Charged-coupled devices for charged-particle spectroscopy on OMEGA and NOVA

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Charge-coupled devices (CCDs) are to be utilized as charged-particle detectors for ρR and implosion symmetry diagnostics on OMEGA and NOVA. Using a large range of MeV charged particles, comprehensive studies have been performed on several back-illuminated CCDs in order to establish their utility for determining particle energy and identity (e.g., H, D, or T). Issues of signal and noise (i.e., especially from neutrons and gammas interacting with the CCDs) are also being investigated. © *1997 American Institute of Physics.* [S0034-6748(97)57401-6]

I. INTRODUCTION

Charged particles emanating from inertial implosions convey detailed information about the plasma conditions and dynamics.[1–6] To date, such spectroscopy has relied largely upon plastic track detectors or nuclear emulsions, methods which can be quite time consuming and difficult to implement. Recently[7–9] we undertook a program to detect and quantify the energy of charged particles via charged-coupled devices (CCDs) (see also Hicks *et al.*,[8] Seguin *et al.*,[9] and Burke *et al.*[10]). The principle is that the charged particle deposits a well defined energy in the sensitive depth of the CCD. This information, when combined with the momentum selectivity of a magnet, allows for the determination both of particle identity and energy. The focus of this article is our test of backilluminated CCDs (Burke *et al.*[10] treats the response of front-illuminated CCDs to protons and alphas).

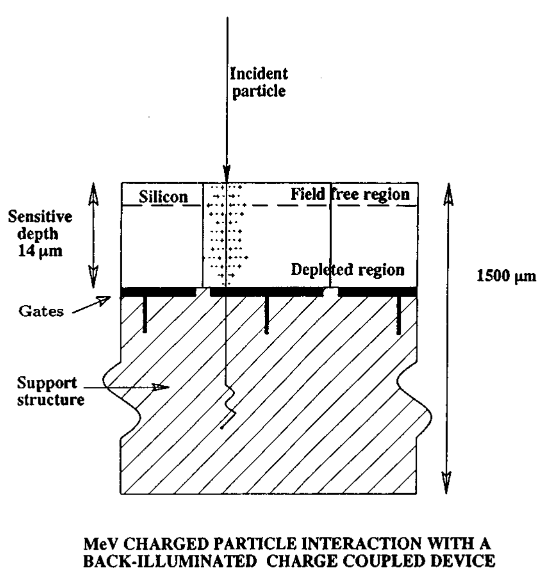

FIG. 1. Schematic of a thinned, back-illuminated CCD. The nominal depletion depth is about 11 μm, and the field-free region is about 3 μm. The sensitive depth is about 14 μm.

II. EXPERIMENTAL ARRANGEMENT

A. Charged-particle device

The CCDs tested are 512×512 thinned, back-illuminated devices manufactured by Scientific Imaging Technologies, Inc.[11] They are about 14 μm in "sensitive" thickness (~11 μm depletion depth, ~3 μm field free region), and are supported by a ceramic structure (Fig. 1). As configured in our experiments, their readout rate is 100 kHz. By cooling the device to −17 °C, the dark current is reduced to levels that are well below the charge generated by ~15 MeV protons, particles with the smallest stopping power used in our experiments.

B. MeV charged particles

Alphas and protons were used to test the CCD response. The alphas were from an ^{241}Am radioactive source (nominal alpha energy is about 5.5 MeV). By using various ranging filters, alpha energies between ~1 and 5 MeV were obtained (Fig. 2). Protons of 3.0 and 14.7 MeV were also generated, and originated from fusion reactions in our Cockcroft–Walton accelerator. By using appropriate ranging filters, proton energies between ~1 and 14 MeV were obtained and

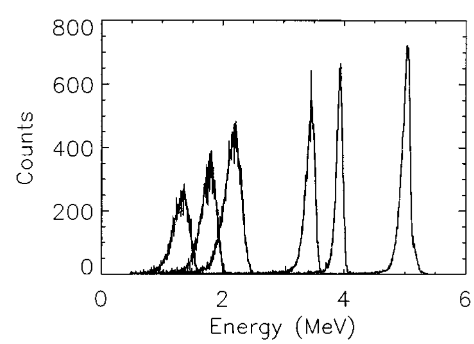

FIG. 2. Alphas of different energies, measured by an SBD, used to test the CCD. Different energies are generated by ranging the alphas down from 5.5 MeV (i.e., ^{241}Am source).

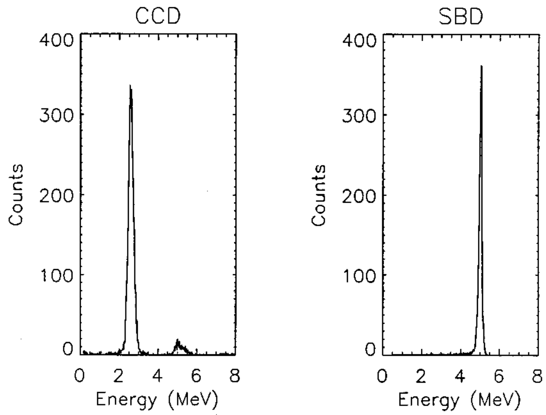

FIG. 3. The spectra of both CCD and a fully depleted SBD response to 5 MeV alphas. Note that a double-count (hit) peak is also evident in the CCD spectrum.

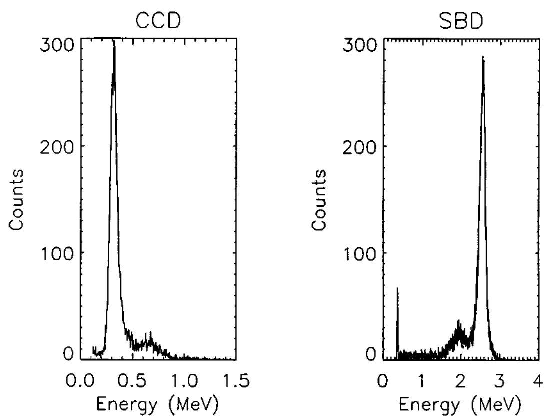

FIG. 4. The spectra of a CCD and a fully depleted SBD to about 2.6 MeV protons.

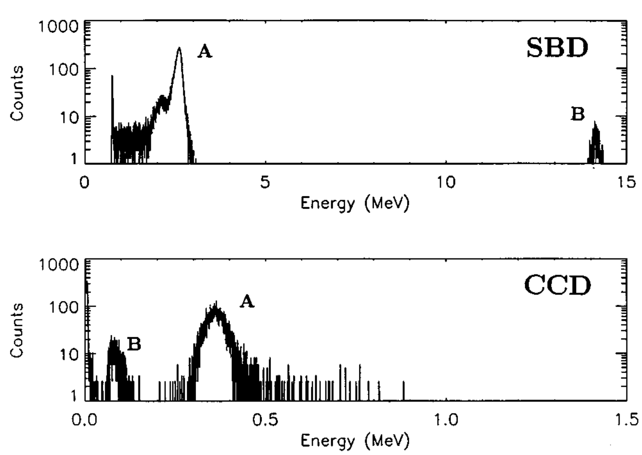

FIG. 5. The spectra of both CCD and a fully depleted SBD response to 2.6 MeV (label A) and 14 MeV protons (label B). As in the SBD spectrum, most of the spectral width of the CCD is due to the fact that the proton spectrum is not truly monoenergetic.

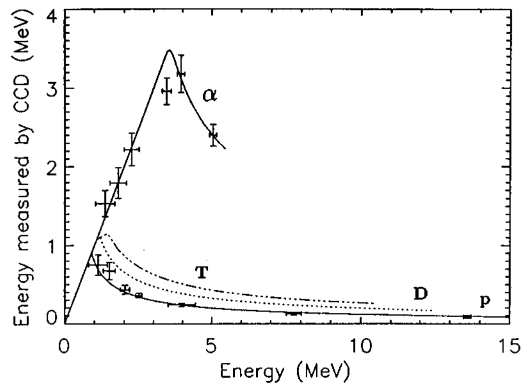

FIG. 6. The comparison of measured CCD responses to alphas and protons of different energies (points) to the theoretical predictions based on a 14 μm sensitive depth for the CCD. The experimental uncertainties are not error bars, but rather correspond to the measured FWHM of the particle energies. The proton energies at about 4 and 7.8 MeV derive from ranging down the 13.6 MeV protons. Therefore straggling increase their energy width of the 4 and 7.8 MeV protons. Similarly, protons at energy about 2.0 and less derive from the 2.6 MeV protons, and spectral broadening/straggling increases accordingly as the energy decreases.

utilized. Because of the large signals generated by both protons and alphas, each of these particles is detected with 100% efficiency by the CCD.

III. EXPERIMENTAL RESULTS

CCD response to 5 MeV alphas is shown in Fig. 3. Figure 4 shows the CCD responses to 2.6 MeV protons. The proton energy was simultaneously measured (Fig. 4) by a fully depleted surface burrier diode (SBD, 2000 μm sensitive depth). Because the sensitive depth of this CCD is small (14 μm), and the proton range $\gtrsim$100 μm, only a fraction of proton kinetic energy is deposited in the CCD (for 2.6 [14] MeV protons, about 0.3 [0.1] MeV is deposited in the CCD). Figure 5 shows both CCD and SBD response to 2.6 and 14 MeV protons. Figure 6 shows the comparison of calculated CCD responses, based on a 14 μm sensitive depth, to protons and alphas of various energies. Good agreement is found. The uncertainties are not really bars, but rather reflect the spectral width of the particle energies. Since the stopping power of tritons and deuterons is intermediate to alphas and protons, we expect that their responses will also match the theoretical curves.

IV. CONCLUSION AND FUTURE WORK

We have demonstrated the feasibility of using a thinned, back-illuminated CCD as the detector elements in a charged-particle spectrometer. The measured energy deposition of these charged particles in the CCDs is found to be in good agreement with the theoretical predictions for a device with a sensitive depth of 14 μm. Future tests will detail the response of the CCDs to neutrons and gammas, which constitute the dominant noise.

ACKNOWLEDGMENTS

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