A scintillator-based particle detector for CRYRING@ESR

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With the unprecedented range of ion species and energies offered by the newly commissioned CRYRING facility, the availability of single ion detectors is of significant importance as part of standard instrumentation as well as for novel experiments. A detector system was constructed on the basis of the YAP:Ce crystal scintillator, which is at once radiation-hard, fast, and affordable. Results of a characterization experiment confirmed the feasibility of the setup for incident ion rates on the order of MHz and found a critical fluence of some 10^{13} cm^{-2} upon which the crystal is rendered locally blind to further ion irradiation. The device was first used in CRYRING commissioning runs in August and November 2018. Future efforts will complete the integration of the detector into the GSI control and data acquisition system MBS.

1 | INTRODUCTION

The realization of the novel FAIR accelerator and storage ring complex achieved a major milestone with the commissioning of the CRYRING facility in late 2017. To fully exploit the multifaceted field of research thus made accessible, robust, and reliable ion detectors are of fundamental importance.[1] These sensors will need to cope with MHz count rates of ions with energies ranging from sub-MeV/u to 15 MeV/u[2] and have to withstand the radiation damage imparted by the energetic ions. On the other hand, neither the energy of the impinging ions nor their charge state need to be resolved, the latter being defined through the beam trajectories that intersect the sensitive surface.

Among the considered approaches for such a detector system is a device that utilizes the YAP:Ce crystal scintillator as the primary stage of ion detection and a photomultiplier tube (PMT) to record the flash of light associated with each incident ion. The detector is mounted on a 700-mm travel length translation stage that interfaces it to the different detector positions on CRYRING that provide access to the beam trajectories realized for different species of charge-exchanged ions. These manipulators are equipped with mounting chambers that can be separated from the ring through valves and allow installation, inspection, and replacement of the detectors without the need for breaking the ultra-high vacuum of the ring itself.
YAP:Ce has been shown to exhibit a significant degree of radiation hardness\cite{3,4} while being a comparatively affordable detector material. Furthermore, it can be easily stored and handled, being nonhygroscopic, chemically resistant, and endowed with a melting point of 1,875°C. Its peak emission wavelength of 370 nm compares favorably with the efficiency maximum of a range of commercially available PMTs, and the light yield reaches up to 40% of the yield obtained with NaI(Tl).\cite{5} The material therefore is a prime candidate for the intended use in an affordable, fast, and resilient ion detector.

2 | EXPERIMENT

The cutaway view displayed in Figure 1 shows the core components of the detector. A 15 mm x 15 mm slab of YAP:Ce is exposed to the incident beam of charge-exchanged ions and constitutes the system’s actual sensitive area. The flash of scintillation light is then detected by a PMT positioned on the far side of a UV-transparent fused silica window; the light collection is aided by a guiding prism with a reflective coating. This design eliminates the need for UHV-capable electronics that withstand the mandatory baking of the complete CRYRING installation, as the readout PMT can be installed from the atmospheric side after baking is completed. Thus, the sole component already in place during evacuation is the scintillator crystal, which cannot be positioned behind a window as this would stop low energy ions before they reach the sensitive material.

In an effort to demonstrate the feasibility of the design and to gauge the assembly’s sensitivity and durability under prolonged ion irradiation, a characterization measurement of the system, without the light guide prism, was conducted at the 3-MV tandem accelerator JULIA operated by the Institute of Solid State Physics at the University of Jena. The investigated ion species—hydrogen, oxygen, and iodine, with energies between 0.1 and 2.4 MeV/u—were chosen to approximately coincide with the expected range encountered in the early phases of CRYRING operation.

A Hamamatsu R8619 PMT converted the scintillation light to an electronic pulse that was fed into an Ortec 474 timing filter amplifier for minor pulse shaping. The signal was then split, with one part conducted to a Rigol DS1102E oscilloscope for observation and acquisition of pulse profiles, whereas an Ortec easy-MCA multichannel analyzer recorded the pulse height spectrum. Spurious background pulses were suppressed by gating the MCA with the help of a Mesytech MCFD-16 constant fraction discriminator to apply a pulse height threshold. Furthermore, the trigger rate of the CFD module was used as an indicator of the incident ion flux. Its control software, together with that of the oscilloscope and MCA, was hosted on a standard desktop PC.

To ensure that the durability investigation for each ion species—energy combination was based on pristine material, a 1 mm x 1 mm beam spot on the detector surface was defined for each run by scanning the beam in two dimensions over a movable aperture realized through a pair of perpendicular, micrometer-precision slits.

3 | RESULTS

Upon ion irradiation, the PMT bias voltage of 1,000 to 1,500 V proved entirely sufficient for pulse heights of some V, so that additional amplification of the primary signal was not necessary. Note that amplification will be required for the final setup, where the introduction of the light guide prism will lead to a less than optimal alignment of the sensitive crystal area and the PMT. With growing ion-induced damage accumulated in the crystal, the observed pulse height was found to steadily decrease, with more marked losses encountered for...
heavier ions. In contrast, irradiation with 2.4 MeV/u protons appeared to cause little damage even after a combined fluence of almost $10^{14}$ cm$^{-2}$, as shown in Figure 2. Machine restrictions of the accelerator made it infeasible to significantly extend the total fluence for this ion species.

However, because the detector system is intended to be purely counting-type, a moderate reduction in the output pulse height does not necessarily compromise its capability. It is only when the average pulse heights finally drop to the critical level established by the heights of random noise pulses emitted by the PMT that the irradiated region of the scintillator has to be considered spent. At this point, the incident beam has to be directed to a virgin part of the crystal by slightly adjusting the detector position or replacing the scintillator altogether. This cutoff was found to be on the order of $10^{13}$ cm$^{-2}$ across the different ion species and energies, with lower values observed for heavier particles. The nominal beam energy, on the other hand, has little impact on this destruction threshold.

Although the localized damage induced by impinging ions does impair the pulse height, it appears to have no effect on the pulse duration. The initial pulse length of about 50 ns allows for particle incidence rates of MHz and does not suffer after prolonged ion irradiation. This lends additional support to the excellent feasibility of the device as a counting detector.

In the context of two commissioning beamtimes at CRYRING in 2018, the detector was first tested on the machine with $\text{H}_2^+$ and $\text{D}^+$ ion beams circulating. Figure 3 summarizes data acquired in the latter experiment, which clearly show the initial injection flash and a subsequent count rate peak associated with the narrowing of the ion beam when electron cooling is applied. Towards the end of the 30-s process, the beam is gradually lost. Unfortunately, excessive background noise, now attributed to stray light from a hot-cathode vacuum gauge, made observation of this stage difficult.

4 | SUMMARY

Based on the radiation-hard YAP:Ce crystal scintillator, a UHV-capable single ion detector was designed, constructed, and tested. Results of a characterization experiment at a 3-MV tandem accelerator confirm both the assembly’s radiation hardness up to fluences of $10^{13}$ cm$^{-2}$ and its capability to reliably record MHz count rates of incident ions, even at low energies below 1 MeV/u. First successful runs of the complete setup were conducted as part of the CRYRING commissioning campaign in August and November 2018; data analysis of these measurements is ongoing.

Future efforts will concentrate on the integration of the detector with the GSI-wide MBS control and data acquisition system, completing the detector’s commissioning as part of the CRYRING standard instrumentation.

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