FAST INORGANIC SCINTILLATORS FOR BEAM DIAGNOSTICS AT EXTREME HIGH VACUUM

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Abstract

Some inorganic scintillators have properties that make them useful for beam diagnostics in storage rings where extreme high vacuum conditions are required. In the present work YAP:Ce and BaF_2 scintillators were used for beam normalization purposes at the accelerator and storage ring CRYRING in Stockholm.

1 INTRODUCTION

An atomic process which changes the charge state of an accelerated ion will cause the ion to leave the stored beam. Such processes can be used for beam diagnostics. Examples are molecular dissociation, stripping of electrons in collisions with rest gas molecules or atoms, and different electron pick-up processes like dielectronic recombination in the electron cooler.

Fast scintillators made of inorganic materials with low vapour pressure are very suitable as detectors to be used in extreme and ultra high vacuum (XHV, UHV). In the following we review the important properties of two comparatively fast scintillators; cerium doped yttrium aluminium perovskite (YAP:Ce) and barium fluoride (BaF_2). We have used these two scintillator materials for diagnostic applications and give a few examples from experiments at CRYRING.

2 DETECTOR PROPERTIES

Recent development has made available a number of new inorganic scintillator materials. Already well known and widely used is BaF_2. Here we also report on applications of a new scintillator; YAP:Ce [1]. As can be seen in Table 1 these two scintillators are fast compared to NaI(Tl), which cannot be used in UHV because it is hygroscopic. Their fast response make them useful also when high count-rates are expected. An advantage of YAP:Ce over BaF_2 is that YAP:Ce is harder and less brittle than BaF_2, which cleaves quite easily. Another advantage is the high light output per MeV (gamma energy) which gives good energy resolution also for detection of charged particles.

Table 1: Properties of BaF_2, YAP:Ce [1] and for comparison NaI(Tl). The parameters are valid for gamma radiation in the region 100 - 1500 keV.

Parameters	**NaI(Tl)**	**BaF_2**	**YAP:Ce**
Number of phe [phe/MeV]	9000 12000	2500	4300
τ_r [ns]	230	0.6 620	27 140
λ [nm]	415	220 320	370
ρ [g/cm^3]	3.67	4.88	5.35
$\Delta E/E$ [%]	6	9	5.7
Time resolution E>1 MeV [ps] E>100 keV [ps]	 350 800	 80	 160 230
Chemical properties	Hygroscopic	Inert	Inert

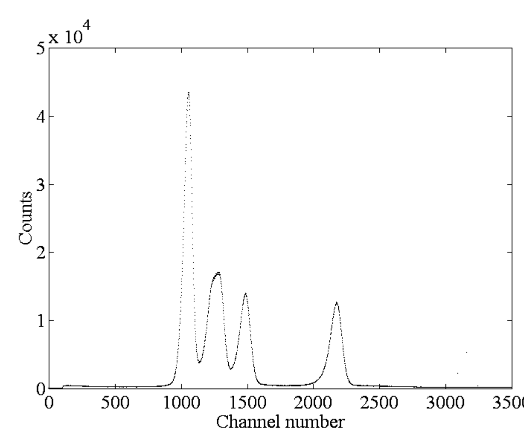

Figure 1: An alpha particle spectrum of ^{226}Ra and daughters recorded with a YAP:Ce scintillator directly attached to a Philips XP2020QUR photomultiplier.

The resolution at 8 MeV, the peak of highest energy in Fig. 1, is 3.3%. This is probably the best resolution found for an inorganic scintillator but at the same time about 10 times worse than what can easily be obtained with a silicon surface barrier detector. On the other hand a YAP:Ce detector can withstand many orders more of particle radiation than a semiconductor detector.

3 EXPERIMENTAL DETAILS

At CRYRING a large fraction of the experiments use singly charged molecular ions and normal singly charged ions. Neutral molecular fragments and singly charged ions, which have been neutralized in some scattering process leave the beam trajectory in next bending magnet. We have placed a BaF_2 detector, which is mounted as a window in the 0^o direction after one of the dipole magnets (the diagnostic section) in CRYRING. This detector is hit by neutralized beam species. A photomultiplier is attached directly to the BaF_2 window and no electric feed-through or cable is needed in vacuum. A YAP:Ce scintillator has been used as a detector for neutralized ions after the electron cooler.

4 APPLICATIONS

Here we present a few experiments performed at CRYRING where scintillators were used in UHV and XHV for normalization and beam current monitoring.

4.1 Measurement of metastable lifetimes by laser excitation of stored Ca^+ ions.

A fraction of the Ca^+ ions produced by the MINIS ion source are in metastable states. After storage in CRYRING the lifetimes of these metastable states can be measured by laser excitation methods [2].

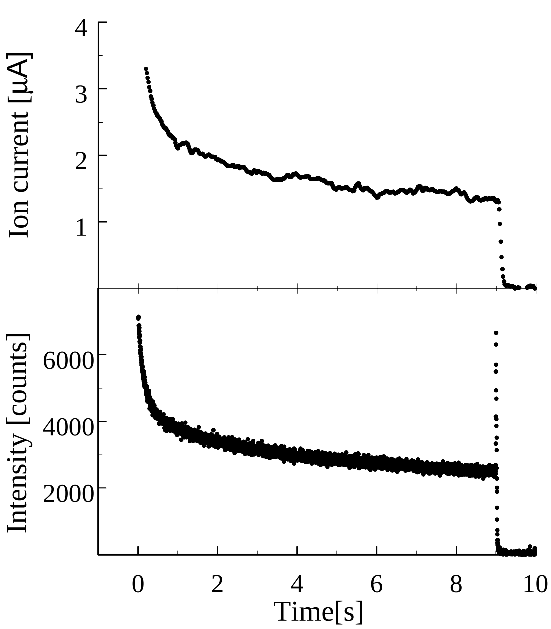

Figure 2: Beam current of stored 40 keV Ca^+ ions as measured by a current transformer (upper figure) compared to a multiscaling spectrum of neutralized Ca^+ ions measured with a BaF_2 detector (lower figure).

However the method requires that the measured metastable lifetime is corrected for the beam life-time. This was achieved by counting the number of neutralized Ca atoms hitting a BaF_2 detector placed in the 0^o direction after one of the bending magnets (Fig. 2, lower part).

It was also necessary to measure the number of ions for each injection into CRYRING. Very accurate normalization for each cycle could be obtained by counting the number of neutral Ca atoms during a time interval 1 - 2 seconds about 1 second after injection (see Fig. 2 and Fig. 3.). The cross-sections for processes leading to neutralization of calcium ions are however dependent on vacuum, velocity, etc. In addition the production of metastable ions in the ion source is not necessarily proportional to the number of produced ions. At times unstable performance of the ion source have been seen. (see Fig. 3)

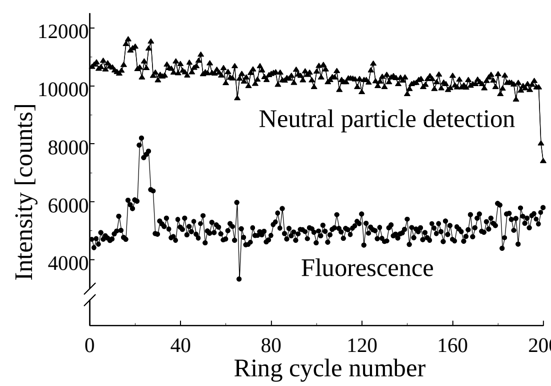

Figure 3: The number of neutral particles per cycle detected in a BaF_2 detector, shown together with a simultaneous measurement of metastable Ca^+ ions detected by laser fluorescence to be in a metastable state.

As can be seen in Fig. 3 changes of ion intensity of 10 % could be accompanied by an almost 100% change of the number of ions in the metastable state. In addition a slow decrease in ion intensity over long time is not necessarily connected with a decrease in the production of metastable Ca ions.

4.2 Detection of neutral molecular fragments in studies of dissociative recombination.

A large number of experiments on dissociative recombination have been performed at CRYRING with the help of the electron cooler. Diatomic molecules like CO^+, CN^+, $^3HeH^+$ or DH^+ (see Fig. 4) were studied. Normally surface barrier detectors are used to detect the neutralized molecular fragments. However heavy fragments damage the silicon detectors within a few days of exposure to stored molecular ion beam intensities of a much more resistant to irradiation with heavy ions than solid state detectors. The spectrum in Fig. 4 was recorded with a BaF_2 detector. The resolution could be considerably improved if BaF_2 was replaced by YAP:Ce.

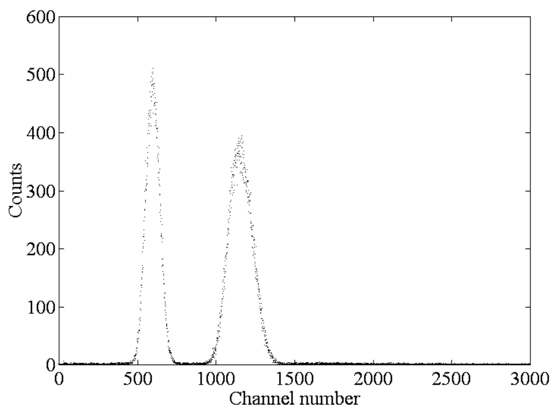

Figure 4: A particle energy spectrum of neutral H and D atoms. In this case dissociation of a beam of 3 MeV DH^+ molecular ions was studied.

4.3 Studies of single event upset (SEU) in electronic circuits.

In these experiments working static RAM circuits were irradiated with scattered heavy ions and the temporary errors in the circuit were registered. A BaF_2 scintillator was used as monitoring detector. The circuits to be tested and the BaF_2 detector were placed at fixed angles with respect to the scattering gold foil which was hit by the beam towards the end of every cycle when magnets are ramped up to maximum field [3]. With this method both the beam current and the number of ions hitting the circuit could be estimated with reasonable accuracy [4].

4.4 Detection of charge changed heavy highly charged ions

At CRYRING highly charged heavy ions can be accelerated to around 10 MeV/u. Ions which change their charge state with one unit leave the beam and can be detected after the passing of one or two bending magnets depending on q/A. A detection system with a YAP:Ce scintillator as detector has been constructed for use in studies of dielectronic recombination in the electron cooler [5]. Details of this detector system are reported in a separate contribution to this conference [6].

5 CONCLUSIONS

We have shown that fast inorganic scintillators can be used for a number of diagnostic and normalization purposes in UHV and XHV environments. The scintillators used are reasonably fast and can withstand irradiation with heavy ions.

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