Meta-materials with intrinsic optical gain: A new possibility to achieve single photon counting with ps-time resolution?

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We propose an active scintillator/photocathode structure that is based on the concept of metamaterials and can be tuned to extreme wavelength response. We focus on the hard x-ray range (10-20KeV) but it could possibly also be tailored to the far-infrared regime. A very fast response time in the 1-5ps range, optical gain, good quantum efficiency for x-rays and the capability to gate the active scintillator with a switching time of 10-20ns are the main advantages of the proposed structure.

The concept of the active scintillator is based on stimulated emission in an optical medium with inversion similar to optical amplifiers in laser systems. The x-ray is absorbed in the medium or in the surrounding waveguide and produces secondary electrons which triggers the stimulated emission process in the medium. The single x-ray photon creates hundreds of wavelength-shifted, monoenergetic, and highly collimated photons. The narrow spectral width and the collimation is used to optimize the cathode for efficiency, speed, and low dark count rate.

The proposed material is based on GaAs-InGaAs micro and nano-tubes (diameter ~ 100 nm - 10µm), hexagonally packed and embedded in a waveguide material. The gain medium, similar to a laser structure, is epitaxially grown on a sacrificial buffer layer on the substrate, subsequently lithographically patterned, and released from the substrate by selective etching and liftoff. The epitaxial film will spontaneously role up due to strain to form a tube which can be picked up and placed and stacked into the three-dimensional scintillator structure. Xiuling Li's group at UIUC has been developing this technology[1-3], testing a wide range of these highly efficient light emitting devices.

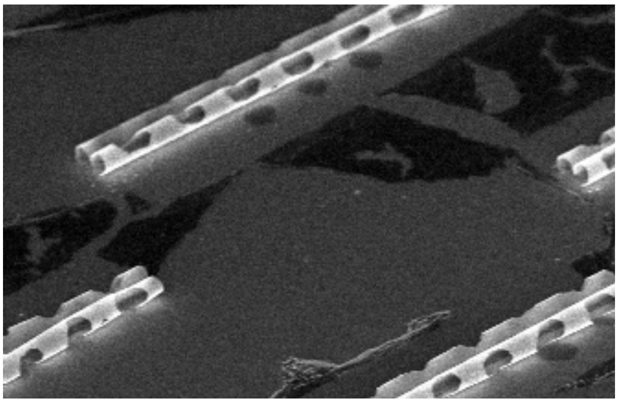

Figure 2: GaAs nano "lasers" detached from substrate

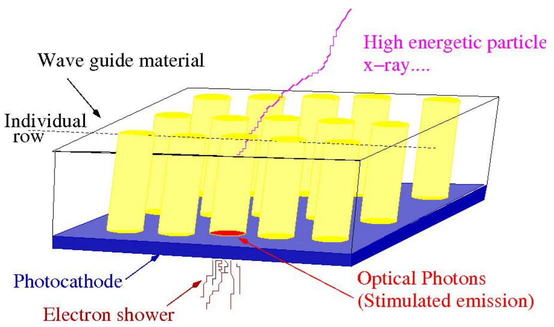

Figure 1: suggested meta-material which is build out of GaAs-nano "lasers" embedded in a wave-guide material. This active scintillator is combined with a highly optimized photocathode.

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References

1. "Geometry effect on the strain induced self-rolling of semiconductor membranes", Ik Su Chun, Archana Challa, Brad Derickson, Jimmy Hsia, and X. Li, *Nano Lett.* 10, 3927-3932 (2010).
2. "Controlled Assembly and Dispersion of Strain-Induced InGaAs/GaAs Nanotubes," I.S. Chun, and X. Li, *IEEE Trans. Nanotech.* 7, 493-495 (2008).
3. "Tuning the Photoluminescence Characteristics with Curvature for GaAs Quantum Well Microtubes," I. Chun, K. Bassett, A. Challa, and X. Li, Applied Physics Letters, 96, 251106 (2010).