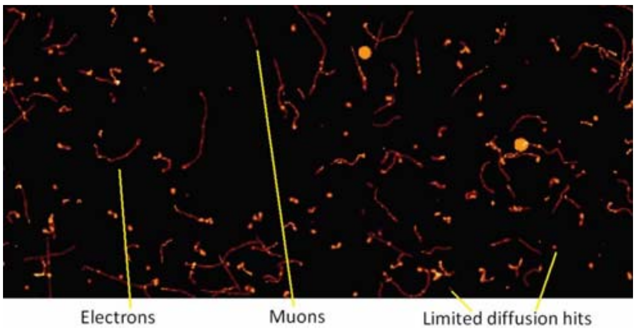


Figure 3. Events recorded with the CCD exposed to different ionizing radiations.

The energy event, as well as the event shape can be used to identify the incident particle.

3. The proposed technique

The proposed technique consists on a boron layer enriched in ^{10}B deposited directly on the CCD silicon surface. After the nuclear reaction $^{10}B(n,\alpha)^{7}Li$ the CCD detects the emitted charged particles. Figures 4 and 5 show a scheme of the experimental procedure.

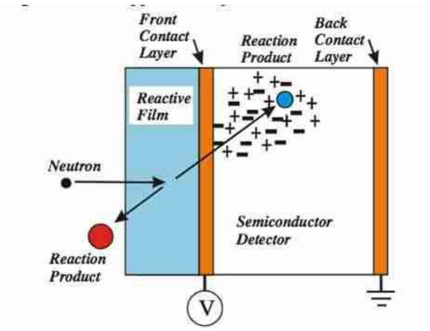


Figure 4. A boron layer is deposited on the surface of a CCD. The charged particles (α and ^{7}Li) emitted after the nuclear reaction are detected in the CCD.

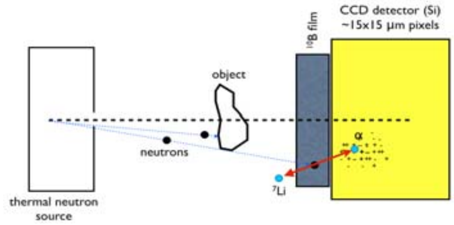
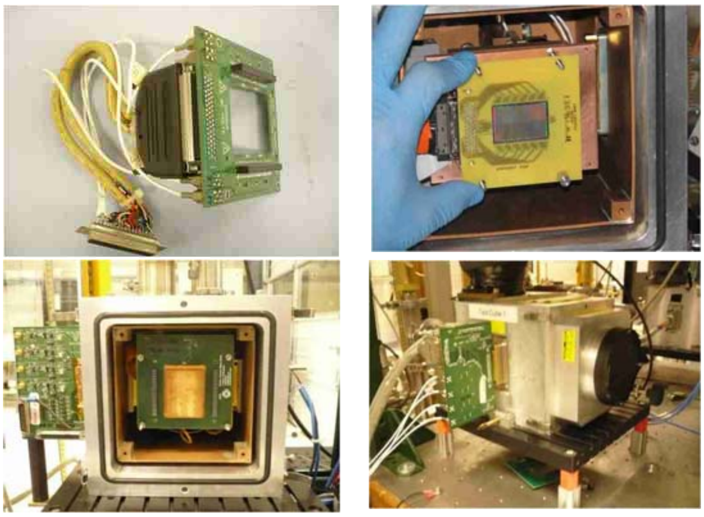


Figure 5. Experimental set up. The sample is placed in a collimated neutron beam.

4. Experimental set up

In figure 6 we show details of the CCD and its connections, as well the box where the CCD is placed and cooled.

(a) **(b)**



(c) **(d)**

Figure 6. CCD with its connections (a). CCD placed in its dewar without the borated surface and without the dewar cover (b and c). CCD dewar with its cover (d).

For this preliminary test, the boron was not deposited directly on the silicon CCD surface, but on an aluminium sheet 2 mm thick.

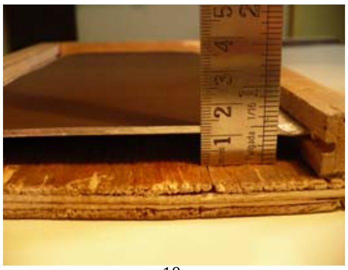


Figure 7. Aluminium sheet with a ^{10}B layer deposited on its surface. The borated face was placed near the CCD surface (less than 1 mm).

5. Results

5.1 Experimental results

For this preliminary test we use as a sample a 1 mm cadmium mask with a cross shape hole placed in contact with the aluminium sheet. A picture of this object is shown in figure 8.

Figure 8. 1 mm Cd sheet with a cross and different holes, employed as a sample.

Employing a ^{252}Cf neutron source, a polyethylene moderator, and the experimental set-up formerly mentioned, we have obtained the neutron image presented in figure 9.

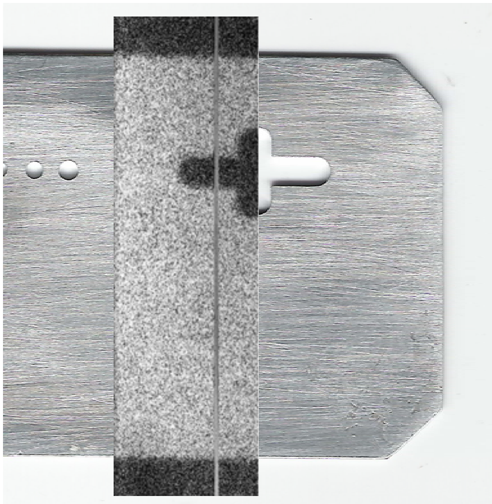


Figure 9. Neutron image obtained with this technique (central part). The background of this figure is a photo of the employed cadmium sheet (zoom of Figure 8). For the neutron image we employ an inverted gray scale. The regions where the CCD detects more alpha events are shown in black.

The energy of the detected alpha particles (adding all the pixel of each event) depends on the cluster size. Figure 10 shows the relationship between these magnitudes.

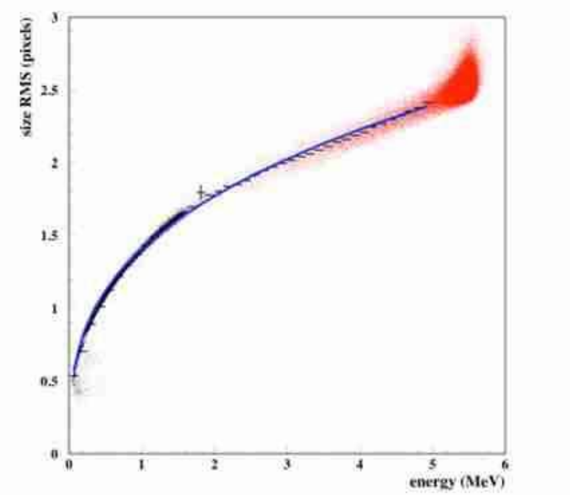


Figure 10. Energy dependence of the cluster size for α particles. Red points were obtained with the ^{241}Am source, and black points with a particles coming from the (n,α) reaction.

The behaviour observed in figure 10 is mainly due to a plasma effect produced by the charged particles in the silicon bulk [6].

5.2 Monte Carlo simulations

It is worth to notice that in this preliminary experiment the boron layer was deposited on an aluminium surface placed at about 1 mm from the silicon surface. For this reason the resolution observed in figure 9 is about 1 mm. The resolution and the efficiency of a detection system with the boron layer deposited directly on the CCD silicon surface were estimated by means of Monte Carlo simulation using the MCNP program. In order to validate the Monte Carlo, in figure 11 we compare the energy spectrum with the experimental.

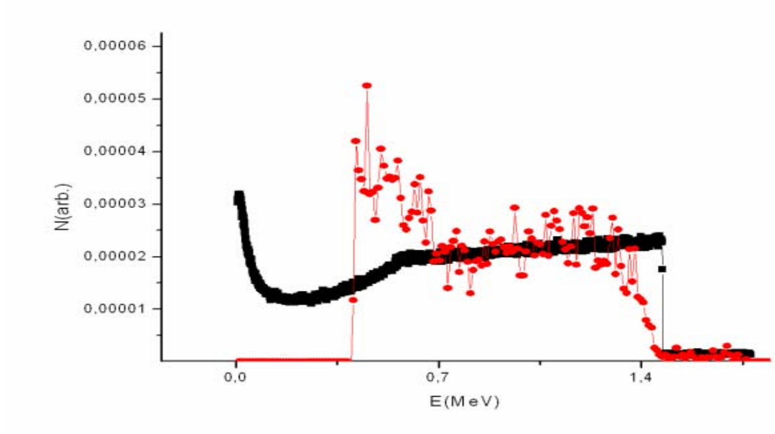


Figure 11. Experimental (red) and simulated (black) energy spectrum.

The simulation does not take into account de ^{7}Li contribution. This is the reason of the difference observed in figure 11 below 0.7 MeV. The simulation neither takes into account a gold layer deposited on the silicon detector used for this measurements. This is the reason of the difference noted at about 1.5 MeV.

In a real experiment a lower level discrimination (LLD) must be selected according to the observed background level. Only events with energy greater than LLD should be counted as neutrons. The detection efficiency is calculated as the area under the energy spectra. For this reason, the optimum boron thickness depends on the LLD. For very large boron thickness most of the neutrons are transmitted without interaction, and for very thick boron thickness the α and ^{7}Li do not reach the CCD. Figure 12 (a) shows the optimum boron thickness T_{opt} (obtained from the simulations without taking into account the ^{7}Li contribution) as a function of LLD. Figure 12 (b) shows detection efficiency for T_{opt} as a function of LLD.

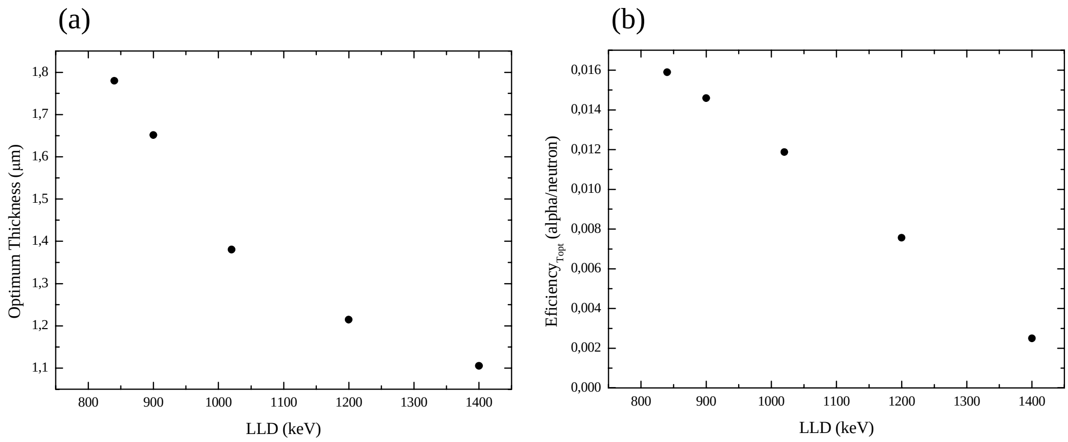


Figure 12. (a) Optimum boron thickness as a function of the lower level discrimination (LLD). (b) Neutron efficiency for the optimum thickness.

Finally, in order to estimate the resolution of the proposed technique we use the SRIM2011 program to simulate the tracks of α particles in ^{10}B and Si. We suppose an α beam of 1780 keV incident the horizontal direction. The results are shown in figure 13.

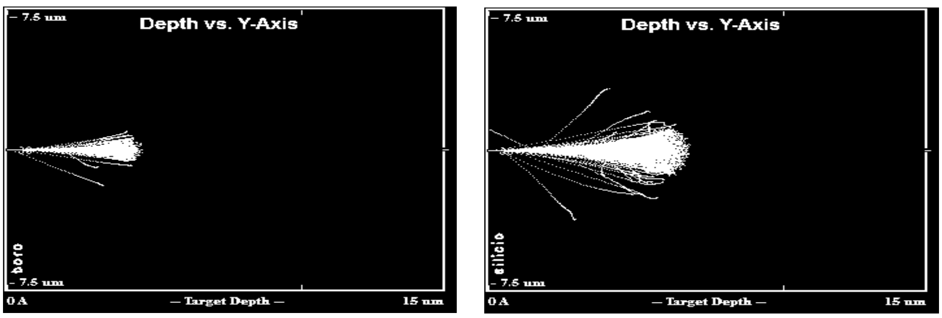


Figure 13. Simulation of α tracks in ^{10}B (left) and Si (right) using the SRIM2011 program assuming an incident α beam of 1780 keV in the horizontal direction.

For ^{10}B we observe a mean α range of 4.4 μm, and for Si a mean α range of 6.4 μm.

6. Conclusion

The preliminary tests of this technique were successful, and the first neutron images were obtained. This technique can be used for different neutron imaging applications, especially in those cases were high resolution in the detection position is required. The gamma events can be easily discriminated analysing the energy events. Other unwanted events (muons, fast neutrons, etc.) can be discriminated analysing the shape of the events recorded in the CCD. From simulations that do not take into account the ^{7}Li contribution, the maximum detection efficiency for thermal neutrons is about 1.6%. The following step is to deposit the boron layer directly on the CCD surface. From a Monte Carlo simulation we estimated a final resolution of about 10 μm. We are analysing the radiation damage effects of a CCD placed directly in an intense gamma and fast neutron beam. The main disadvantage of this kind of CCD is that the present image collecting time does not permit neutron-time-of-flight measurements.

References

[1] J. Estrada, et al., Prospects for a Direct Dark Matter Search Using High Resistivity CCD Detectors, arXiv:0802.2872v3, 2008.
[2] J.R. Janesick, Scientific Charge-Coupled Devices, SPIE Press, Bellingham,WA, 2001.
[3] Dark Energy Survey Collaboration, The Dark Energy Survey, astro-ph/0510346, 2005.
[4] S.E. Holland, D.E. Groom, N.P. Palaio, R.J. Stover, M. Wei, IEEE Transactions on Electron Devices ED-50 (2003) 225.
[5] C. Abbott, et al., Ground-based andairborne instrumentation for astronomy, in: I.S. Mc Lean, M. Iye (Eds.), Proceedings of the SPIE, vol. 62 69, 2006.
[6] J. Estrada, J. Molina, J.J. Blostein, and G. Fernández, Plasma effect in silicon charge coupled devices (CCDs), Nuclear Instruments and Methods in Physics Research A 665 (2011) 90–93.