Advances in Parametric X-Ray Production at the RPI Linear Accelerator

B. Sones, Y. Danon, and R. Block

Mechanical, Aerospace and Nuclear Engineering Department, Rensselaer Polytechnic Institute, Troy, NY 12180-3590, Sonesb@rpi.edu

INTRODUCTION

Parametric X-Rays (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 from crystal planes according to Bragg's Law, which relates photon energy, d-spacing between planes, and the diffraction angle. Consequently, tunable x-ray production is possible with the rotation of a target crystal. The motivation of this work is the development of this intense, tunable, polarized, and quasi-monochromatic x-ray source for practical applications such as medical imaging and material characterization.

This phenomenon was first demonstrated in 1985 at the Tomsk synchrtron when Baryshevsky, et al. [1] used 900 MeV electrons interacting with a diamond 220 crystal plane to produce 6.96 keV PXR. Since then, there have been several efforts to characterize the PXR photon distribution and the polarization of PXR [2,3,4,5,6]. Other efforts have capitalized on the tunability of x-rays to propose applications in material detection using near K-edge transmission measurements [7] as well as improvements to mammography configurations [8].

PRACTICAL CONSIDERATION OF EXPERIMENTAL CONDITIONS

The physics of PXR is solidly supported by theoretical predictions for idealized experimental conditions when thin perfect, single crystals interact with mono-energetic electron beams having point-like spot sizes and no beam divergence. Under these idealized conditions, the PXR energy is solely dependent on the orientation between a crystal plane and the direction of the incident electron beam, and the photons are uniquely distributed about the Bragg condition with zero intensity at the Bragg angle [9]. In 1997, Brenzinger, et al. analytically characterized the effects of collection solid angle, electron beam spot size, and electron divergence on the distribution of PXR [10]. Using that study, convoluting these effects with the idealized PXR production both broadened the photon distribution and eliminated the minima at the Bragg angle.

RPI PXR IMPROVEMENT STRATEGIES

Since its first observation in May 2002, PXR production at the RPI LINAC has focused on three improvement strategies: (1) minimize electron beam divergence, (2) establish real-time beam alignment techniques, and (3) photon collection at higher currents. Figure 1 shows recent PXR data demonstrating the energy tunability (about 44% about the Bragg condition of 17.7 keV) and the linear relationship between energy and rotation angle.

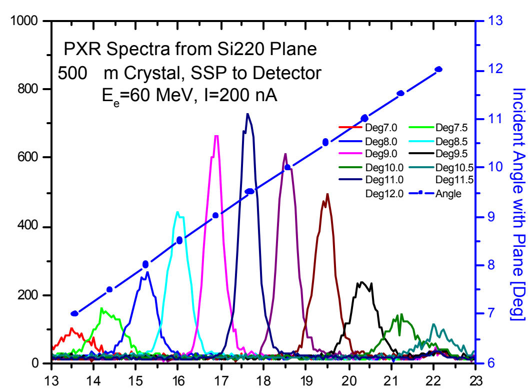

Fig. 1. PXR produced from 60 MeV electrons interacting with the Si 220 Plane.

Reduction of Electron Divergence

We observe broadened PXR photon distributions when scanning 3 degrees about the Bragg angle. Calculations show that the small photon collection angle (about $80*10^{-9}$ steradian) and the electron spot size (<1 cm diameter) contribute little broadening compared to Monte Carlo calculated electron divergence (about 30 mrad mean value) from the existing water-cooled, aluminum output window. To reduce this effect, the output window was replaced with a 254 m thick, pure Be (Z=4) foil. An analytical expression predicts that the divergence is reduced to a mean of 5 mrad. From MCNP calculations, the new Be window is also expected to reduce the total Bremsstrahlung production by an order of magnitude at 17.7 keV. While the Be window was installed in January 2003, other contributions to the beam divergence such as electron focusing and steering remain.

Beam Alignment

Laser alignment techniques are used to properly position the crystal and detector with respects to the LINAC. The target crystal movement is done remotely with a 3-axis goniometer with 0.001 degree resolution. Unfortunately, the electron beam can drift in position and change focus in real time under the low operating currents (100-200 nA) used for present PXR experiments. Use of Optical Transition Radiation (OTR) has allowed the development of a real-time beam monitor. OTR is produced when relativistic electrons travel from one medium to another [11,12]. This emission of visible light allows us to monitor the electron relative beam intensity, shape, and size. Using a back-scattering geometry, we have imaged the beam using 1 mil thick aluminum and stainless steel foils. The use of a quartz plate produced even brighter beam spots.

PXR Detection

The existing Si Amptek CR-100 (resolution to 350 eV at 17 keV) detector is best suited for characterizing the PXR energy tunability with crystal rotation. However, the detector also observes high-energy gamma rays that both interfere with the counting of PXR and scale with the increase of LINAC current. This limits the full use of the RPI LINAC capabilities and prevents the maximization of measured PXR intensity. For increased current, we have acquired a FDI GemStar x-ray CCD with 18 mm detection face. This offers spatial resolution, signal gating, and digital integration, which will be used for future imaging application for PXR.

RESULTS

In summary, progress has been made in the investigation of PXR using the RPI LINAC. Since replacing the A1 output window, measured PXR spectra show no evidence of diffracted bremsstrahlung produced from the new Be window. While there was no indication of narrowed PXR energy lineshapes, the measured PXR count rates, under otherwise similar conditions, increased by a factor of 3 after installing the Be window and using the new electron beam monitoring technique.

REFERENCES

[1] V.G. Baryshevshy, et. al., *Angular distribution of parametric X-rays*, Phys. Lett. 110A, 447 (1985).

[2] K.H. Brenzinger, et. al., *How narrow is the linewidth of parametric X-ray radiation?*, Phys. Rev. Lett. 79, 2462 (1997).

[3] A.V. Shchagin, V.I. Pritupa, and N. A. Khizhnyak, *A fine structure of parametric X-ray radiation from relativistic electrons in a crystal*, Phys. Let. A, 148, 485 (1990).

[4] R. B. Fiorito, D. W. Rule, M. A. Piestrup, Qiang Li, A. H. Ho, and X.K. Maruyama, *Parametric X-ray generation from moderate energy electron beams*, Nuc. Inst. Methods B79, 758 (1993).

[5] S. Asano, I. Endo, M. Harada, S. Ishii, T. Kobayashi, T. Nagata, M. Muto, K. Yashida, and H. Nitta, *How intense is parametric X radiation?*, Phys. Rev. Lett. 70, 3247 (1993).

[6] T. Akimoto, M. Tamura, J. Ikeda, Y. Aoki, F. Fujita, K. Sato, A. Honma, T. Sawamura, M. Narita, and K. Imai, *Generation and use of parametric X-rays with an electron linear accelerator*, Nuc. Inst. Methods A459, 78 (2001).

[7] F. Hagenbuck, et. al., *Novel Digital K-Edge Imaging System with Transition Radiation from an 855-MeV Electron Beam*, IEEE Transaction on Nuclear Science, Vol 48, No 3 (2001)

[8] M.A. Piestrup, X. Wu, V. V. Kaplan, S. R. Uglov, J. T. Cremer, D. W. Rule, R. B. Fiorito, *A design of mammography units using a quasimonochromatic x-ray source*, Rev. Scientific Inst. 72, 2159 (2001).

[9] Y. Danon,, B. Sones, R. Block, *Novel X-ray Source at the RPI LINAC*, Proceedings, ANS Annual Meeting, 2002.

[10] K. Brenzinger, et. al., *Investigation of the Production Mechanism of Parametric X-Ray Radiation*, Z. Phys. A 358 (1997) 107.

[11] A. Lumpkin, W. Berg, B. Yang, M. White, *Linac Beam Characterization at 600 MeV Using Optical Transition Radiation Diagnostics*, Conference Proceeding, Beam Instrumentation Workshop, 1998.

[12] D. Giove, et,al, *Optical Transition Radiation Measurements on the Elettra LINAC*, Conference Proceeding, PAC 97 (1997).