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COMPACT PXR SOURCE: achievable parameters and possible applications

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Channeling-2008 (26 September – 01 November 2008) Erice, Italy

Monochromatic X ray imaging

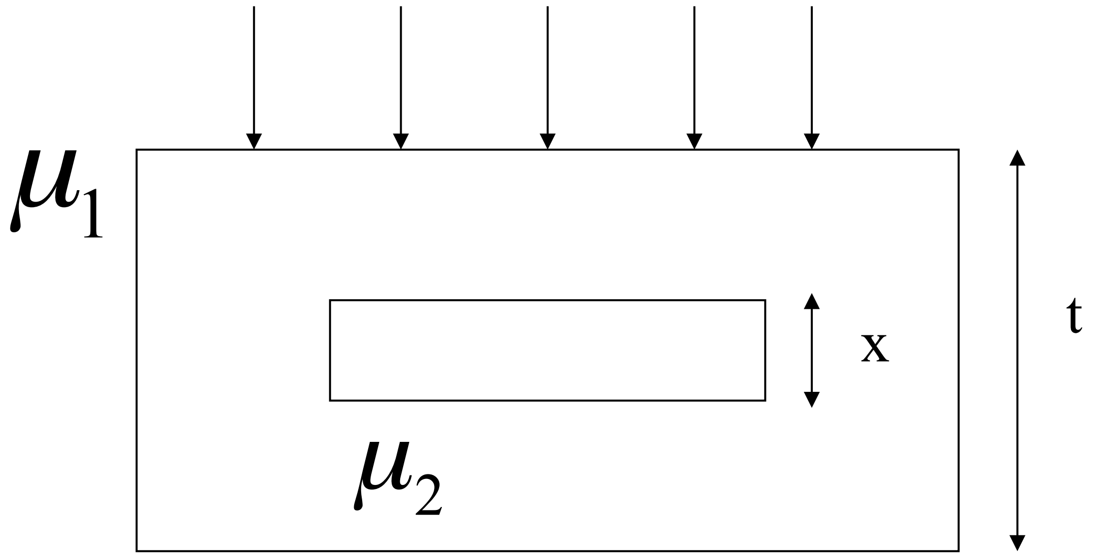
By narrowing x-ray spectrum inside of the range required for a specific medical imaging application, a patient's radiation-induced damage may be significantly reduced.

It has been evaluated that x-ray examinations performed with quasi mono-energetic x-rays (even 15-20%) will deliver a dose to the patient that will be up to 70% less than dose deposited by a conventional x-ray system [P. Baldelli [et al] // Phys. Med. Biol. 49 (2004) 4135].

Optimal X-Ray Energies for Medical Imaging

- mammography - 17-20 keV;
- radiography of chest, extremities and head - 40-50 keV;
- abdomen and pelvis radiography - 50-70 keV;
- digital angiography - ~33 keV.

Evaluation of X-Ray Flow for Medical Imaging



$$N = k^2 (1 + R) \exp(\mu_1 t) / (\varepsilon (\Delta \mu x)^2 x^2)$$

The Physics of Medical Imaging / S. Webb (Ed.), Bristol: Hilger, 1978.

What do we need for *in vivo* quality imaging?

Number of x-ray quanta needed to visualize 1.0 mm^3 of biological tissue at 1% contrast is **~3x10^7 photons/mm^2**.

Due to heart beat and breathing above photon flux must be provided within ~**1/100 s**.

Photons must penetrate considerable field of vision.

What do we exactly need for *in vivo* quality imaging?

We need, for example,

$3\text{x}10^{7}$ mm^{-2} * 100x100 mm^{2} / 10^{-2} s =

~$3\text{x}10^{13}$ photons/s

with tunable x-ray energy in 10-70 keV range

Mono-chromaticity could be of ~10^{-2} for a patient's dose reduction

Radiation background should be low

Table-top storage ring MIRRORCLE-20

Electron energy – 20 MeV

Average current – about units of ampere

Due to strong multiple scattering only thin (some tens microns) x-ray production targets can be used to avoid the beam destruction

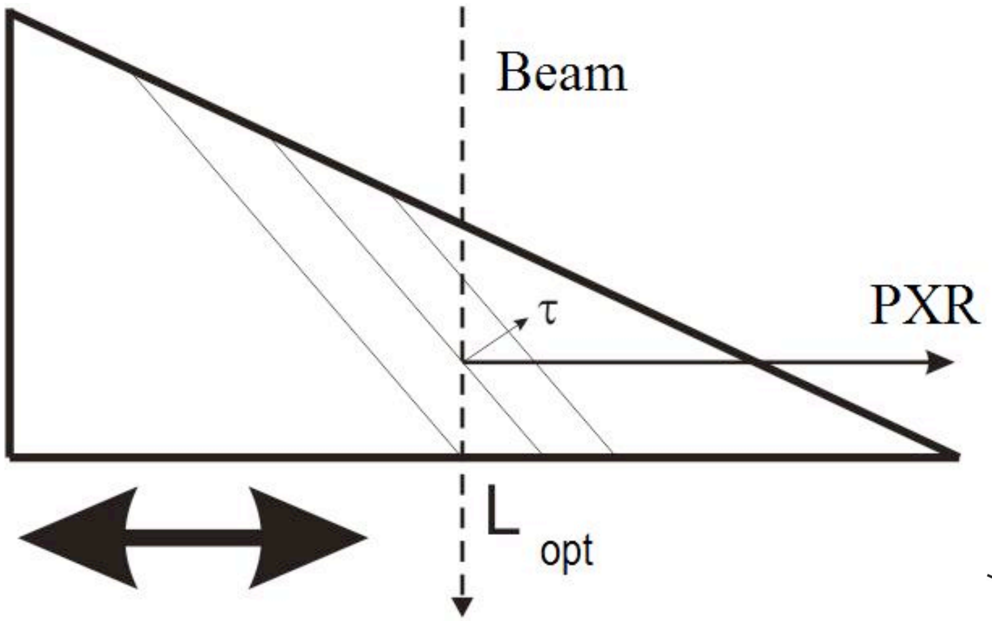
Number of BR photons from such thin target will be much lower than come from massive anode of a conventional x-ray tube

Motivation to use PXR

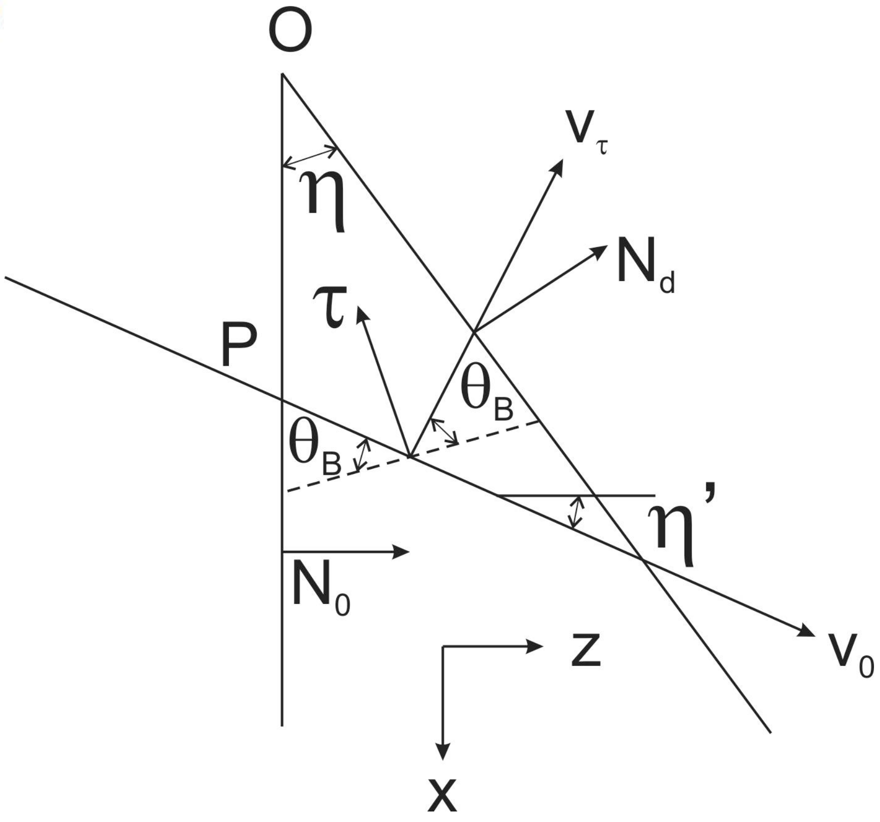
- it is quasi-monochromatic x-rays
- x-rays energy can be changed smoothly by single crystal target rotation
- it is directed and polarized x-rays
- x-rays energy does not depend on energy of incident charged particles
- radiation angle can be as large as

  180 arc degrees - it means, one may work at virtually low background
- Optimal target thickness – 10-100 μm of light crystal material (diamond, silicone, graphite, LiF, quartz, etc) – weak multiple scattering

Optimal PXR crystal target - wedge



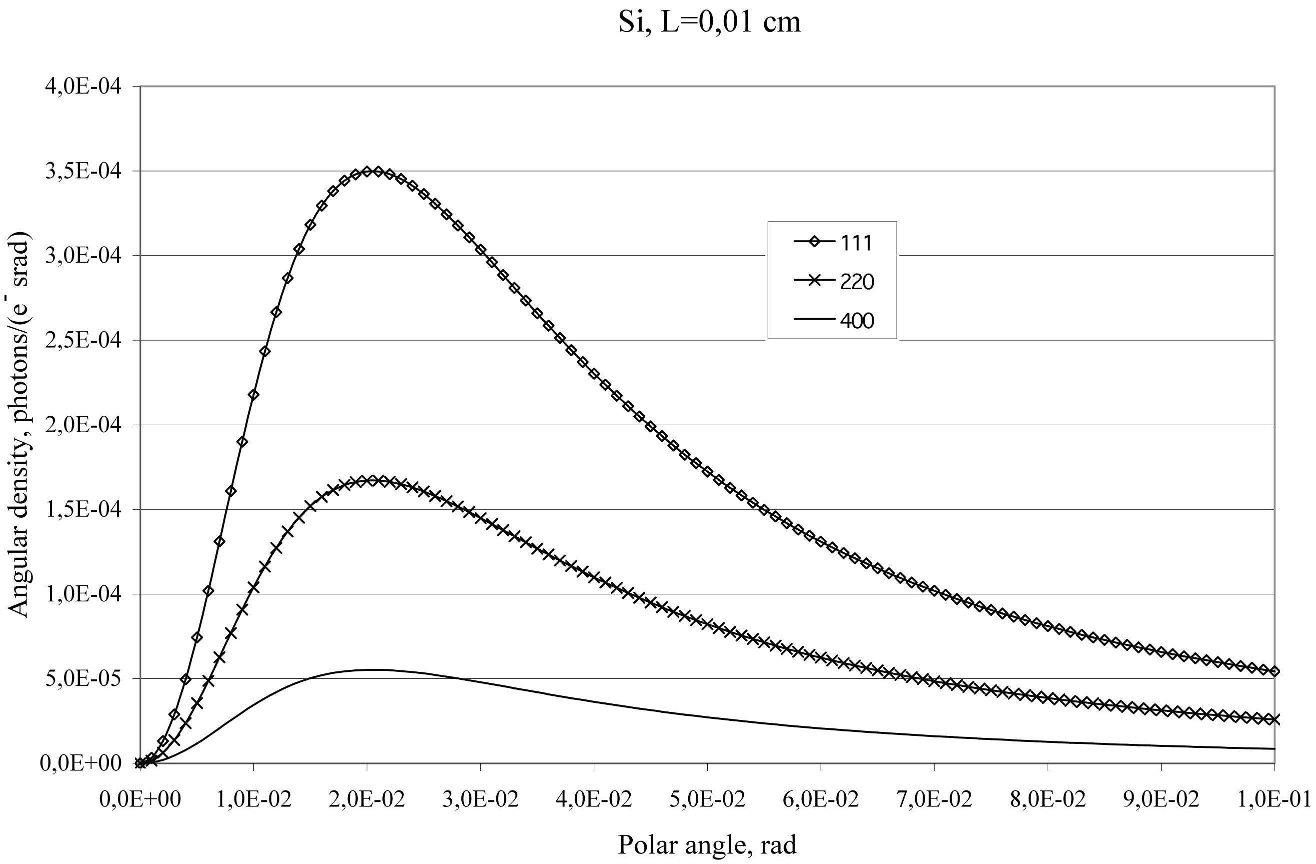
$$\frac{\partial N}{\partial \omega \partial \Omega} \sim \exp\left(-\frac{L}{L_a}\right)$$



Soft PXR intensity at M-20

- Target Si (111) wedge shaped;
- Bragg angle = 45 arc degrees; E_{PXR} = 2.8 keV;
- Absorption length 3.57 μm;
- Geometry – Symmetric Laue;
- Wedge thickness 0.01 cm;
- Wedge angle - 30 degrees;
- Energy resolution (integration) $\Delta\omega/\omega = 10^{-3}$;
- Intensity of PXR+diffracted TR = **$\sim 2\times10^{-6}$ ph/e^{-}**;
- Intensity of diffracted BR = **$\sim 5\times10^{-6}$ ph/e^{-}**.

Evaluations of 33 keV PXR emission from 20 MeV electrons



Dia 20 cm at 1.5 m
~$7\cdot10^{-2}$ rad

Quantum Yield:
(111) - $3\cdot10^{-6}$ /e^-
(220) – $4.5\cdot10^{-7}$ /e^-
(400) – $1.4\cdot10^{-7}$ /e^-

E_e = 20 MeV, Si target of L=0.01 cm thickness, 33 KeV x-rays, symmetrical Laue case for (111), (220), and (400). Angles between electron velocity direction and direction to diffraction reflex are ~6.9, 11.2, and 15.9 degrees, respectively.

Reflex integral intensity at M-20

We may have

up to 10^{-5} ph/e * 10^{19} e/s = 10^{14} s^{-1}

X ray photons with tunable energy of 10^{-3} monocromaticity

Target heating

Collision energy deposition ~2 MeV/g/cm^2.

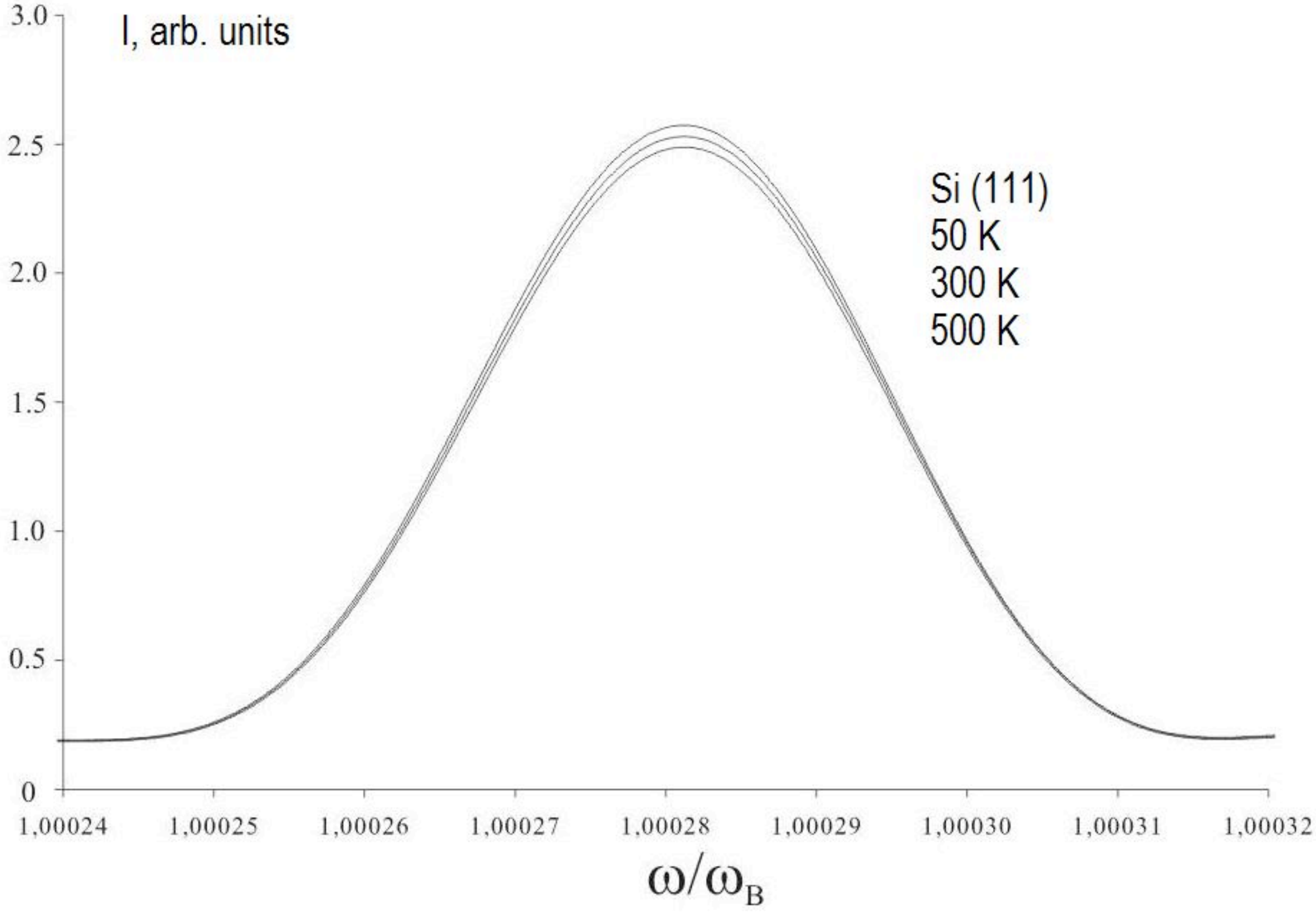
For 100 µm ^{14}Si (2.33 g/cm^2) energy deposition will be ~40 keV – few tens kW for order of ampere beam currents.

$$\boxed{P_i = \frac{\Delta T \cdot S \cdot \sqrt{c\lambda\rho}}{1.11 \cdot \sqrt{\tau_i}}}$$

For Si target of 3x3 mm^2 dimensions power needed to heat it up to state of plastic deformation (~650 °C) = ~100 kW.

Effective heat removal from a target is needed

PXR intensity dependence on crystal Si target temperature



Conclusions and Prospects

- PXR at M-20 can be used for quality *in vivo* low dose imaging with quasi-monochromatic tunable x-rays at low background
- PXR at M-20 can be used for selective action on organic compounds important for life sciences
- PXR at M-20 can be used for effective generation of soft X and T rays

Thank you for attention