COMPACT PXR SOURCE: achievable parameters and possible applications

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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

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

What do we need for \textit{in vivo} quality imaging?

Number of x-ray quanta needed to visualize 1.0 mm$^3$ of biological tissue at 1\% contrast is \(~3 \times 10^7\) 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 \textit{in vivo} quality imaging?

We need, for example,

\[ 3 \times 10^7 \text{ mm}^{-2} \times 100 \times 100 \text{ mm}^2 / 10^{-2} \text{ s} = \sim 3 \times 10^{13} \text{ photons/s} \]

with tunable x-ray energy in \textit{10-70 keV} range

Mono-chromaticity could be of \( \sim 10^{-2} \) for a patient’s dose reduction

Radiation background should be low
Table-top storage ring MIRORCLE-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; $E_{\text{PXR}} = 2.8$ keV;
- Absorption length $3.57 \, \mu\text{m}$;
- 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 = $\sim 2 \times 10^{-6}$ ph/e$^-$;
- Intensity of diffracted BR = $\sim 5 \times 10^{-6}$ ph/e$.\$
Evaluations of 33 keV PXR emission from 20 MeV electrons

\[ E_e = 20 \text{ MeV}, \text{ Si target of } L=0.01 \text{ cm thickness, 33 KeV x-rays, symmetrical Laue case for (111), (220), and (400). Angles between electron velocity direction and direction to diffraction reflex are } \sim 6.9, 11.2, \text{ and } 15.9 \text{ degrees, respectively.} \]
We may have up to $10^{-5} \text{ ph/e} \times 10^{19} \text{ e/s} = 10^{14} \text{ s}^{-1}$ X ray photons with tunable energy of $10^{-3}$ monocromaticity.
Target heating

Collision energy deposition $\sim 2$ MeV/g/cm$^2$. For 100 $\mu$m $^{14}$Si (2.33 g/cm$^2$) energy deposition will be $\sim 40$ keV – few tens kW for order of ampere beam currents.

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

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