X-Ray Energy Detection Using Silicon Field Emission Imaging Array

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In our previous work [1], silicon field-emission array (FEA) tips were used as an x-ray imager with high-count rate and high spatial resolution. Incident x-ray photons penetrate the fully-depleted silicon substrate, generating electron/hole pairs (EHPs). The holes are collected by the p+ doped layer, while electrons drift to the spatially-defined nanotips, where they are field-emitted into the vacuum. Finally, the emitted electrons are collected and amplified by a micro-channel plate (MCP). Therefore, the Si is being used for energy conversion, and electron emission. The imager is conceptually depicted in Figure 1.

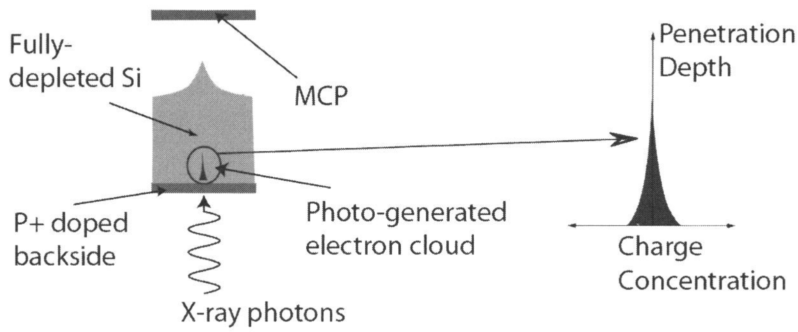

Figure 1: X-ray Imager and Energy Detector (Width of electron cloud depict concentration, not lateral diffusion)

We extended the concept of our previous work to energy detection. The incident x-ray photon, depending on its photon energy and the material of the detector, will generate a specific number of EHPs and penetrate an energy-dependant distance into the substrate. The collected electron current generates a distinct pulse width and height, which correlates to the specific energy of the incident photon. Note that in diffractometric applications, all incident photons strike the semiconductor at normal to the plane. The amplified pulses, unlike ordinary energy detectors, are spatially specific to the photon impact; therefore, this method produces both an imager and an energy detector. This capability is unavailable in any other x-ray imaging method and therefore, is valuable in x-ray diffractometric applications.

Using an Fe55 x-ray source in our experimental setup, it is estimated that a single photon absorption event will generate an average of 1616 electron/hole pairs in the fully-depleted Si substrate. While the holes are collected by the p+ doped layer, the photo-generated electrons are distributed along a penetration depth d_p, taken as the depth at which the charge concentration has decreased to 1% of the peak concentration. The majority of the electron concentration is generated near the point of entry, and decreases to zero exponentially past the penetration depth. The phenomenon is described by Pavlov and Nousek (Eq. 3 from [2]) and Figure 2 shows the electron distribution for both a Fe55 (Kα) photon, with 5.9keV energy and a Ti Kα photon with 4.5keV. The penetration depth for the two photons is calculated to be 58μm and 36μm, respectively.

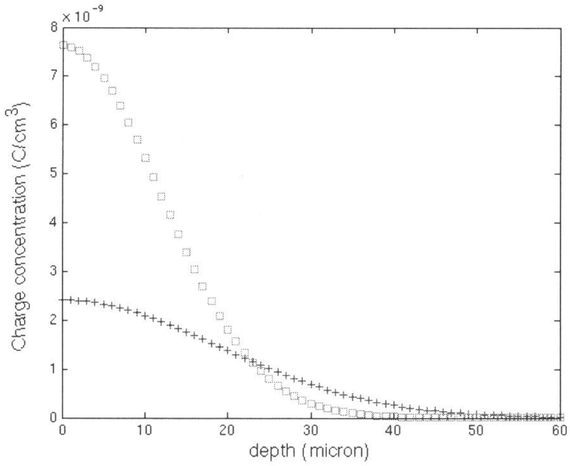

Figure 2: Charge concentration profile vs. penetration depth for Fe55 Kα (plus) and Ti-Kα (square)

Since the electron cloud is generated in a fully depleted region, across a 300μm-thick Si substrate, where the electric field is calculated to be 2.5×10^4 V/cm, the cloud will drift at saturated velocity to the nearest field-emitting tip. Because of the high axial electric field, the transverse drift occurs quickly and the diffusion length is small; therefore, we neglect the lateral diffusion effect [2]. Figure 3 depicts the current pulses that will be generated by either a single photon event from both Fe55 or Ti Kα photon.

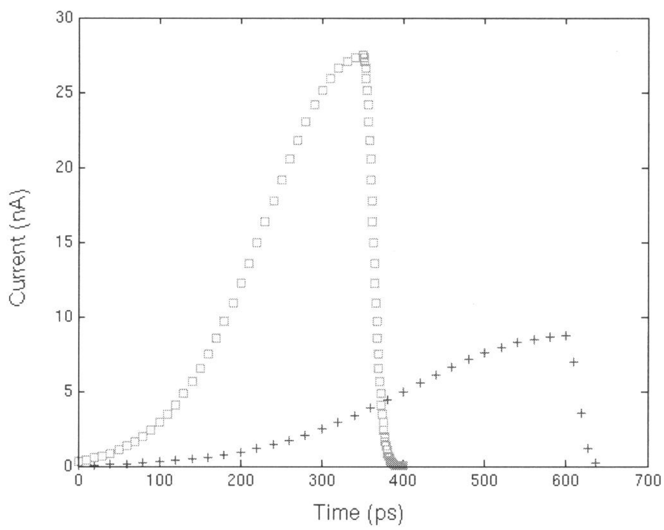

Figure 3: Current pulse for Fe55 Kα (plus)and Ti-Kα (square), note its different magnitude and pulse width.

The pulse widths are estimated to be 600ps and 385ps and the peak current magnitude is estimated to be 8.6nA and 30nA for Fe55 and Ti Kα, respectively. The photo-generated pulses are sufficiently unique to the incident x-ray such that individual pulses can not only be spatially imaged, but also energy resolved.

[1] Y. Wang, C. E. Hunt, Y. Diawara, "X-ray Imaging Detector Using Silicon Field Emission Tip Array Energy Conversion," *Digest of the 18th International Vacuum Nanoeletronic Conference* pp 52-53 (2005)

[2] G.G. Pavlov, J.A. Nousek, "Charge Diffusion in CCD X-ray Detectors," *Nuclear Instrument & Methods in Physics Research A* 428 pp 348-366 (1999)