DIFFRACTION X-RAY SPECTROMETER

J.Cićek, D.Cika, V.Valković
Ruđer Bošković Institute, Zagreb

High energy resolution X-ray spectrometer to be used in the study of charged particle induced X-ray emission is described. The spectrometer will be used for the analysis of the essential trace elements and their compounds in biological material as well as for the study of multiple inner-shell ionization processes induced by heavy ions. The disadvantage of this detector is a small energy range for one configuration of the crystal or one position of the PSPC. The X-ray energy region is easily changed by selecting different crystal types and their Bragg angle. In this work the construction of an X-ray crystal spectrometer with the position-sensitive proportional counter (PSPC) is described.

The PSPC parameters such as gases, pressures and windows can be changed, while the position readout remains the same. The X-rays enter the PSPC through a mylar window with evaporated nickel layer.

The cathode plane is subdivided into strips which sample the avalanche at any of the anode wires. The cathode strips are connected to the signal processing electronics with delay line position readout by an universal double-edge connector.

The PSPC can be rotated around the center of the crystal in the θ-2θ mode. The target, crystal and the PSPC are placed in the vaccum chamber.

Introduction

A crystal X-ray spectrometer has been used for many years in the study of diferent processes (X-rays emitted from a variety of targets and projectiles) since it has a high energy resolution compared with semiconductor detectors. However, its step-scanning feature has a disadvantage of possessing low efficiency. For example, in a usual PIXE (particle induced X-ray emission) measurment using a Si(Li) detector, it is difficult to separate signals of adjacent, light element, or light element impurities in a heavy element matrix, because of the response function of the detector.

High energy resolution will be provided with a broad range X-ray crystal spectrometer using a position sensitive proportional counter for the detection of X-rays dispersed by a plane crystal.

Spectrometer

Our spectrometer is shown shematically in fig 1. Proton beam is generated in the 6 MV Tandem Van de Graff accelerator laboratory. X-rays produced by ion-atom collisions in the target are incident on the flat crystal and are reflected in accordance with the Bragg condition $2d\sin\theta=n\lambda$.

The PSPC probe is rotated around the center of the crystal in the $\theta-2\theta$ mode. The crystal is instaled on a goniometer head GH, so one can chose the angle θ. The detector position can be now automatically set at a suitable position 2θ. X-rays emitted with a Bragg angle varying by as much as about 15° may be analyzed simultaneously.
Type of the crystals for X-ray diffraction depends on a range of energy we are intrested in. Its size is about 80x20x2 mm^3. However, some crystal will diffract a greater

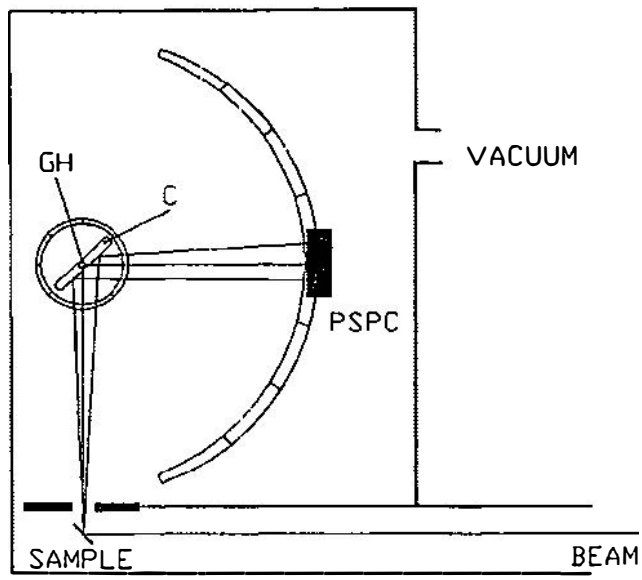

Figure 1. A schematic diagram of the diffraction X-ray spectrometar

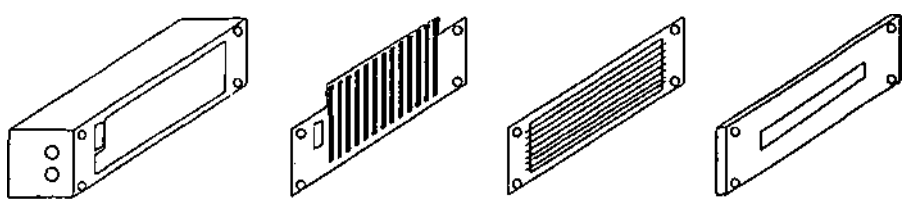

Figure 2. A basic design of the PSPC

fraction of incident radiation than will other one The term commonly used for diffraction efficiency is integral reflection coefficient R and it varies with wavelenght as well as with crystal composition and structure (Ref.1). The resolution of a crystal depends on the perfection of the crystal lattice over its entire diffraction surface. Local distortions in the lattice cause diffraction to occur over a range of θ angle and result in a finite line width W for each X-ray line .

As can be observed by reffering to Bragg's law. the spacing 2d limits the maximum wavelength which can be diffracted to $\lambda_{max}=2d$. Table 1 lists a few of the common spectrometer crystals along with their caracteristic. The range of an energy are determined according to the geometrical arrangment of our crystal spectrometer. The distance L between the sample and the crystal, and between the crystal and the PSPC are 25 cm. Minimum and maximum θ are 10° and 80°, respectivelly.

T A B L E I

CRYSTAL	PLANES	2d (A)	Range of energy for 10° to 80° (keV)
LiF	220	2.8	25.2 - 4.4
LiF	200	4.0	17.8 - 3.12
Quartz	$10\bar{1}0$	8.5	8.4 - 1.4
KAP	001	26.6	2.7 - 0.5

Basic design of the position sensitive proportional counter is shown in fig.2. The concept of this class of detector is that the detector dimensions can be chosen, within certain limits, accompanied by any necessary changes in gases, pressures, windows, etc. while the position read out remains the same.

The cathode plane is subdivided into strips which sample the charge induced on the cathode plane by avalanche at any of the anode wires. Very fine position resolution in the coordinate parallel to the anode wires is achived by determining the centroid of the charge induced on the cathode plane (Ref.2).

For one special cause we chose next principal parameters. X-rays enter the PSPC through a 8 x 2 x 10^{-3} cm^3 mylar window, the inside of which is covered with evaporated nickel.
The anode plane consists of 8 wires, 2mm apart. The PSPC is operated at anode voltage of 2 kV. We have chosen the spacing beetwen anodes to be about equal to the spacing between the anode and readout plane, $s = d \approx 2mm$. The cathode plane is made in printed circuit board technic. Center to center spacing of cathode readout strips is w=1.5mm, number of strips are 62.

Al plate with mylar window, anode plane with connections and cathode plane with printed readout strips are mounted on the Al support case. The detector is designed that it can be operated with or without gas flow. The type of gas depends on the energy range we are intrested in. X-ray conversion efficiency for various gases as a function of energy and of effective active region thickness are ploted in ref 3.

Special geometry of our system is determined from the requirement that there should be a linear relation between the position calculated as the centroid of the charge samples and the true position.(Ref.3) The centroid is determined by using continous delay line as the position readout. Position readout electronic is connected to the detector via standard IBM PC/XT 31 pin double edge connector. Delay line position sensing is used because of its availability and a good cost/perfomance ratio. It employs only two signal outputs for each coordinate of the

detector. The delay line is physically independent of the detector, so it can be used with detectors of different sizes.

A necessary condition for minimum noise is that the delay line should be properly terminated with it's characteristic impedance Z_o, in order to avoid possible reflections at high counting rates. This is done by an active resistance realized by feedback ("electronically cooled" termination). The connection of the detector cathode strips to the delay lines and the feedback termination are illustrated in figure 3.

The relations for the section capacitance and inductance are:

$$C_s = T_D / (N \times Z_o) = C_E + C_{STRIP}$$

$$L_s = T_D \times Z_o / N$$

For proper matching it should be

$$R_{IN} = 1/g_m \times C_o / C_f = Z_o$$

$$C_s/2 = T_D / 2NZ_o = C_{IN}\ ,\quad C_{IN} = C_{gm} + C_f + C_{STRAY}$$

The characteristic impedance of the delay line should be high, which is equivalent to a low total capacitance of the readout electrode. The time delay of the line (T_D) should be between 0.5 and 1 μs

Choosing $Z_o = 500\ \Omega$

$T_D = 1\ \mu s$

gives us $C_s = 32$ pF

$L_s = 8\ \mu H$

$C_{IN} = 16$ pF

The capacitors C_f and C_{STRAY} which are not related to the gain g_m should be minimized. Signal processing for detectors with delay line is shown in figure 3a.
Signall form the preamplifiers are processed with delay line shaping amplifiers and zero crossing detectors. The time difference of the detectors output signal is the position measure:

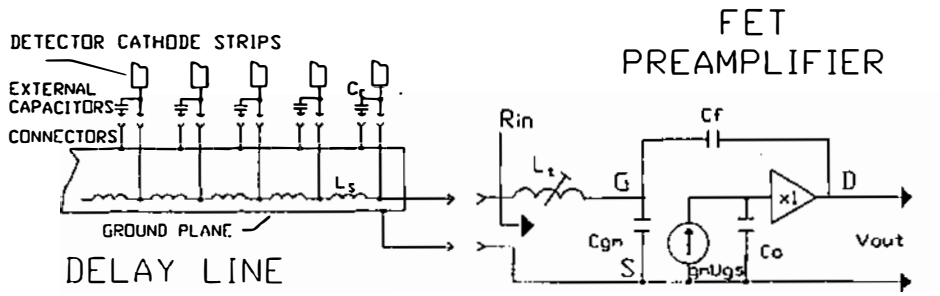

Fig. 3: "Electronically cooled" matched termination

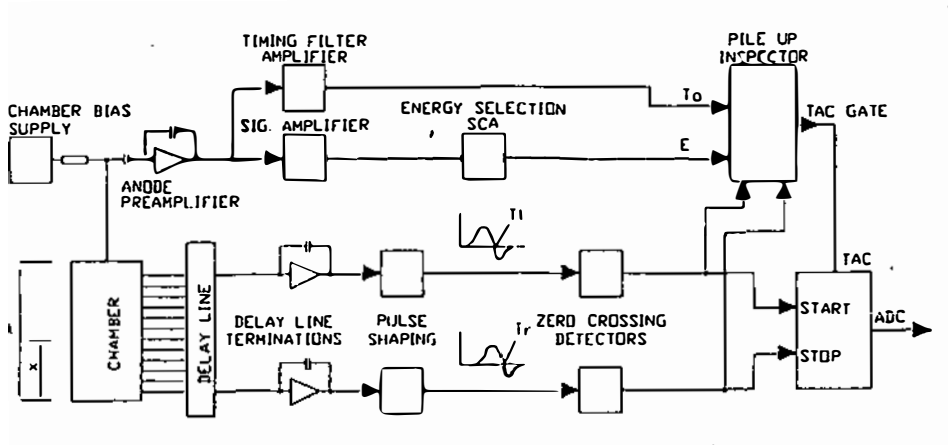

Fig. 3a: SIGNAL PROCESSING BLOCK DIAGRAM

$$\frac{t_r - t_l}{T_D} = 2\frac{x}{l} - 1$$

The pile-up inspection circuit monitors the time intervals between succesive anode signals, as well as the sum of the time intervals t_r and t_l. This sum is constant ($\approx T_D$) if only one signal is present in the delay line.

Resolution

A geometrical arrangement for the target, plane crystal and PSPC is shown on fig.4. An X-ray with an energy of E(keV) is diffracted by the crystal and detected at the position x(mm) on the PSPC.

In the geometry, the position x is defined as the distance from the center of the PSPC.

Then the position x is deduced as

$$x = \frac{2L}{\mathrm{tg}(\theta_c - \theta)}$$

L(mm) is the target-crystal and the crystal-detector distance. θ the Bragg angle of a diffracted X-ray which goes perpendiculary through the center of the PSPC window. The energy of X-ray can be expressed as a polynomial of the position x(Ref.4),

$$E = E_c \left(1 + \frac{x}{2L}\,\mathrm{tg}\theta_c + \left(\frac{x}{2L}\right)^2 \left(\mathrm{tg}^2\theta_c + \frac{1}{2}\right) + \left(\frac{x}{2L}\right)^3 \left(\mathrm{tg}^3\theta_c + \frac{1}{2}\,\mathrm{tg}\theta_c\right) + \ldots.\right)$$

where

$$E_c = \frac{12.4}{2d\sin\theta_c}$$

The half width of X-ray peaks on the position spectra W(mm) is converted in the unit of energy as

$$\Delta E = \frac{dE}{dx} \cdot W$$

The observed line width W depends on source width, instrumental resolution, position resolution and natural line width.

The position resolution is determend by the PSPC geomery and the signal processing electronic. The width of instrumental resolution partially comes from the fact thet the incident direction of the X-rays is not vertical to the window surface of the PSPC. The other origin of the instrumental resolution is crystal imperfections which has been discussed earlier.

A p p l i c a t i o n

The advantages of high energy resolution make the X-ray diffraction spectrometer uniquely suited for a variety of ion-atom colision studies.

For example, X-ray spectra are sensitive to the chemical environment of the emitting atom and can yield information on the atomic and electronic structure of host materials. The spectra resulting from heavy ion excitation are discussed in series of papers (Ref.5). Highly energetic heavy ions are capable of producing multiple inner-shell ionization. The first peak in such X-ray spectra, is composed of the usual $K_{\alpha 1}$ i $K_{\alpha 2}$ lines, whereas the peaks which folow are satellite peaks composed of K_{α} X-rays arising from configurations having L-shell vacancies. Measurements have been made of X-rays emited from a variety of targets and projectils.

The principal of X-ray diffraction spectrometry can be used for study of X-rays emitted from the fast ions too. Doppler shifting and broadening has been discussed in some paper by C.R.Vane (Ref.6). One more intresting problem is detection of light element in a heavy-element matrix, such as light

element impurities in a semiconductor or a metal (Ref.7)

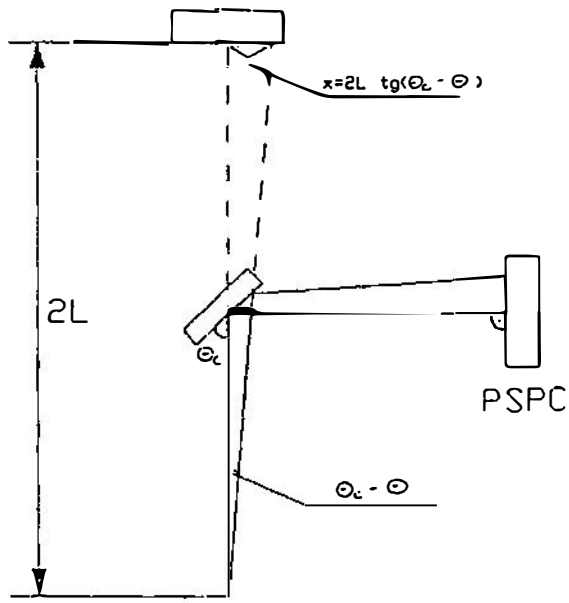

Figure 4. A usual arrangement of source, crystal and PSPC of the plane crystal spectrometer

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