Opportunities, Similarities and Differences in X-ray and Electron Detectors

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Traditional 2D pixilated detectors employed at X-ray light sources or in Transmission Electron Microscopes (TEM) for imaging and diffraction consist of scintillating phosphors, fiber-optically coupled to Charge-Coupled Devices (CCD). In both cases the fiber optic coupling protects the CCD from radiation damage, and for X-rays, use of fiber optic tapers also allows large areas to be covered.

Over the past 30 years in particle physics, though, 2D pixilated detectors for charged particle tracking have used direct detection in silicon. Detector topologies have been based on CCDs, hybrid pixels (a pixilated sensor bump-bonded to a corresponding readout integrated circuit) or Active Pixel Sensors (APS – where the readout integrated circuit is itself the sensor).

Direct detection in a semiconductor offers significant advantages in signal-to-noise, hence quantum efficiency, and potentially in spatial resolution. At the same time, dynamic range and radiation hardness are potential challenges. For electrons in silicon, the range in μm (and thus the Point Spread Function) is very roughly the electron energy in keV. For energies of interest in TEM (<100 – 300 keV) this suggests either large pixels on thick sensors[1] or small pixels on thin sensors[2]. For X-rays above about 1 keV, the sensor thickness required for high charge collection efficiency ~E^n, with n~2.8 for Si. A 300 μm sensor is fully efficient for energies below about 8 keV (Si) or 20-25 keV (Ge and GaAs), thus suggesting thicker sensors.

At LBNL, we have developed 100s of Megapixel/second (Mpix/s) detectors for X-rays[3] and 100s[4] to 1,000s[5,6] of Mpix/s detectors for electrons. Detection of lower energy (<1 keV) X-rays and (<100 keV) electrons present additional challenges. As the range for these particles is quite short, the amount of inert material seen by these particles must be minimized. In addition, in order to ensure single particle (especially single X-ray) detection, the electronic noise must be small (10s of electrons). We have produced a 10,000 Mpix/s X-ray CCD with readout in 65 nm CMOS, and are working towards an APS which could be used for both soft X-rays and electrons at higher speeds. These developments will be described, together with a discussion of the issues related to data collection and processing at very high frame rates.

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