DIAGNOSTICS OF CRYSTAL-RADIATOR OF POSITRONS BY BACKWARD GOING X-RAYS

(Characteristic X-rays, diffracted transition X-rays, parametric X-rays)

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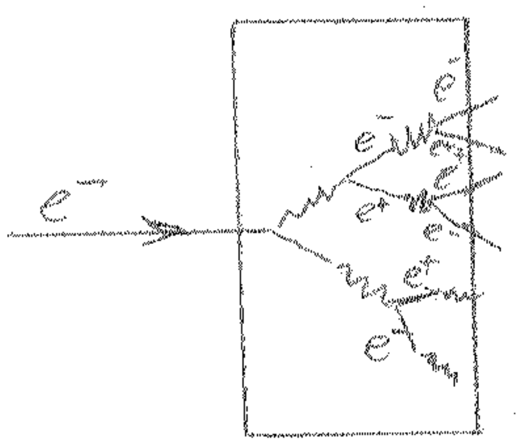
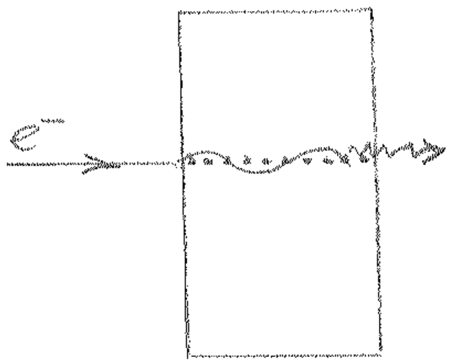
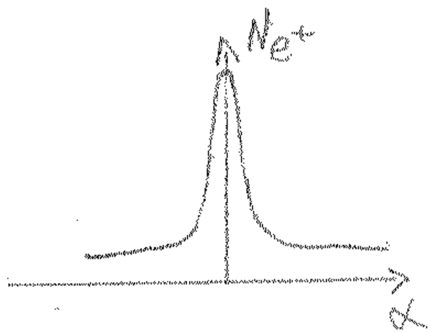
Conventional production of positrons



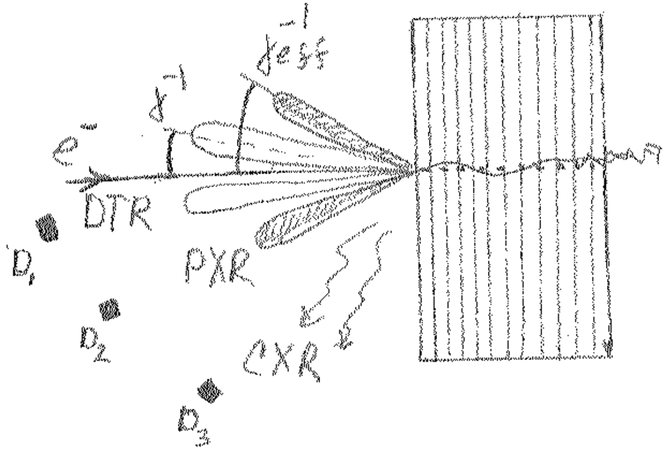
Production of positrons due to channeling and coherent bremsstrahlung in crystal (Chehab, 1989)

Now is applied in production of positron beam for storage rings





Production of X-rays in backward direction from crystalline converter



Proposal: Backward going X-rays may can be observed and used for diagnostics of crystal-radiator state and alignment.

Let us estimate intensities and angular properties of X-ray radiation emitted in backward direction from Si crystal

- Characteristic X-ray radiation (CXR)
- Parametric X-ray radiation (PXR)
- Diffracted transition X-ray radiation (DTR)

- **The yield of characteristic X-ray radiation (CXR) from Si.**
- The yield in backward direction from a thick target is $$Y_{CXR} = \frac{dN}{d\Omega} = \frac{n_0 T_e}{4\pi} \omega_K \sigma_K$$
- Where $\omega_K = 0.047, \;\; T_e = 13.3\mu m, \;\; n_0 = 5.0 \cdot 10^{22} cm^{-3}, \;\; \hbar\omega_k = 1.74 keV$

- **Si K-shell ionization cross section**
- The CXR is isotropic. All available experimental data and calculations by different theories are shown in next figure from
- [А.В. Щагин, В.В. Сотников. Формула для поперечного сечения ионизации К-оболочки атома Si релятивистскими электронами в тонком слое кремния. Вісник харківського національного університету, № 777, серія фізична, “Ядра, частинки, поля”, Випуск 2/34/, Харків, 2007, с. 97-101], Shchagin et al [NIM B V.48, 1994, pp. 9-13.

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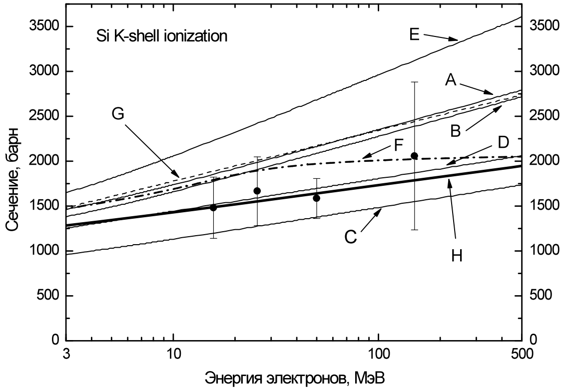

- Approximation of experimental data is: $$\sigma_K(barn) = 134 \ln \gamma + 1025$$
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- To take into account the density effect, we have to use effective relativistic factor

$$\sigma_K(barn) = 134 \ln \gamma_{eff} + 1025, \qquad \gamma_{eff} = \left(\gamma^{-2} + \left(\frac{\omega_p}{\omega} \right)^2 \right)^{-1/2}$$

The yield of the PXR in backward direction in the framework of the Ter-Mikaelian theory

- The yield in the PXR reflection is
- [Shchagin, Rad.Phys.Chem. V.61, 2001, pp.283-291]

$$\frac{dN}{d\Omega} = \frac{e^2 L \left|\chi_{\vec{g}}(\omega)\right|^2 k}{2\pi\hbar\varepsilon_0^3 \xi \left(V\xi^{-1} - \vec{V}\vec{\Omega}\right)} \cdot \left| \frac{\vec{k} \times \vec{k}_0}{\left(\vec{k}_\perp - \vec{g}_\perp\right)^2 + k^2 \gamma_{eff}^{-2}} \right|^2$$

- The yield in the PXR reflection in backward direction is

$$\left(\frac{dN}{d\Omega}\right)_{bw} = \frac{4n\left|\chi_{\vec{g}}(cg)\right|^2}{137\xi^2\sqrt{\varepsilon_0}} \cdot \frac{\rho^2}{\left[\rho^2 + \gamma_{eff}^{-2}\right]^2}$$

- The yield in the maximum of the PXR reflection in backward direction is

$$\left(\frac{dN}{d\Omega}\right)_{bw} = \frac{\left|\chi_{\vec{g}}(cg)\right|^2 \gamma_{eff}^2}{137 \cdot 16 \cdot \pi \cdot \left|\chi_0''\right| \xi^2 \sqrt{\varepsilon_0}}$$

- at observation angle $\theta = \pi - \gamma_{eff}^{-1}$

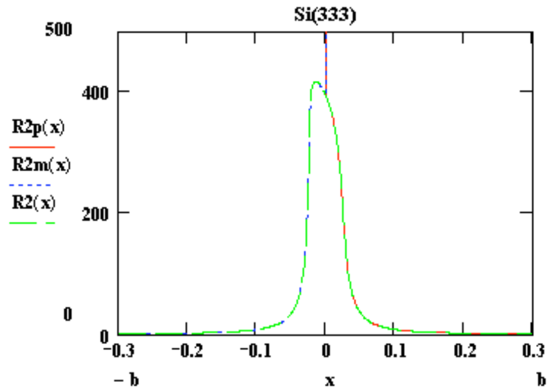
The yield of the diffracted transition radiation (DTR) in backward direction

The DTR yield in the framework of calculations of Caticha [Phys.Rev. A40, 4322, (1989)] and Backe, Kube, Lauth [NATO ARW, Yerevan 2001] in the field of density effect for PXR) at high incident electron energy E>100 MeV at condition

$$\gamma_{eff}^{-1} << |\chi_0|$$

$$\left(\frac{d^2N}{d\Omega\frac{d\hbar\omega}{\hbar\omega}}\right)_{bw} = \frac{|R_A|^2\rho^2}{137\cdot\pi^2\cdot\left(\rho^2+\gamma^{-2}\right)^2}$$

- where $|R_A|^2 = \left|-y \pm \sqrt{y^2-1}\right|^2, \quad y = \frac{2\varepsilon + i\chi_0''}{\chi_H' + \chi_H''}, \quad \varepsilon = \frac{\Delta\omega}{\omega}$
- $|R_A|^2$ is the Darwin-Prince curve:



- The yield of DTR in the maximum of DTR reflection is
- at observation angle $\theta = \pi - \gamma_{eff}^{-1}$

$$\left(\frac{dN}{d\Omega}\right)_{bw\max} = \frac{\alpha\cdot\gamma^2}{4\cdot\pi^2}\frac{\int_{-\infty}^{\infty}|R_A|^2\, d\hbar\omega}{\hbar\omega}$$

Results of calculations

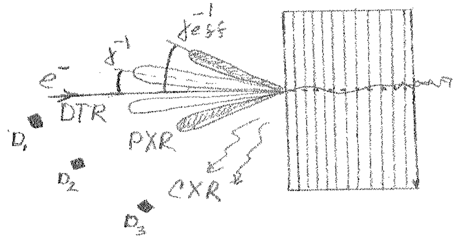
Properties of CXR and PXR

Energy	Si CXR, 1.74 keV, depth 13.3mkm		Backward going PXR from Si in maximum, <111> is parallel to incident electron velocity vector. The yield is saturated due to the density effect			
E_e, MeV	Y_{CXR} with dens.eff. (quanta/sr)	Y_{CXR} without dens. eff. (quanta/sr)	(111) $Y_{PXR\ max}$ angle/E/T_e	(333) $Y_{PXR\ max}$ angle/E/T_e	(444) $Y_{PXR\ max}$ angle/ E/T_e	(555) $Y_{PXR\ max}$ angle/E/T_e
250	3.89 10^{-4} quanta/sr	4.62 10^{-4}	0.92 10^{-4} quanta/sr 14.42 mrad 1.977 keV 1.51 mkm	3.22 10^{-4} quanta/sr 5.32 mrad 5.931 keV 28.9 mkm	5.35 10^{-4} quanta/sr 4.00 mrad 7.908 keV 66.7 mkm	1.92 10^{-4} quanta/sr 3.22 mrad 9.886 keV 128.8 mkm
500		4.85 10^{-4}				
1000		5.08 10^{-4}				
2000		5.31 10^{-4}				
4000		5.54 10^{-4}				
8000		5.77 10^{-4}				

Properties of DTR

Energy	Angle	Backward going DTR from Si in maximum, <111> is parallel to incident electron velocity vector, $Y_{DTR\ max}$, quanta/steradian			
E_e, MeV	gamma^{-1}, mrad	(111)	(333)	(444)	(555)
250	2.04	2.83 10^{-3}	3.74 10^{-4}	2.30 10^{-4}	6.53 10^{-5}
500	1.02	1.33 10^{-2}	1.50 10^{-3}	9.2 10^{-4}	2.61 10^{-4}
1000	0.51	4.52 10^{-2}	6.0 10^{-3}	3.68 10^{-3}	1.05 10^{-3}
2000	0.255	1.81 10^{-1}	2.4 10^{-2}	1.47 10^{-2}	4.18 10^{-3}
4000	0.127	7.24 10^{-1}	9.6 10^{-2}	5.89 10^{-2}	1.67 10^{-2}
8000	0.064	2.9	3.84 10^{-1}	2.35 10^{-1}	6.69 10^{-2}

Example



As an example, consider properties of X-rays from Si (444) at 250 and 8000 MeV

Properties of X-ray radiation Si, (444), **250 MeV**			
	CXR, 1.74 keV	PXR, 7.908 keV	DTR, 7.908 keV
Angle of maximum yield, mrad	any	4.00 mrad	2.04 mrad
Yield, quanta/(el-n*steradian)	4.62 10^{-4}	5.35 10^{-4}	2.30 10^{-4}
Si, (444), **8000 MeV**			
Angle of maximum yield, mrad	any	4.00 mrad	0.064 mrad
Yield, quanta/(el-n*steradian)	5.77 10^{-4}	5.35 10^{-4}	2.35 10^{-1}

Results and discussion

We propose to perform diagnostics of the crystal-radiator state and alignment at production of positrons due to observation of X-rays in backward direction. 3 kinds of radiation can be observed simultaneously:

Characteristic X-ray radiation

Parametric X-ray radiation

Diffracted transition radiation

Such diagnostics can provide next capabilities:

1. Provision of optimal preliminary alignment of the crystal-radiator as well as control of the alignment during operation at different temperatures.

2. Control of degradation of the crystal radiator at different depths due to observation of CXR and PXR reflections of different order – from a few to hundreds of micrometers.

3. Control of the temperature of the crystal radiator at different depths with use of the temperature dependence of the PXR yield

4. Control of near-surface layer of the crystal due to diffracted transition radiation.

5. Control of the total charge of the incident electron beam due to observation of the CXR that is independent of the crystal degradation.

To observe the X-rays, one have to install X-ray spectrometer at backward observation angle.

Thanks for attention