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Large area photon-counting X-ray or particle image sensor using pixelated scintillator

Photon counting based X-ray imaging is known to be superior in performance as compared to the state of the art charge integration X-ray imaging. This is obvious at very low fluxes where photon counting yields quantum limited noise, yet also at high fluxes photon counting yields a DQE advantage over integration. A second advantage of photon counting is that it offers the possibility to extract spectral information from each photon separately, thus without multiple exposures or an increased X-ray dose.
Most, if not all of today's successful photon counting X-ray imagers are based on "direct detection". From pure detection performance standpoint this approach is ideal: the photo-electric conversion happens in a very limited volume, the energy quantum is deposited in a narrow trace or cloud of secondary electron-hole pairs, which are quickly and with little sideward dispersion collected by the electric drift field. The limiting factor for the widespread use of direct detection in photon counting imaging is the cost and manipulation of the semiconductor material.
The alternative route, indirect detection, i.e. detection of X-ray photons by absorbing them in a high-Z scintillator, then detecting the secondary, visible light radiation by a visible light image sensor, is a much more economically viable. Many scintillators are inexpensive, easy to co-integrate, and CMOS visible light event counting is an easily scalable and mature technology.
However, the indirect detection has a few annoying disadvantages as compared to direct detection: the overall indirect process has a significantly lower photon to electron conversion, suffers from slow decay times, and especially suffers light dispersion and thus poor MTF, and poor reproducibility of charge packet sizes, making photon (and particle) energy measurements unreliable.
It was concluded earlier that a root-cause solution to these issues would be the use of "segmented"or "pixelated"scintillators [1]. These could confine the secondary charges within the pixels, thereby challenging the MTF and particle/photon energy measurement capabilities of direct detectors, yet at an order of magnitude lower cost. In principle the cost per unit area of such photon counting array will approach that of the present state of the art CMOS based X-ray plates.
In this project we propose to develop a CMOS ROIC plus a pixel-matched pixelated scintillator in collaboration with Philips Medical (see abstract 75 referring to the pixelated scintillator itself).
The development will aim to realize a prototype with
• A CMOS photon packet counting arrays of at least 1cm2, yet aiming to wafer size, depending of budget, concepts working further on the prior experience.
• It will feature in-pixel sense-amplifications, multiple thresholds (or energy resolution), counting and multiplexing means.
• Although we are inspired by X-ray photon counting and energy discrimination, it is conceptually capable to do the same with HE particles, as these are also detected by scintillators.
• The fabrication of a corresponding pixelated scintillator
• The hybridization and packaging of a decent number of devices (ROIC + Scintillator)
• Experimental verification of such hybrid devices under the X-ray beam, with verification of DQE and compare to the state of the art
• Further experimental use and test in disciplines as medical X-ray, and interested partners in particle physics, NDT, etc.

1. B.Dierickx, S. Vandewiele, B. Dupont, A. Defernez, N. Witvrouwen, D.Uwaerts, "Scintillator based color X-ray photon counting imager", Workshop on medical applications of spectroscopic X-ray detectors, CERN 22-25 April 2013 (slides available at www.caeleste.be)

Summary

The purpose of the project is to design and manufacture a large 2D array of X-ray (and particle) counting pixels. The design include the CMOS ROIC as well as the pixelated scintillator.
Due to the segmentation of the scintillator one will overcome the weak point of scintillators: the pooir MTF due to sideward spreading of the light, and the Lubbert's effect that preclude an accurate particle/photon energy measurement.

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