The New Annular Si Drift Detector µPIXE System at Sandia

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EXTENDED ABSTRACT

Sandia and Rontec GmbH have developed an annular, 12-element, 60 mm², Peltier-cooled, translatable, Silicon Drift Detector that we call the SDD-12. The body of the SDD-12 is 22.5 mm in total thickness and easily fits between the sample and the upstream wall of the Sandia microbeam chamber. At a working distance of 1mm, the solid angle is 1.09 sr. The energy resolution is 170eV at count rates <40 Kcps, and 200eV for rates of 1Mcps. X-ray count rates must be maintained below 50Kcps when protons are allowed to strike the full area of the SDD. Another innovation with this new µPIXE system is that the data are analyzed using Sandia’s Automated eXpert Spectral Image Analysis or AXSIA.

1. INTRODUCTION

A continuing challenge facing µPIXE has been to obtain large solid angles for the x-ray detectors in the confined geometry required for a nuclear microprobe. Sandia and Rontec have developed a new µPIXE system on the Optical-Nuclear-Electron Microscope (µ-ONE) that meets this challenge by employing the emerging Silicon Drift Detector (SDD) technology to realize an annular x-ray detector.

In 2000 Struder et al.1 proposed a design for an annular array of 12 Silicon Drift Detectors (SDDs) to be used for x-ray fluorescence (XRF), and this detector was later commercialized by Rontec2 GMBH utilizing an annular 12 element SDD array manufactured by KETEK3 GMBH. In 2002, Sandia placed a contract with Rontec to modify the design of their XRF system to be compatible with µPIXE and fit into the µONE system.

2. THE SILICON DRIFT DETECTOR FOR µPIXE

The main advantage of an SDD with respect to a Si(Li) detector is that although the detector covers a relatively large area, the electrons drift through a cylindrical electric field to the gate of an internal FET located at the center of the cylindrical electrodes. The drain of this FET is of very small size and capacitance, and because of that the noise level is lower and the energy resolution higher. At Peltier cooling temperatures (263K), one has a comparable energy resolution of a Si(Li) detector that must be liquid nitrogen cooled (77 K). Another advantage of the SDD is that the signal shaping time is much smaller, only .25 µs, allowing up to 100 times quicker acquisition.

To modify the Rontec XRF SDD detector to work for our PIXE system, the housing of the XRF detector was completely redesigned. Firstly, the SDD Si chip and associated x-ray apertures were moved forward to increase the solid angle. 12 independent SDDs are
positioned in a ring around a central hole through which the protons are transmitted. Each of these detectors has an area of $5\text{mm}^2$ and an active thickness of $280\mu\text{m}$. Half the detectors are at a radius of $3.4\text{mm}$, the other half at $5.6\text{mm}$. Calculations of the solid angle of this detector showed that the solid angle maximum is reached for a working distance (target to SDD chip) of $3.05\text{mm}$. This working distance was unattainable due to mechanical constraints, and a compromise was made to set this distance at $4\text{mm}$, with an associated solid angle of $1.09\text{sr}$. A special x-ray collimator-diaphragm array was machined to define the takeoff angle for this working distance. With this setting, the sample is positioned only $1\text{mm}$ in front of the detector housing. The system can also be operated at second working distance of $9\text{mm}$, or $6\text{mm}$ from the housing to the target, that matches the working distance of the OM-40 microscope, and this setting provides a solid angle of $0.54\text{sr}$. A photograph of the SDD12 detector assembly is shown in Fig. 1.

![Fig. 1. Photograph of the SDD12 detector assembly. This miniaturized design is approximately the size of a pack of cigarettes.](image)

### 3. PERFORMANCE TESTS

The initial performance tests of the SDD12 were performed using unfocused $3.0\text{ MeV}$ protons on a stainless steel sample. The goals of these experiments were to quantify the energy resolution of the system as a function of count rate, and to determine the effects of protons when transmitted through the Be window into the SDD chip.

To measure x-ray energy resolution, in the absence of transmitted protons, a $1\text{mm}$ Mylar disc was placed in front of the $8\mu\text{m}$ Be window to range out scattered protons. The proton beam current was then adjusted to provide a range of detected x-ray count rates from $10\text{Kcps}$ to over $4\text{Mcps}$. The Fe $K_\alpha$ resolution of the sum spectra is $195\text{ eV}$, which exceeds the $200\text{eV}$ specification given to Rontec. In Fig. 2 we plot the Fe $K_\alpha$ energy resolution as a function of measured count rate. At low count rates the resolution was even better, $170\text{ eV}$, and the $\sim200\text{ eV}$ resolution was maintained up to count rates of $1\text{Mcps}$. The resolution stays below $250\text{eV}$ up to $3\text{Mcps}$ and then rapidly degrades. There are probably several explanations for this degradation, but the most obvious is that the Rontec ADCs have $6\mu\text{s}$ conversion times, and because there are 12 data channels, this would seem to limit data collection to $2\text{Mcps}$ (this is...
the bold line in the figure). This data shows that the SDD12 should probably not be operated above count rates of 1Mcps.

Figure 6. X-ray energy resolution (FWHM) measured as a function of total count rate. A 1mm Mylar window stopped protons from entering the SDD chip. This data suggests that the SDD12 should be operated below 1Mcps to insure high energy resolution is maintained.

4. CONCLUSIONS

In a collaborative effort, Rontec and Sandia have developed a 60 mm$^2$, Peltier-cooled, annular Silicon Drift Detector, the SDD12, specifically for performing µPIXE analyses with a nuclear microprobe. The thin (22.8 mm), annular design maximizes solid angle at a minimum working distance of only 1mm. 12 simultaneous channels allow for data collection at very high rates of 1Mcps without sacrificing energy resolution (<200 eV at 6.4 keV). Full depletion of the ~280 µm thick detector provides approximately 90% collection efficiency of 10 keV x-rays.

The SDD12 represents a major advance in energy dispersive x-ray detectors for microanalysis. The solid angle and count rate capability are both ~100x larger than conventional Si(Li) detectors. This means that using the beams already available on systems, µPIXE (or just PIXE) experiments that use to take a minute will now take a second, an hour run reduces to a minute, and an experiment requiring a day – only an hour! Further, the SDD12 permits the 4x reduction of spot sizes (with a much larger reduction of beam current), that has improved the resolution available on the Sandia µONE system to a micron, and for state-of-the-art µPIXE systems, this should make possible experiments with beams of only 100nm.

REFERENCES