FY23 Topic Areas Research and Technology Development (TRTD)

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

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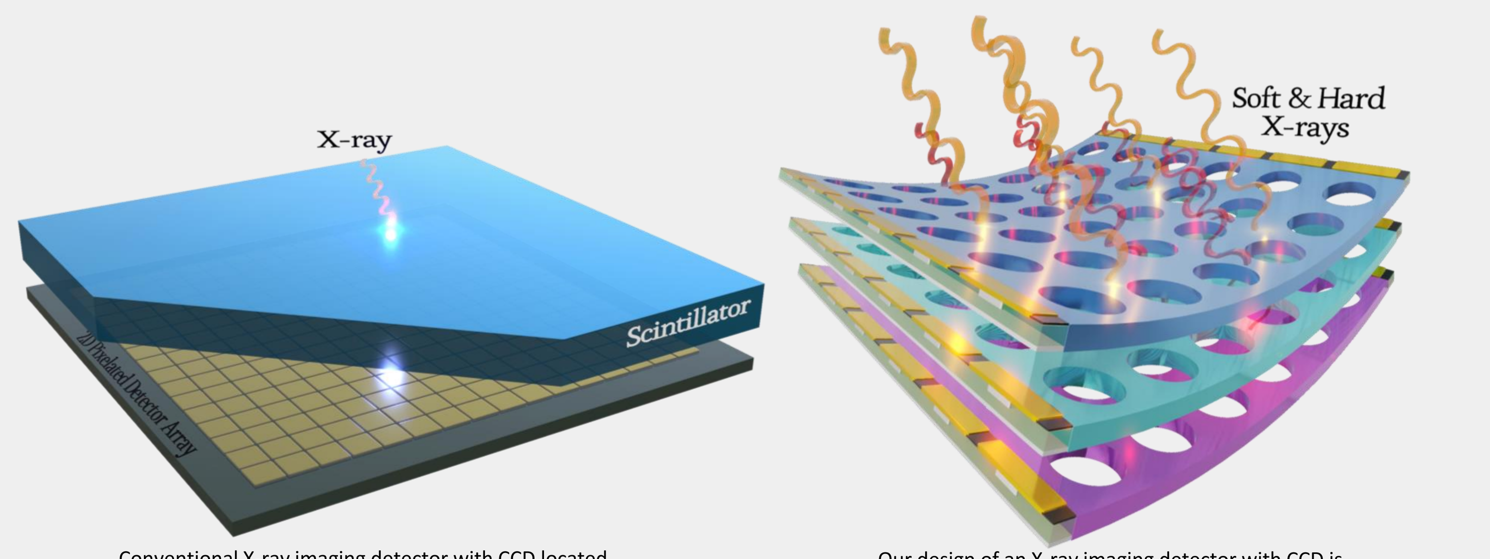
OBJECTIVE

- 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.

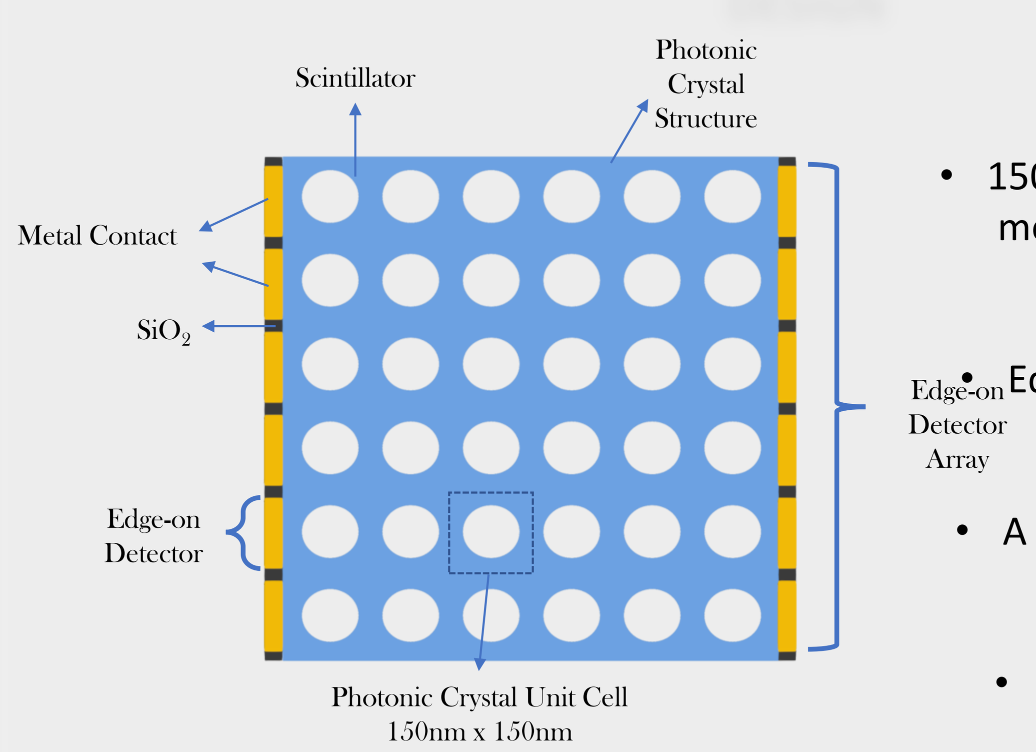
MOTIVATION

- 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[1].
- 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.

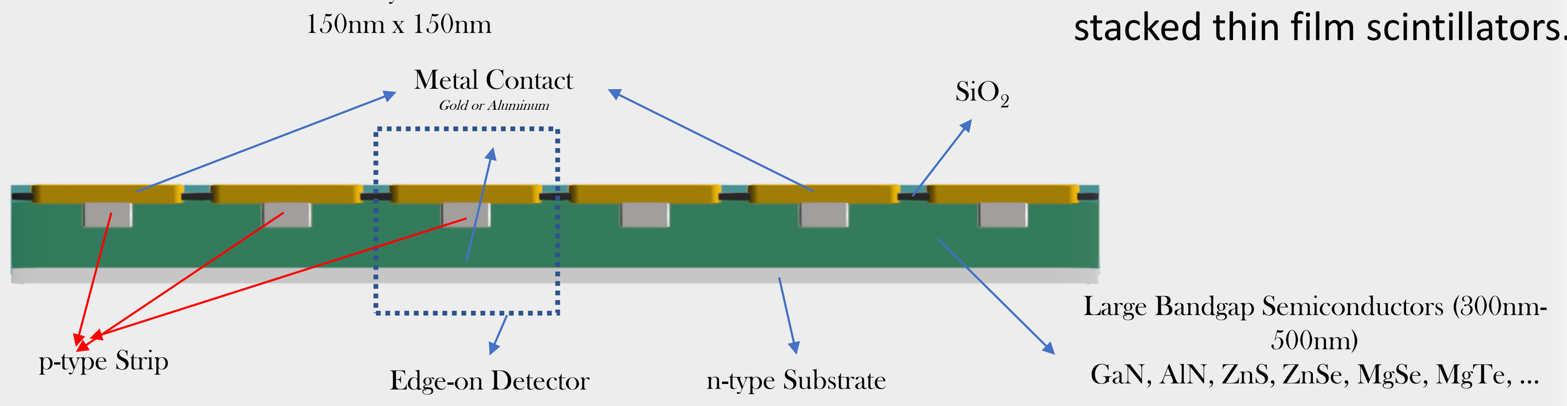


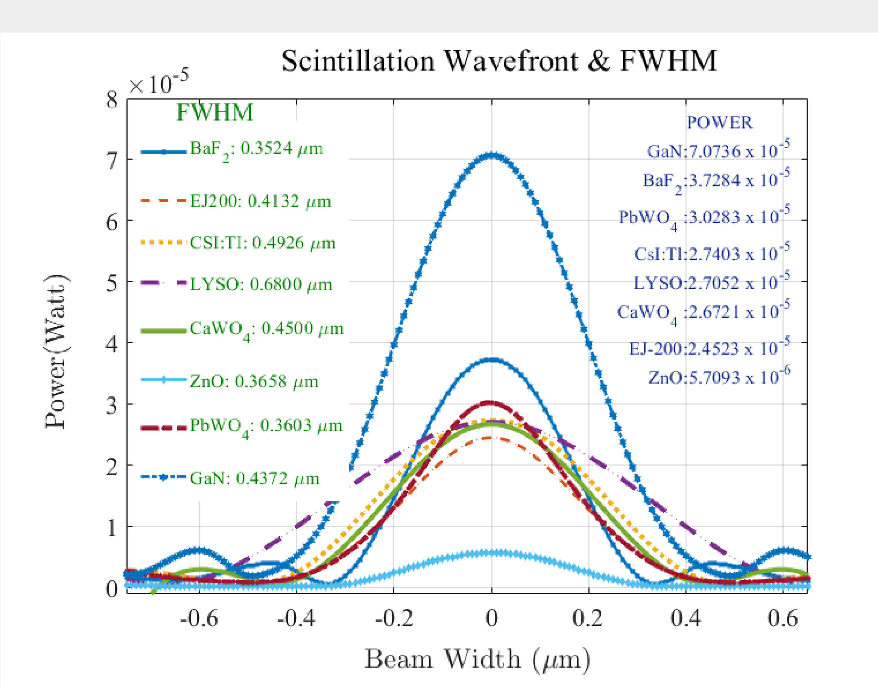
Conventional X-ray imaging detector with CCD located at the back of the active layer. Our design of an X-ray imaging detector with CCD is located at the perimeter of the active layer which can also be curved.

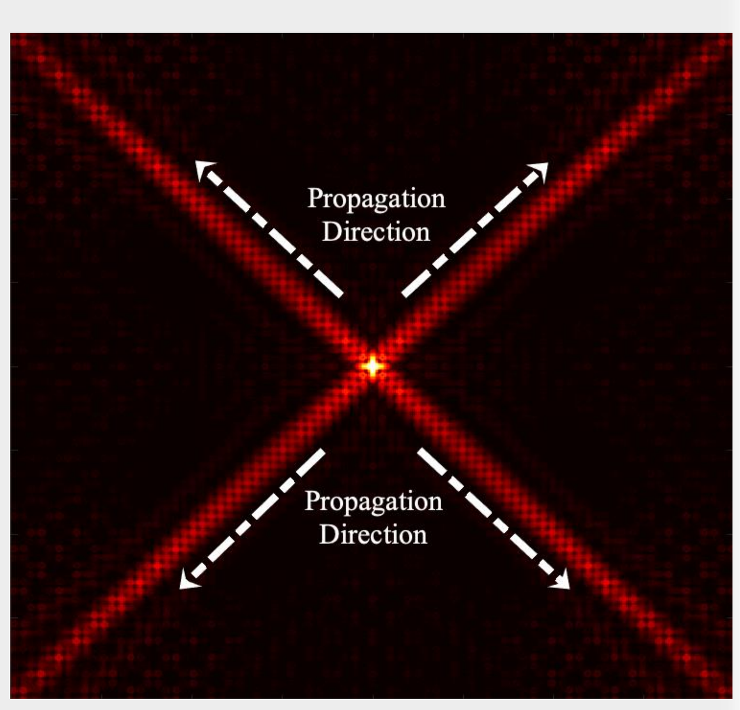
DESIGN



- 2-dimensional photonic crystal structure, which consists periodic cylindrical air holes.
- 150nm unit cell size of Photonic crystal media, with ~ 500 nm thick scintillator thin films.
- Edge-on detectors integrated laterally to the active scintillation layers.
- A simple p-i-n structure for perimetric pixels.
- Multilayer architecture of variety of stacked thin film scintillators.







The spatial 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 BaF_2 PhC is shown in the visual on the right.

SIMULATIONS

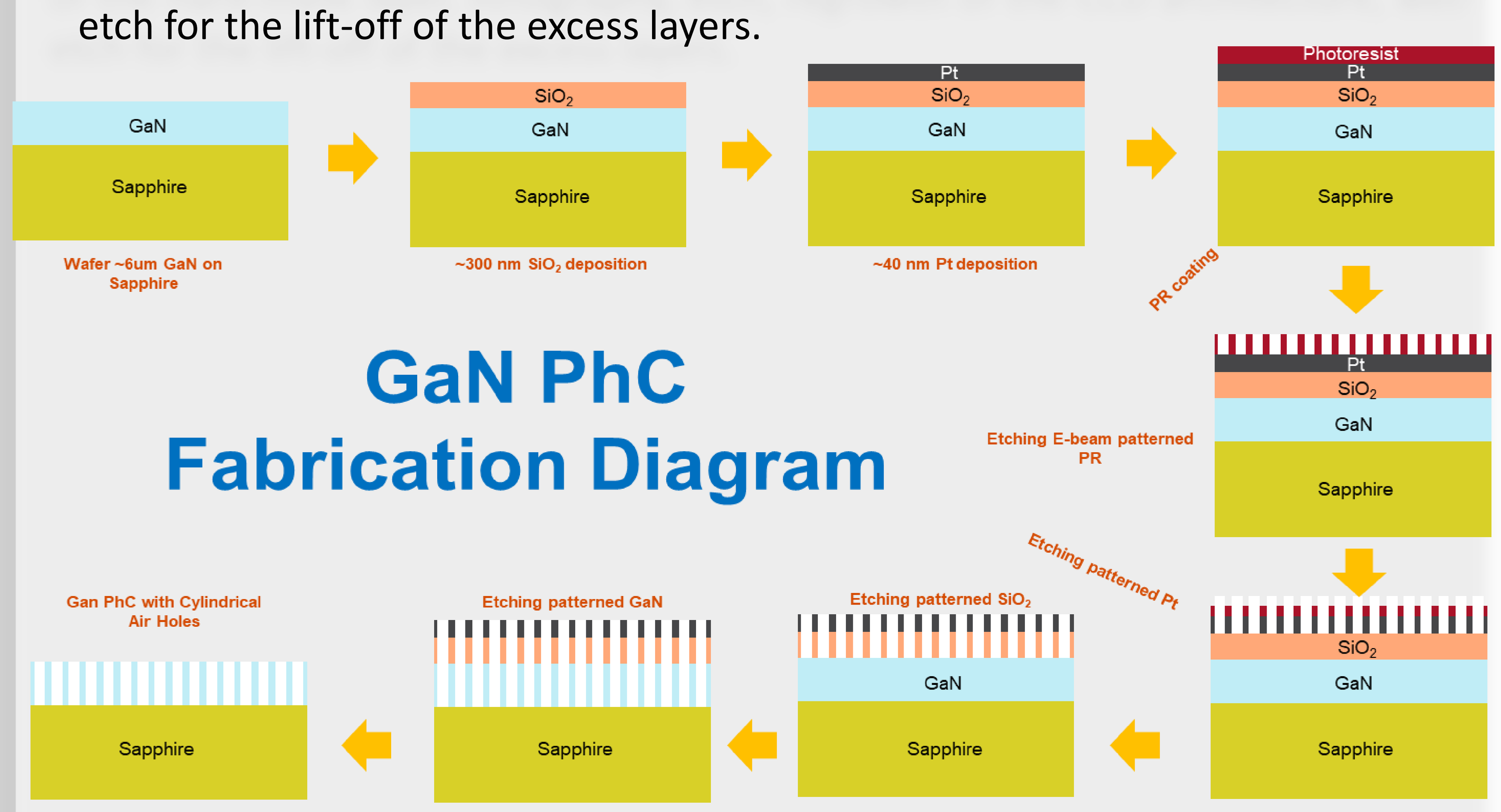
MPB MIT-Photonic Bands For computing the band structures, or dispersion relations, and electromagnetic modes of periodic dielectric structures.

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

FABRICATION

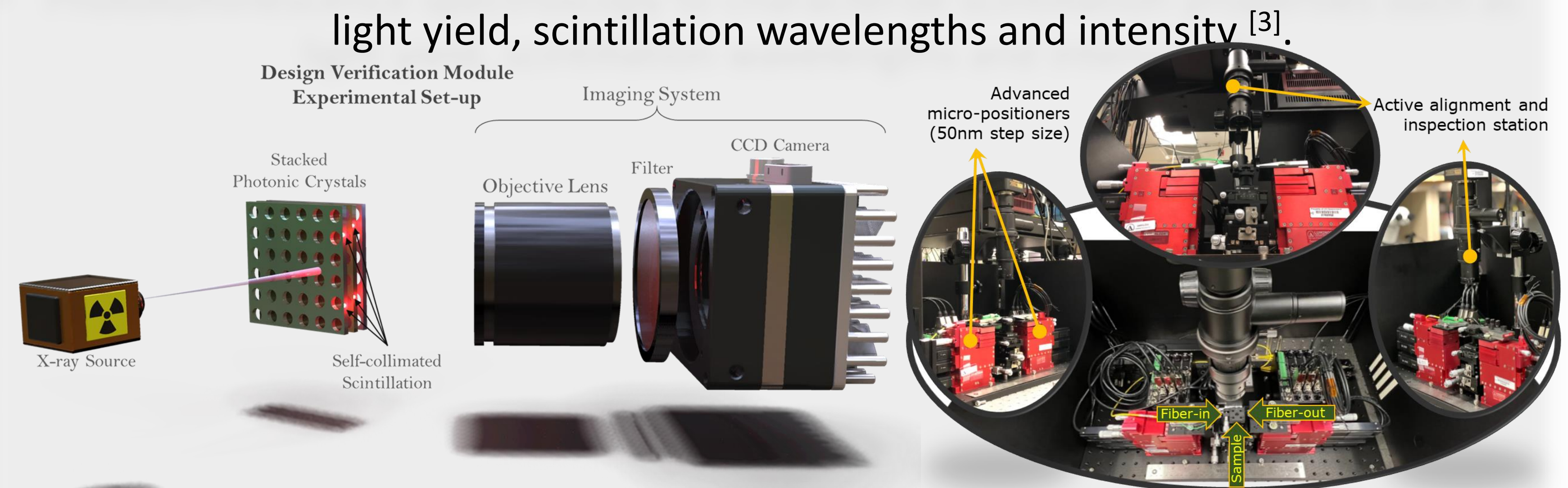
Two main steps of fabrication;

- E-beam lithography for patterning and Inductively Coupled Plasma (ICP) etching to realize photonic crystal structure.
- The integration of perimetric CCDs via multi-stage wafer processing; deposition of the hard-mask layer, lithography, etch, regrowth of the CCD architecture, wet-etch for the lift-off of the excess layers.



CHARACTERIZATION

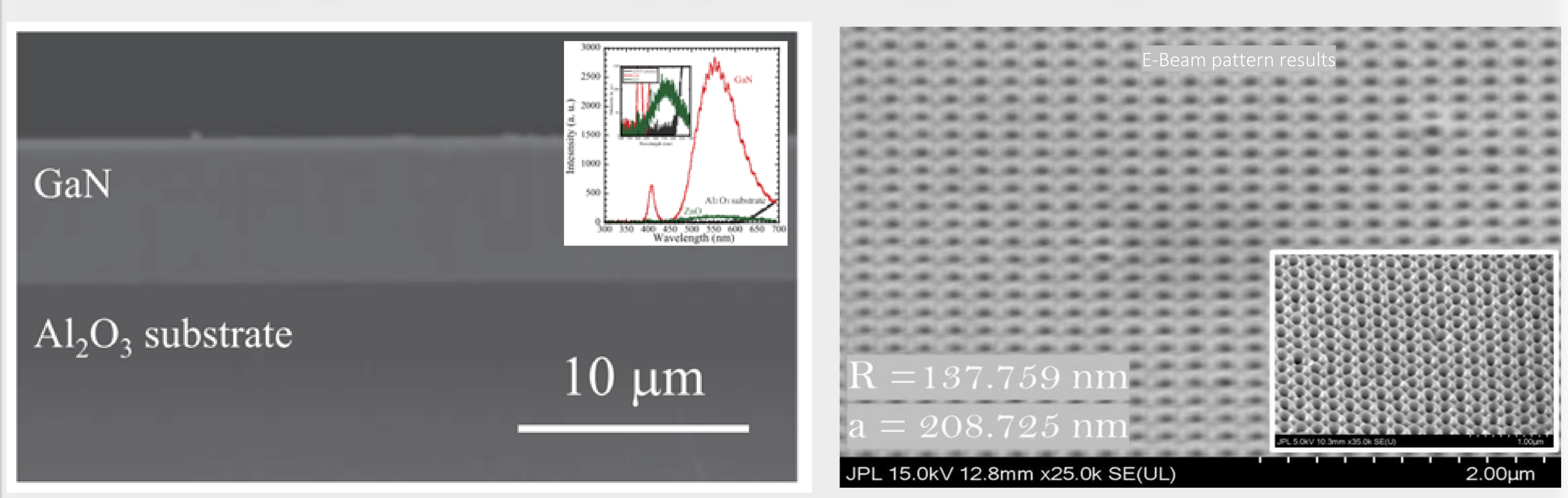
- X-ray induced scintillation spectroscopy: energy resolution and spatial resolution analysis with required apparatuses for focusing and filtering[2].
- Photoluminescence spectroscopy to characterize scintillation properties such as light yield, scintillation wavelengths and intensity [3].



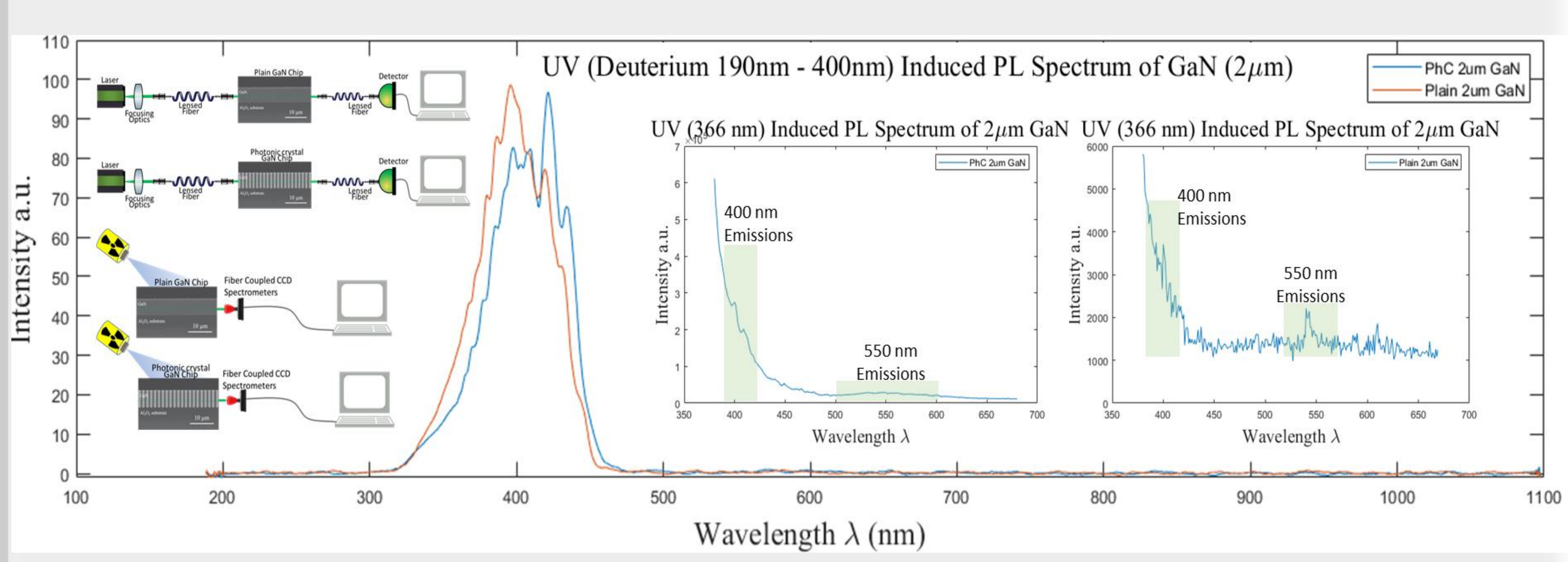
(LEFT): The figure shows an experimental setup for verification of the self-collimated scintillation. The objective lens with a specific X-ray filter is focused on the sides of the active layer where the self-collimated in-lane scintillation will be observed. (RIGHT):Portable X-ray Detector/Material (Spectral and Spatial) Characterization Module: Computerized system for remote control of the micro-positioners. Fiber coupled system (fiber-input/-output). Broadband (400nm-2500nm) super-continuum light source (2 Watt) with ultra-narrow bandwidth (<2nm) filtering capability.

RESULTS

- 200 nm – 500 nm spatial resolution with about or less than 3% ~ energy resolution at 662 keV.
- Polarization sensitive imaging with an engineered PhC structure.
- Broadband X-ray imaging including soft, tender and hard X-rays (0.1-100keV).
- Reduced coupling loss with the X-ray optics of the space telescopes.



(LEFT): GaN wafer: 5um epi-GaN on Sapphire substrate which has X-ray induced emission peaks around 400 nm (10%) and 550 nm (90%). (RIGHT): The SEM image of very first fabrication iterations. A successful fabrication of uniform, anisotropic cylindrical air holes with such a high aspect ratio of 1:20, thickness of ~2um.



Various illustrations regarding testing and characterization. The main graph shows the spectrum of light emissions from plain and PhC GaN upon deep-UV excitation. The illustrative images on the left side show different test and characterization setups based on material and the source. The two inset figures on the right show the spectrum of emitted light based on monochromatic (366nm) UV excitation.

References:

[1] Yasar, F., Kilin, M., Dehdashti, S., Yu, Z., Ma, Z., & Wang, Z. (2021). Spatially resolved x-ray detection with photonic crystal scintillators. *Journal of Applied Physics*, *130*(4), 043101.
[2] Roques-Carmes, Charles, et al. "A framework for scintillation in nanophotonics." Science 375.6583 (2022): eabm9293.
[3] Varney, C. R., et al. "X-ray luminescence based spectrometer for investigation of scintillation properties." Review of Scientific Instruments 83.10 (2012): 103112.
[4] Yanagida, Takayuki, et al. "Photoluminescence and scintillation properties GaN." Applied Physics Express 14.8 (2021): 082006

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