National Aeronautics and Space Administration

FY24 Topic Areas Research and Technology Development (TRTD)

A Novel X-ray Imaging Detector Concept: Stackable Photonic Crystal Scintillators with Lateral Edge-On Detector Array

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Strategic Focus Area: Electronics, Devices and Sensors

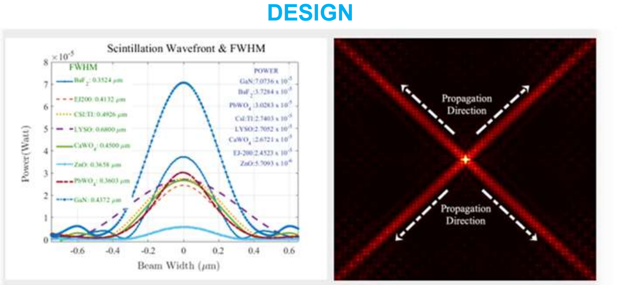
OBJECTIVE

- Develop a novel X-ray imaging detector architecture, which introduces perimetric charge coupled device arrays as pixels integrated laterally.
- Offering a single imaging detector having energy resolving capability with high spatial resolution in broad X-ray energy regimes.

BACKGROUND

- Filling the technology gaps prioritized by the "Decadal Survey on Astronomy and Astrophysics in 2020s."
- Using a photonic crystal structure collimating and guiding the scintillation in an in-plane geometry.
- A novel concept with perimetric pixels, which unnecessiates 2D CCD/CMOS coupled at the back, and enables the stacking of thin film layers of a variety of scintillators.
- An opportunity for flexible (polyvinyl-toluene) imaging detector application for better optical-angular-coupling efficiency.
- Polarization-sensitive imaging capability.

DESIGN



The special resolution parameters, which refer to the FWHM of the beam wavefronts for some scintillators are shown in the left figure. The illustration of the self-collimation in BaF2 PhC is shown in the visual on the right.

SIMULATION

MPB MIT-Photonic Bands — For computing the band structure, or dispersion relations, and electromagnetic modes of periodic dielectric structures.

Ansys Lumerical — For computing Fourier transforms base finite-difference time and frequency simulations for the validation of the self-collimating PhC structures.

APPROACH

- We designed and engineered photonic crystal structure consisting of periodic cylindrical air holes with square lattice to flatten and straighten the iso-frequency contours.
- We identified the straightest iso-frequency contour with periodicity a=208.725nm and an air hole diameter d=137.759 nm, and the self-collimation level was 0.3795 in the k-w diagram for 550nm scintillation

RESULTS

Robust detection mechanism; pixels on the edges, stackable active layers/detectors, broadband detection with wide bandgap materials. Improved spatial resolution. One device with multi-functionality. To prepare for future strategic missions, the astrophysics decadal survey recommends commencing mission and technology maturation of an X-ray large strategic mission which has tremendous promise to answer fundamental questions in physics and astronomy and to open vast new discovery opportunities.

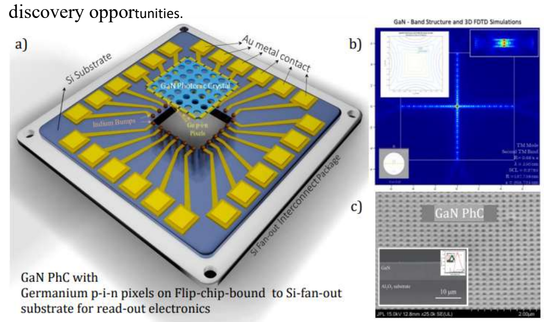


Figure 1: a) A schematic of single layer GaN photonic crystal with Germanium p-i-n peripheral pixels compatible to flip-chip integration on the indium bumps of the Si fan-out interconnect package. It shows an illustration of the detector architecture to be integrated with the readout circuitry. b) GaN PhC top view of self-collimated 550 nm scintillation, flat iso-frequency contours (left top inset), edge view of light extraction from PhC (right top inset), a diagram of cylindrical airhole (left bottom inset), self-collimation parameters (right bottom inset). c) An SEM image of the fabricated GaN PhC and 5um GaN thin film on Al2O3 substrate (inset image).

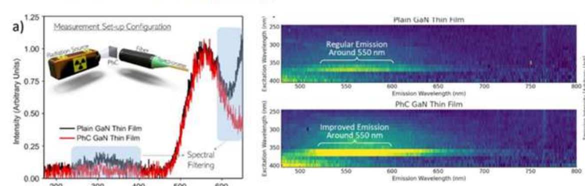


Figure 2. a) X-ray induced scintillation emission spectra of PhC GaN film deposited on Al2O3 substrate. Measurements were made on the edge. b) PL response of PhC GaN film deposited on Al2O3 substrate showing improved illumination and light yield

SIGNIFICANCE OF RESULTS TO JPL AND NASA.

The significance of this work to NASA/JPL lies in its potential to contribute to advancements in X-ray detection technology for space missions such as Chandra and NuSTAR. The development of a GaN-based scintillator with a photonic crystal (PhC) design offers improvements in energy resolution, radiation resistance, and temperature stability, which are important for the challenging conditions of space. The architecture, which allows for multi-layer stacking and edge detection, provides a pathway to more compact detectors with enhanced quantum efficiency and broader energy detection capabilities. For missions like Chandra, which focuses on high-resolution X-ray imaging, and NuSTAR, which observes high-energy X-rays, these developments could offer more precise imaging systems that support better analysis of cosmic phenomena and planetary surfaces.

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Publications: Firat Yasar,a) Richard E. Muller, Arezou Khoshakhlagh, and Sam A. Keo, "Large-area fabrication of nanometer-scale features on GaN using e-beam lithography", *"Journal of Vacuum of Science,"B* 42, 022801 (2024),

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