PROGRESS WITH LOW INTENSITY DIAGNOSTICS AT ISAC

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Abstract

The ISAC accelerators presently deliver various stable and radioactive ion beams with energies ranging from 2 keV/u up to about 5 MeV/u. Beam intensities also vary enormously being as low as a few hundreds ions per second for certain radioactive ion species and as high as 100 enA for stable and pilot beams. Monitoring of beams with currents lower than ~0.5 epA requires a dedicated diagnostic instrumentation which typically makes use of radiation tolerant single particle detectors. Several such devices have been built and are under development at TRIUMF. Secondary electron emission monitors, solid state and scintillator detectors, many with a count rate capability in excess of 10^6 pps are employed. Device controls and data acquisition are integrated into the EPICS environment and provide standardized, simple and transparent operation.

INTRODUCTION

ISAC is a facility for production and post-acceleration of radioactive ion beams (RIB). RIBs are produced by interaction of a 500 MeV proton beam with a thick target and istotope separation on line (ISOL) with the energy of 2 keV/u and are delivered to low energy experiments or to the accelerator complex. A radio frequency quadruple (RFQ) and a drift tube linac (DTL) boost the beam energy to the range between 150 keV/u and 1.5 MeV/u upon request from medium energy experiments of the ISAC-I complex. A recently constructed SC linac adds up to 40 MV of energy to the beam and sends it to high energy ISAC-II experimental areas. The final beam energy depends on the mass to charge ratio of accelerated species and could be as high as 22 MeV/u for A/Q=2 and 8 MeV/u for A/Q=6 but limited to 5 MeV/u by the present operation licence (upgrade to 11 MeV/u operation is expected soon). All accelerators operate in the CW regime. In addition to RIBs, stable beams are produced, accelerated and transported for tuning the accelerators and experimental apparatus.

Beam intensities that are dealt with at ISAC span an enormous range from a few hundreds particles per second (pps) for certain radioactive ion species to almost 100enA for stable pilot beams. To cover the entire range of beam intensities two sets of diagnostics are available all around the ISAC facility. The high intensity diagnostics includes faraday cups (FC), wire scanners, slit scanners and resonant capacitive pickups with typical sensitivities in the nA range. The lowest beam current measurable with a FC equipped with charge integration electronics is in the range of a few epA. Monitoring beam currents lower than ~0.5 epA is performed by low intensity diagnostic devices. It is possible to operate low intensity diagnostics with higher beam currents using calibrated beam attenuators.

ISAC LOW INTENSITY DIAGNOSTICS

Low intensity devices make use of radiation resistant detectors capable of single particle detection. The choice of a particular detector (among other factors) is determined by the beam energy. For example, a very short (stopping) range of low energy ions prohibits use of windowed detectors or detectors with metal contacts at the input face. A very high signal gain is also required in this case as the energy transferred to the detector is low. In general, a suitable detector should be capable of operating at high count rates of up to about 10^7 pps and survive a high cumulative dose. A good energy or time resolution could be helpful in rejection of signals arising from decay products of radioactive beams.

A properly designed low intensity monitor is a very powerful beam diagnostic tool that delivers various beam related information, such as the intensity, beam transverse profile and time structure, the beam energy and phase, the beam purity. As any other diagnostic instrument, a low intensity device is required to be inexpensive, robust and reliable, simple in maintenance and operation. The above considerations have been taken into account in development, design and construction of low intensity diagnostics for ISAC facilities. Presently, there are about 25 low intensity devices in operation at ISAC.

SEE Monitors

Since secondary electron emission (SEE) is essentially a surface effect it is particularly suited for detection of low energy ions. Secondary electrons extracted by a beam from a target are guided in an applied electric field towards a detector that amplifies the incoming signal by a factor of 10^5 to 10^6, so even a single ion can be observed, in principle. Channel electron multipliers (CEM) 7550m from ITT and Magnum 5903 from Burle, are used in ISAC SEE monitors for detections of secondary electrons. Compared to micro-channel plates (MCP), CEMs are more robust, less expensive and demonstrate lower dark count rates. However, CEMs are not particularly suited for timing applications due to a significant signal transient time spread (few ns). Each SEE device is equipped with a thermal electron source for test purposes. A 45° motorized V-shaped slit is installed upstream for transverse beam profile measurements.

There are few limitations associated with SEE monitors as intensity measuring devices. Only few secondary electrons per incident ion are produced on average from a typical (metal) target. Along with the CEM gain fluctuation this results in a very broad pulse height distribution that makes impossible separation of pulses from incident radioactive ions and their decay products. Also, superimposed with the CEM gain loss due to aging, this leads to a slow reduction of the detection efficiency.

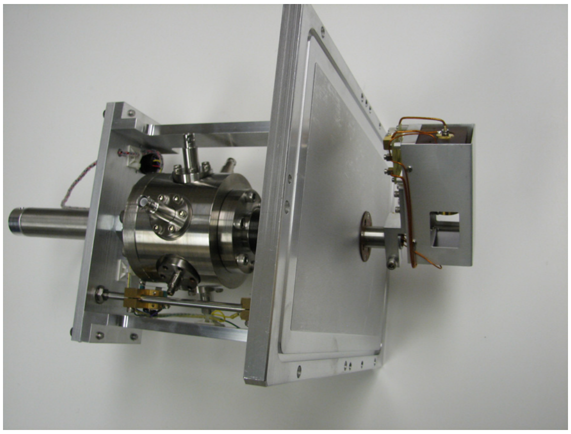

Figure 1: ISAC CEM based SEE monitor.

Thus, absolute intensity measurements require frequent calibrations and gain adjustments by increasing the high voltage (HV) bias. The integral life time of a typical CEM is about 10^{11} ions. It is expected that performance of SEE monitors could be improved if a target with a very high coefficient of secondary electron emission is used. Few tests with boron doped diamond samples looked promising but still more studies are required in this direction.

Three MCP based SEE monitors with a very high time resolution comprise the ISAC time-of-flight system for beam energy measurements [1]. Thanks to the adjustable gain of MCPs the system operates in a wide intensity range starting from about 10^3 pps.

Silicon Detectors

Silicon detectors have been routinely used for diagnostics of medium and high energy beams since the very beginning. For the reason of a low radiation resistance their applicability is limited to very low beam intensities < 10^4 pps. Two silicon detectors are used for timing and RF cavities phasing at high beam intensities by sampling a small fraction of the beam scattered from a thin gold foil [1].

Scintillator Detectors

Scintillator detectors are presently seen at ISAC as a principle low intensity diagnostic tool in the medium to high energy range for a favourable combination of their characteristics. YAP:Ce inorganic scintillator has been successfully used for ion detection [2]. This scintillator material is radiation tolerant with the life time expectation of ~10^{13} ions per cm^2. Scintillations rise faster than in 1 ns and decay for about 30 ns allowing for count rates in excess of 10^6 pps and time measurements with sub-ns resolution. At beam energies higher than a few MeV the light output is sufficient for detection with avalanche photodiodes (APD). These are very compact devices and fit the tight space available in typically crowded diagnostics boxes. Two types of silicon APD have been used so far: a 16mm SD630-70-74-500 from Advanced Photonix, Inc, and a 13mm x 13mm S-1315-P from RMD, Inc. Both have the similar maximum gain of about 250 and the pulse rise time of 15 ns. The latter has a slightly higher leakage current but smaller in size and mechanically better suited for vacuum applications. YAP:Ce crystals were acquired from Proteus, Inc in thicknesses of 0.2 mm for medium energy application and 1 mm for high energy ones with diameters up to 25 mm. One face of each crystal (the input face in the detector) was coated with 150 nm Al and grounded in the detector housing to drain the charge from the scintillator volume. Although APDs are not directly exposed to ion beams that fully stop in the scintillator material, some damage occurs from the radioactive decay products. Data on APD life time is not available yet. A reasonable energy resolution of 7% to 10% was obtained with these monitors (Fig.2).

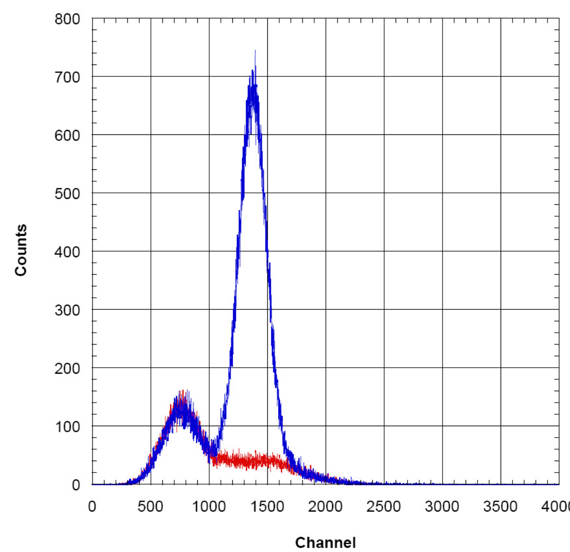

Figure 2: Spectrum of the ^{22}Ne beam at 1.5 MeV/u measured with 0.2mm thick YAP:Ce viewed by a SD630-70-74-500 APD. The background (red) is caused by radiation coming from the DTL situated just 1m upstream the monitor.

Diamond Detectors

Diamond detectors become ever more popular in beam diagnostics due to their outstanding resistance to high irradiation doses. They have been in use for heavy ion detection [3,4] and existing problems are well understood although the technologies of their reliable and repeatable production have not been fully established yet. Making good ohmic contacts still remains a challenge in the detector manufacture process. The ISAC low intensity diagnostics program has concentrated the major effort on single crystal (SC) diamond detectors as less suffering from problems of charge trapping observable in polycrystalline materials.

SC diamond materials are available in small sizes inadequate for intensity monitoring and, therefore, the main area of their applications at ISAC is considered to be time resolved measurements. In particular, our hope is

Figure 3: TRIUMF built single crystal diamond detector for the purpose of low intensity diagnostics.

that they will replace silicon detectors in cavity phasing and bunch length measurements. To this end, the present detector housing was designed for mechanical compatibility with the existing hardware (Fig.3).

The first detector was constructed in 2008 from a 0.4mm thick 3.5mm x3.5 mm SC diamond plate fabricated by Element Six. Metal Ti/Al contacts were sputtered at a local university. This detector demonstrated the best achieved so far energy resolution of 0.7%, a very good stability and no signs of space charge building up. Few other 0.5mm thick 4.7 x 4.7mm^2 crystals with Ti/Pt/Au contacts were supplied by Diamond Detectors, UK. Surprisingly enough, these ones showed signs of charge trapping and a rather poor energy resolution of 1.7%.

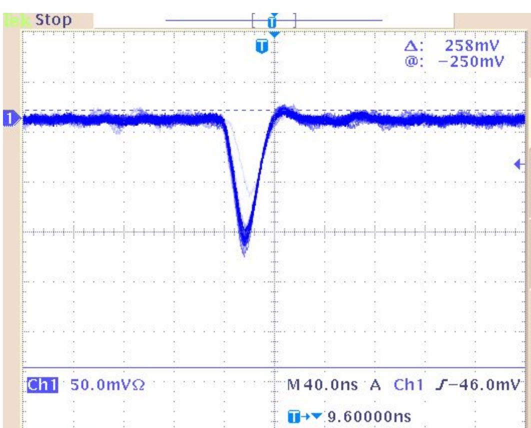

Figure 3: Signal produced in SC diamond detector by 1MeV/u ^{18}O ions. The pulse shape is determined by characteristics of the integrating amplifier.

Whether the problems are due to the contacts or crystal quality itself has not been understood yet. The measured drift velocity of 60μm/nsec at the applied field of 1V/μm is somewhat lower than it was reported by some others [3]. The pulse rise time of <500ps was observed and most certainly limited by the bandwidth of available amplifiers.

The signal from diamond detectors is nearly four times smaller compared to silicon ones. Few dedicated low noise wide band and integrating amplifiers were built in-house.

MONITOR CONTROLS AND DATA ACQUISITION

Monitor controls and data acquisition are highly integrated into the EPICS-based ISAC control system [5]. Mechanical actuators of the monitors are "true" EPICS devices. The data acquisition system is built largely on the basis of commercial NIM and VME modules. The modules are controlled by a VME CPU running Linux. The same CPU provides interface to the control system. The fast data acquisition is performed by a set of applications communicating with the EPICS soft IOC channel by means of a run-time database resident in a segment of the OS supported shared memory. The system health monitoring is accessible through watchdogs and error message logging. The on-line data processing is done by a number of Matlab applications run on a remote host. An essential function of the monitor controls is the device protection, e.g., from excessive current and poor vacuum conditions. Such function is realized by interlocking actuators with vacuum gauges and high current faraday cups. In addition, the monitors are immediately retracted by the Control System if the count rate exceeds allowable levels. A dedicated bias application rumps the HV bias up and down when the related monitor is inserted or retracted. The user interface is identical for different monitors, except for special cases, such as beam time-of-flight and phase monitors. The system is highly automated and transparent to the users.

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