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7. Optimization of Parametric X-Ray Production, B. A. Sones, Y. Danon, R. C. Block (RPI)

A novel, tunable X-ray source using the 100-MeV electron linear accelerator at Rensselaer Polytechnic Institute is currently under development. The objective of this investigation is the optimized production of Parametric X-rays (PXR) for future applications in medical imaging, material characterization, and detection of explosives and nuclear materials. The investigation has three phases: theoretical optimization and experiment design, data acquisition, and data analysis. The experiment is designed to maximize photon flux and minimize the energy spread for the desired photon energy, which may range from 10–100 keV depending on the application.

PXR are generated from the interaction of relativistic electrons with the periodic structure of single crystals. A broad distribution of "virtual photons" is associated with electrons moving through a medium at relativistic speeds. These photons diffract according to Bragg's Law. This results in the production of Parametric X-rays emitted with various energies at different positions with respect to the crystal.

PXR have several novel and useful characteristics which have sensitive geometric dependence. The energy of the PXR is de-

termined by the orientation of the incident electron to the diffracting crystallographic planes and the diffraction direction determined by Bragg's law. Rotation of the crystal with respect to the electron beam allows the PXR energy to be tuned. For any given energy, the radiation is emitted with a unique angular distribution of two Lorentzian cones, separated by a characteristic angle of about 10 milliradians from the Bragg angle, with zero intensity precisely at the Bragg angle. PXR can be emitted at large angles relative to the electron beam which helps avoid the Bremsstrahlung background. Although the natural energy spread of the PXR is on the order of several eV [1], the observable width depends on the geometry of the experiment.

The first experimental realization of PXR was in 1985. Baryshevsky et al. [2] used 900-MeV electrons from the Tomsk synchrotron and a diamond crystal. In 1990, Shchagin et al. [3] produced PXR using the LINAC at Kharkov (Ukraine). Compared with synchrotrons, linear accelerators offer the promise of less expense, less residual radiation, and greater portability for PXR research. In the past decade, a number of LINAC facilities have contributed to PXR research [4–6].

The preliminary part of the RPI optimization rests with maximizing photon flux through selection of the target crystal. The following characteristics were considered: crystal structure, lattice parameters (size); bulk thickness; electric, thermal, and absorptive properties; and the growth and polishing techniques. Figure 1 presents theoretical calculations for a variety of well-documented single crystals: Si, Ge, Cu, Pyrolytic Graphite, and W. PXR intensities were calculated for (111), (220), and (002) planes at Bragg angles from 5 to 90 degrees. The differential intensity at the peak of one of the angular distribution cones was integrated across a 1 mm² detector surface placed at a distance of 1 m from the crystal. For each crystal the peak intensity appears at different Bragg angles and different X-ray energies.

Pyrolytic graphite shows the most promise for photon energies less than 25 keV while copper and tungsten are best at higher energies. However the mosaic spread of the graphite might degrade these results, and this will be further investigated.

The subsequent part of the RPI optimization is the minimization of the photon energy distribution. The PXR experiment has strong dependence on geometry. Most theoretical PXR calculations (including those used to generate Fig. 1) assume some ideal conditions about the incident electrons.

In practice, four characteristics of the electron beam contribute to broadening the PXR energy distribution: the electron energy distribution, spot size, beam divergence, and electron scattering from the window and inside the crystal. The electron energy affects the characteristic angle defining the spatial spread of the two Lorentzian cones for a given PXR energy.

The other three factors directly affect the PXR energy by introducing small changes to the experimental geometry. The PXR energy is dependent on the $\sin \phi$, and inversely related to $1 - \cos \Omega$ where ϕ is the angle between the electron velocity and the crystallographic plane, and Ω is the angle between the plane and the diffracted PXR. Spot size varies the location of the generation of the PXR, and introduces change in Ω for a fixed detector location. Both the electron beam divergence and electron scattering change ϕ . Initial calculations suggest for the current RPI LINAC electron beam, this energy broadening amounts to 2–3% of the PXR energy.

Steps to evaluate and reduce the effects of these factors are done experimentally by profiling of the electron beam and working to focus it: analytically by incorporating these factors into the theory and numerically by developing a Monte Carlo method for convoluting the resulting PXR energies and intensity at a given detector position.

So far our work has concentrated on theoretical calculations of PXR production and the definition of optimal experimental conditions necessary to maximize PXR intensity and minimize its energy spread. We are now finishing the preliminary optimization calculations and entering the experimental phase.

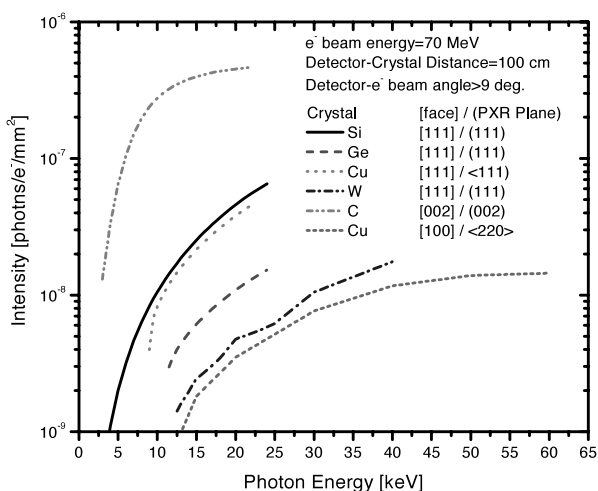


Fig. 1. Calculated X-ray intensities for several 500 μm thick crystal targets for several reflection planes and crystal face planes. The upper energy limit of each case was limited by a requirement of an angle of more than 9 deg between the detector and the electron beam axis.

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