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Effect of Pixel Pitch on Neutron-Induced White Pixel Generation in CMOS Image Sensors

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1. Introduction

CMOS image sensors (CIS) are widely used in various fields including space and nuclear applications [1–3]. In these radiation environments, incident particles interact with the silicon lattice and produce displacement damage, which introduces bulk defects that act as Shockley-Read-Hall generation centers within the depleted region of the photodiode [1, 2]. These defects generate excess dark current, and pixels exhibiting abnormally high dark-signal increases are commonly referred to as white pixels or hot pixels, which directly degrade the image quality of the sensor [3].

Previous studies have investigated the relationship between pixel pitch and dark current distributions for pixel pitches ranging from 4.5 to 14 μm, demonstrating that the depleted volume scales with pixel pitch and governs the mean number of nuclear interactions per pixel [1]. Displacement damage effects have also been characterized in backside-illuminated CIS with pitches on the order of 11 μm [2], and in-orbit CCD degradation models have been validated for 13.5 μm pitch detectors [3]. These works have established a solid understanding of radiation-induced degradation in relatively large pixel geometries. However, state-of-the-art CIS for consumer, automotive, and industrial applications increasingly adopt sub-micrometer pixel pitches, and systematic experimental data on pixel-pitch dependence in this regime remain scarce.

This work presents experimental results comparing white pixel generation across three CIS device groups with pixel pitches of 0.64, 0.70, and 1.00 μm, all sharing an identical pixel architecture, irradiated at the TRIUMF Neutron Irradiation Facility. By isolating pixel pitch as the sole design variable, this study provides a direct quantitative comparison of white pixel susceptibility across different sub-micrometer pitches.

2. Methods and Results

Three CIS device groups with pixel pitches of 0.64, 0.70, and 1.00 μm were used in this study. All three groups share an identical pixel architecture, including the same photodiode type, transfer-gate structure, and inter-pixel isolation, so that pixel pitch is the only design variable. Ten devices per pitch were irradiated at the TRIUMF Neutron Irradiation Facility with cumulative 1-MeV-equivalent neutron fluences up to the order of 10^9 n/cm². Dark-frame measurements were performed at seven steps including a baseline under uniform readout conditions. A white pixel was defined as one whose dark-signal increase from the baseline exceeded 80 DN, and the white-pixel fraction was obtained by normalizing the white-pixel count to the total pixel count of each device, thereby removing the confounding effect of differing sensor areas and pixel densities across the three groups.

Fig. 1 shows the white-pixel fraction as a function of neutron fluence for the three pixel pitches. All three groups follow a power-law dependence on fluence with a similar exponent of approximately 0.9, indicating a common damage accumulation mechanism regardless of pitch. Across the entire fluence range, the 1.00 μm pitch devices consistently exhibit the highest white-pixel fraction, while the 0.64 and 0.70 μm groups show comparable levels. At the maximum fluence, the 1.00 μm devices yield a white-pixel fraction approximately 1.7 times that of the 0.64 μm devices. This result is consistent with the larger charge-collection volume of larger pitch pixels increasing the per-pixel susceptibility to displacement damage.

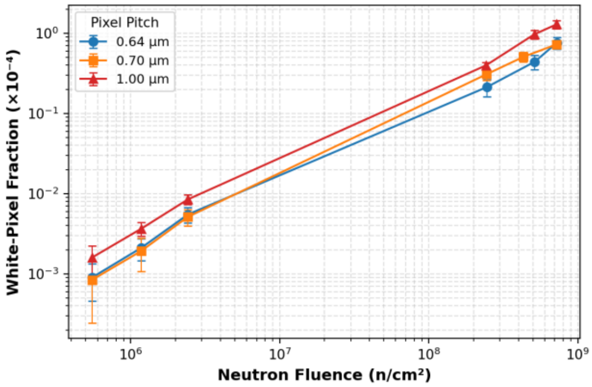

Fig. 1. White-pixel fraction as a function of neutron fluence for three CIS device groups with pixel pitches of 0.64, 0.70, and 1.00 μm.

Table I summarizes the white-pixel fraction and mean dark signal increase at the maximum fluence. The mean dark signal increase of the 1.00 μm pitch devices is approximately 1.6 times that of the 0.64 μm devices, showing a consistent trend with the white-pixel fraction results. The similar ratio observed in both metrics suggests that the pitch dependence affects not only the tail of the dark-signal distribution but also the overall average degradation level.

Table I: Comparison of white-pixel fraction and mean dark signal increase at maximum fluence for three pixel pitches.

Pixel Pitch (µm)	White-Pixel Fraction ($\times 10^{-4}$)	Mean Dark Signal Increase (e^-/s)
0.64	0.76 ± 0.13	2.40 ± 0.04
0.7	0.73 ± 0.09	2.36 ± 0.11
1.00	1.29 ± 0.16	3.85 ± 0.22

3. Conclusions

This study examined the effect of pixel pitch on neutron-induced white pixel generation using three CIS device groups with pitches of 0.64, 0.70, and 1.00 µm sharing an identical pixel architecture. The results show that the 1.00 µm pitch devices exhibit approximately 1.7 times the white-pixel fraction and 1.6 times the mean dark signal increase compared to the 0.64 µm devices. The 0.64 and 0.70 µm groups show comparable degradation levels, suggesting that the pitch effect becomes more pronounced above a certain threshold. These findings confirm that pixel pitch is a significant factor in white pixel susceptibility under neutron irradiation and can serve as a practical design guideline for CIS intended for radiation environments.

Future work will develop a predictive model for white pixel generation and extend the analysis to additional pixel design parameters such as photodiode type and isolation structure.

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