

ALMY Stability

Kevan S Hashemi and James R Bensinger

Brandeis University

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Introduction

An ALMY sensor is a transparent, position-sensitive, optical sensor made by depositing amorphous hydrogenated silicon (a-Si:H) onto a glass plate [1]. It was conceived of by the Max-Planck Institute for Physics in Munich (MPI), and developed by them in collaboration with EG&G Heimann in Wiesbaden. MPI proposed that ATLAS use the ALMY sensor in its muon alignment system [2].

The ALMY sensors manufactured by EG&G Heimann have amorphous silicon deposited in a square of width 20 mm.. There are 64 strips of conductive indium-tin oxide on the upper surface of the silicon, and 64 more strips on the lower surface. The lower strips are at right angles to the upper strips. Each upper strip forms a schottky barrier junction with the silicon. When these junctions are reverse-biased, the silicon acts as a photodiode.

Photocurrent generated in the silicon flows from the nearest upper strip electrode to the nearest lower strip electrode. If you shine a laser beam upon the sensor, you can deduce its horizontal position by calculating the centroid of the currents in the vertical strips, and its vertical position by calculating the centroid of the currents in the horizontal strips. When the laser beam has a pure gaussian profile, its position can be measured with accuracy of order 1 μm [2].

We found that the ratio of photocurrent to incident light power in our ALMY sensors, which we call the ALMY *sensitivity*, decreased where the sensor was exposed to a red laser. This lead to measurement errors of tens of micrometers.

The photoconductivity of amorphous silicon solar cells decreases during exposure to light [3]. This decrease is called the Staebler-Wronski Effect, after its discoverers. According to Tsai et al [5], when electron-hole pairs recombine in amorphous silicon, the energy they release can break silicon bonds, and so create dangling bonds. Dangling bonds decrease the silicon's photoconductivity. Annealing at 160 °C for several hours eliminates dangling bonds and restores the photoconductivity [4]. If the sample is not annealed, however, the dangling bonds will remain indefinitely [4,5].

Tsai et al demonstrated that the Staebler-Wronski Effect is a feature of pure a-Si:H. The effect is independent of wavelength for wavelengths less than 1 μm. It does not occur at longer wavelengths. When amorphous silicon is uniformly illuminated by visible light with intensity of between 50 and 700 mW/cm², and for durations of up to five hours, Tsai et al report that

$$\frac{dN}{dt} = \frac{I^2}{N^2}, \quad (1)$$

where N is the concentration of dangling bonds in the amorphous silicon, I is the incident light intensity, and t is time. Tsai et al also report that the photoconductivity of amorphous silicon is proportional to I/N . Using this relationship, and integrating Equation 1, we obtain

$$= \frac{bI}{(1 + a I(t)^2 dt)^{1/3}}, \quad (2)$$

where σ is the photoconductivity, and a and b are constants with dimensions cm⁴ mW⁻²s⁻¹ and s⁻¹ cm mW⁻¹ respectively.

Equation 2 implies that if the photoconductivity of a sample of amorphous silicon is reduced by 50% through exposure to light of a particular intensity and for a particular time, light with one tenth the intensity will take eight hundred times longer to produce a second 50% drop. The initial exposure would, to some extent, stabilize the photoconductivity of the amorphous silicon with respect to further illumination. But if the sensitivity of the ALMY sensor is directly proportional to its photoconductivity, this stabilization is not adequate for continuous use in the ATLAS experiment.

The sensitivity of an ALMY sensor, however, might not be affected by its photoconductivity. The sensor is a reverse-biased photodiode. If the bias voltage is large enough, the photocurrent is limited by the number of photons absorbed in the silicon, not by the photoconductivity. In the

sections below, we present the results of our efforts to stabilize ALMY sensors by pre-exposing them to white light for several days.

Errors Due to Instability

We exposed an ALMY sensor (serial number VS71) to a laser with diameter 1.5-mm, power 1 mW, and wavelength 670 nm for thirty-five days. The total photocurrent in the sensor decreased by 13% after three days, and by 26% after thirty days, as shown in Figure 1.

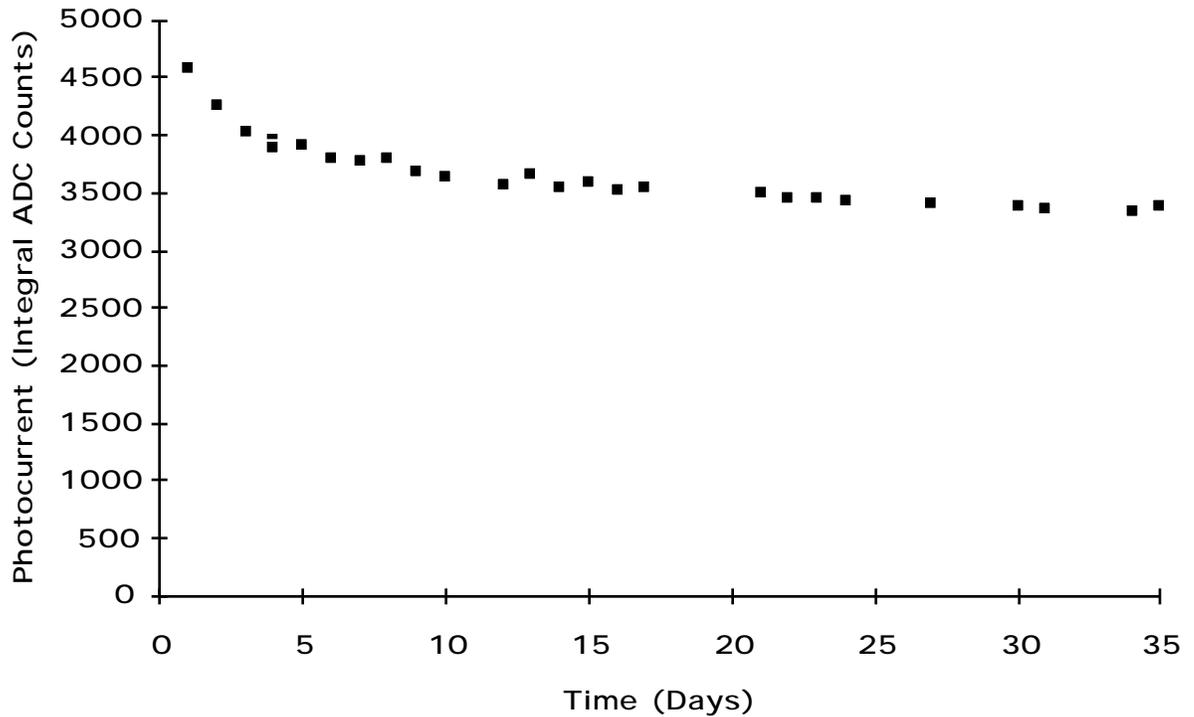


Figure 1: The total sensor photocurrent verses time during exposure to a 1-mW, 1.5-mm diameter laser beam.

Before, during, and after its exposure to the laser, ALMY VS71 was attached to a motor-driven x-y stage. Before the exposure, we used the stage to move the laser along a horizontal strip electrode. We moved the laser in steps of 312 μm from the center of one vertical strip to the next. The laser passed from left to right over the subsequently exposed region. At each step, we calculated the centroid of the vertical and horizontal strip photocurrents, which we recorded as the ALMY measurement of the laser position. After the exposure, we repeated these measurements with the laser in the same places as before. The differences between our two sets of ALMY measurements is shown in Figure 2. The exposed region is

centered at position 0 mm. It extends 0.75 mm to the left and right. The greatest difference between the two sets of measurements occurs at the edges of the exposed region. On the left edge, the difference is $-60\ \mu\text{m}$. On the right edge, it is $+60\ \mu\text{m}$.

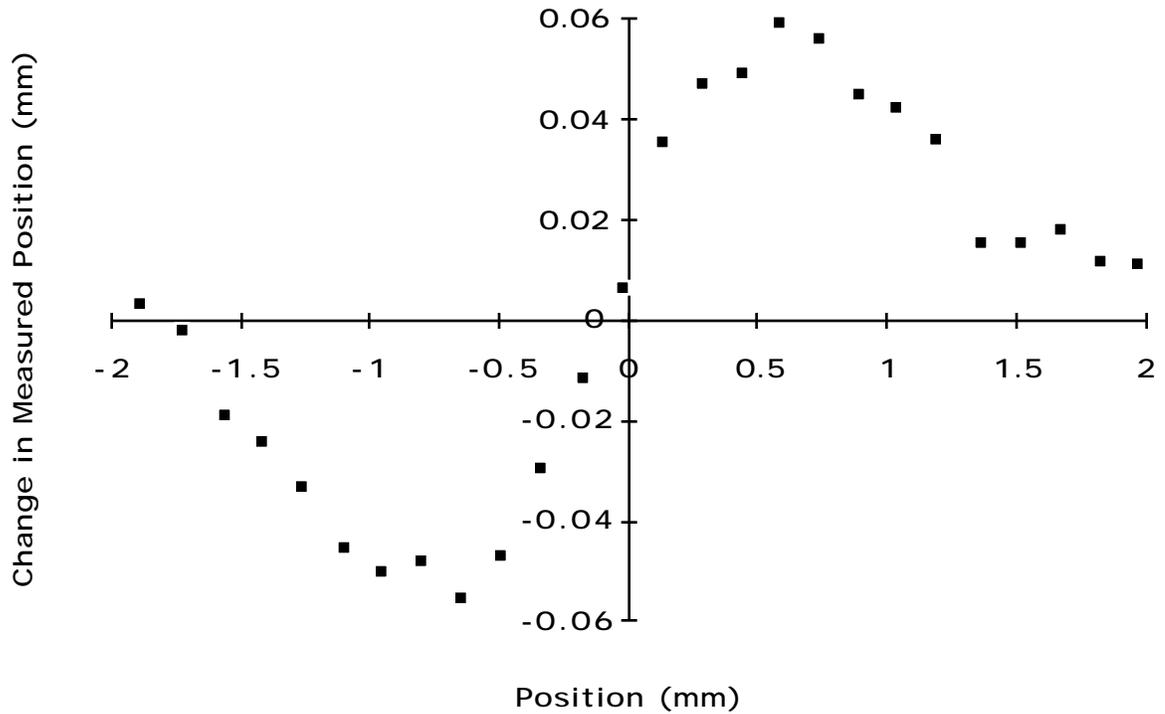


Figure 2: The change in ALMY measurement in the neighborhood of a thirty-five day exposure to a 1-mW, 1.5-mm diameter, 670-nm wavelength laser. The center of the exposed region is at position 0 mm.

Figure 3 shows the photocurrent after the exposure plotted against horizontal position. The drop in sensitivity at the center of the exposed region is clearly visible. The exposed region is centered at position 0 mm.

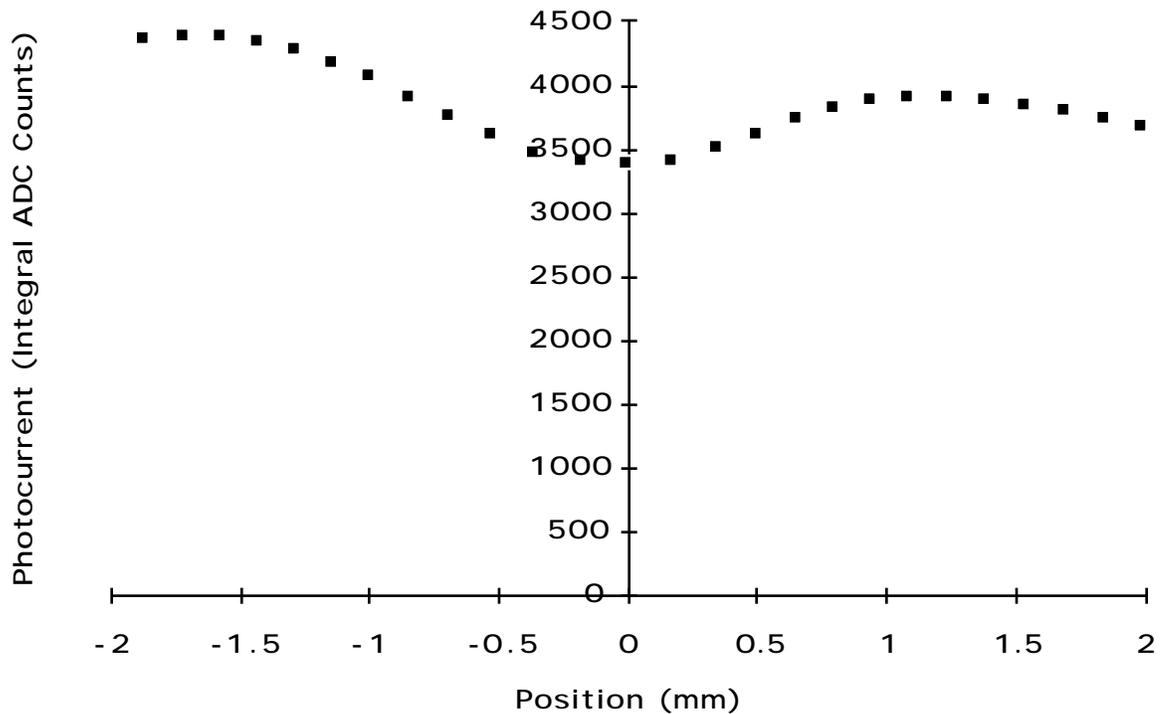


Figure 3: Photocurrent versus horizontal position after exposure.

According to the literature [3,4,5], the Staebler-Wronski Effect should be at least as rapid when the sensor's reverse bias voltage is reduced to zero. We performed an experiment with the sensor bias voltage set to zero, and exposed a fresh part of the sensor to our laser. We raised the sensor bias voltage to 3.3 V only to measure the photocurrent. On the second day, the photocurrent had dropped by 8%, which is similar to the 7% drop we observed on the second day with continuous 3.3 V bias. We did not continue the experiment past the second day.

Short-Term Laser and Sensor Stability

With our motorized x-y stage, we were able to measure the sensitivity of ALMY sensors on a two-dimensional grid. For these measurements, we focused a laser beam into a spot just wider than the strip pitch. The sensor strips were 302 μm wide, separated by 10 μm gaps, so the pitch was 312 μm [2]. We attenuated the spot power to 35 μW , or intensity of 40 mW/cm^2 , which was small enough to avoid saturating the sensor electronics, and also to avoid affecting the sensitivity of the sensor during the measurements. For each scan line, the laser passed along the center of a horizontal strip, and stopped at the centers of alternate vertical

strips. We recorded the total photocurrent at each position, and took this to be a measure of the local sensitivity of the sensor.

Consecutive scans of the sensitivity of freshly unpacked sensors differed by up to 20%. Figure 4 shows two scans of a freshly unpacked sensor (serial number VS20).

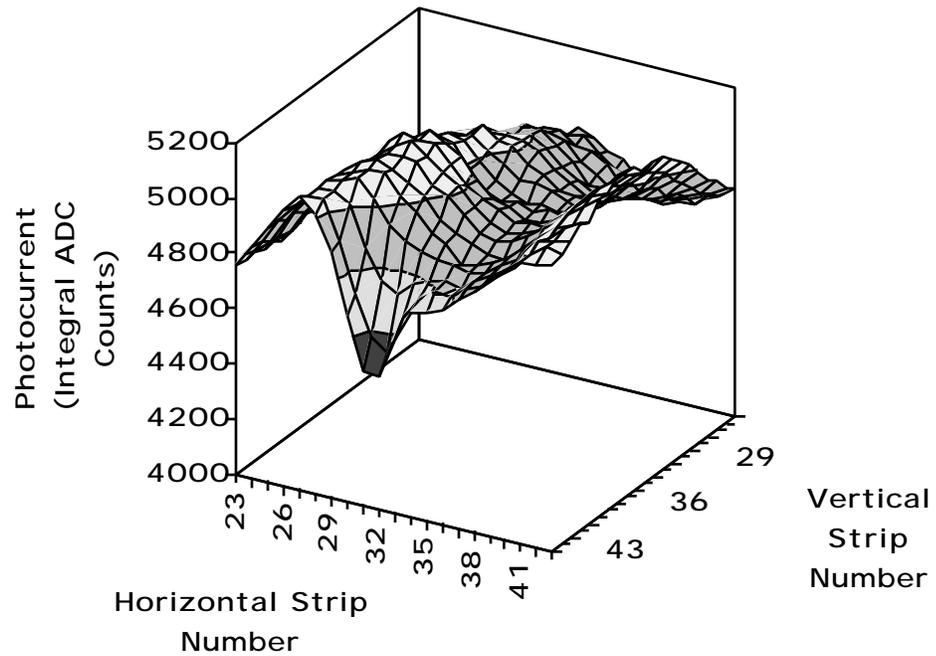


Figure 4a: The first scan of ALMY VS20.

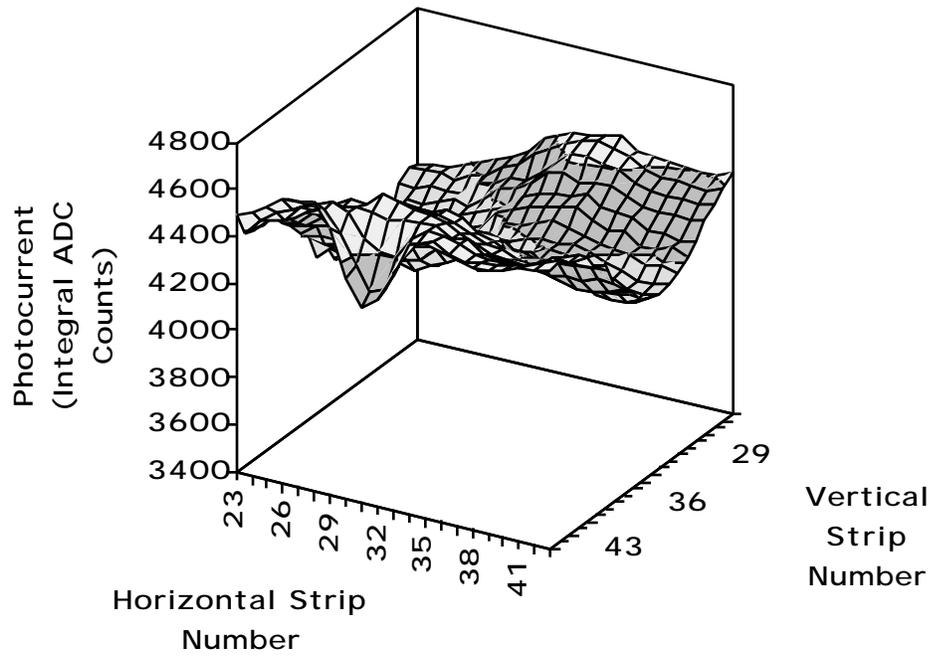


Figure 4b: The second scan of ALMY VS20

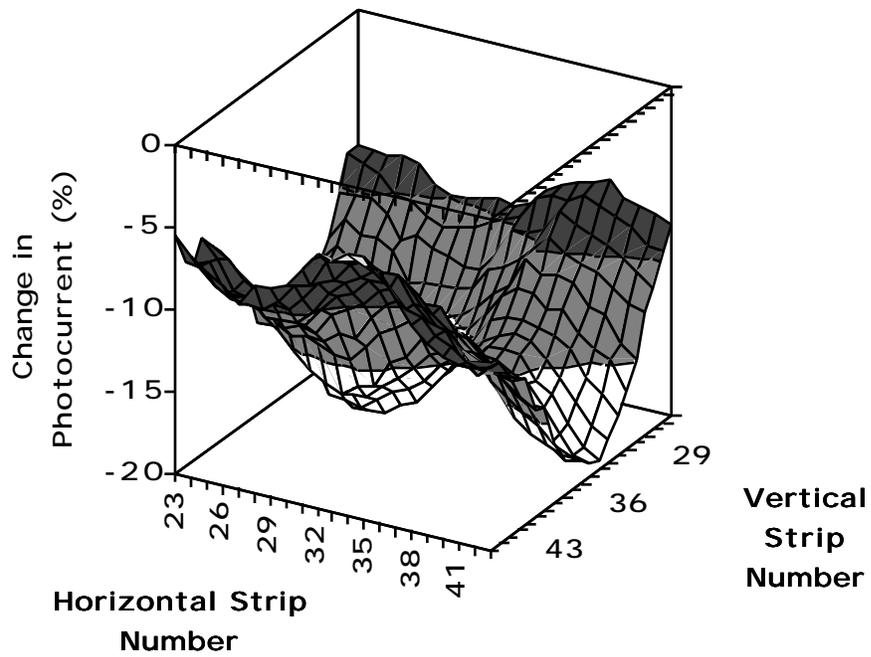


Figure 4c: Difference between the two scans of ALMY VS20.

We made dozens of measurements of the power of our laser beam. The power was constant to within 1%. We measured the power of the attenuated laser spot before, during, and after each scan. It was constant to within 1 μ W, or 3%, with a measurement error of the same size. In any case, random fluctuations in the laser power during the raster scans cannot account for the smooth two-dimensional features we see in Figure 4.

We later found that the sensitivity of the sensors we had exposed to white light varied by less than 2% from one scan to the next, in contrast to the 20% variations we obtained with the same sensors before they were exposed. The exposure to white light took place with no power applied to the sensor or its electronics. We concluded that fluctuations in the sensitivity of the fresh sensors is a feature of the sensors themselves.

Exposure to White Light

We thought that by exposing an ALMY sensor to bright light we might lower its sensitivity uniformly and render it resistant to further illumination. The brightest light source we could find to illuminate an entire sensor was a slide projector. Figure 5 shows the results of our experiment with the slide projector and ALMY VS20. The data for Scan 1 comes from Figure 4a. It shows the photocurrents recorded along the thirty-fifth horizontal strip, just after the sensor was unpacked.

We exposed the sensor to the slide projector for forty-eight hours. We performed Scan 2. The photocurrents we recorded along the thirty-fifth horizontal strip are shown in Figure 5. The sensitivity dropped by approximately 25%.

We shone a 1-mW, 1.6-mm diameter, 632-nm wavelength laser upon the sensor for fifteen hours, near the intersection of horizontal strip thirty-five and vertical strip thirty-three. The laser intensity was less than 20% of that of the slide projector. Nevertheless, after Scan 3, we found that the sensitivity had dropped by 30% at the center of the exposed region. The photocurrents we recorded along the thirty-fifth horizontal strip are shown in Figure 5.

We exposed the sensor to the slide projector for another forty-eight hours. We performed Scan 4. Measurements taken along the thirty-fifth horizontal strip are shown in Figure 5. The sensitivity dropped by approximately 25% all across the sensor, except in the region previously exposed to the laser. In the center of this region, the sensitivity rose by almost 10% to the level of the rest of the sensor.

Finally, we exposed the sensor to the laser for a second period of twenty-four hours. This time the laser was centered upon horizontal strip number thirty-six and vertical strip number thirty-three (300 μ m above the center of the previous exposure). We performed Scan 5. Measurements

taken along the thirty-sixth horizontal strip are shown in Figure 5. The sensitivity at the center of the exposed region dropped by over 30%, making a total drop of 60% from Scan 1.

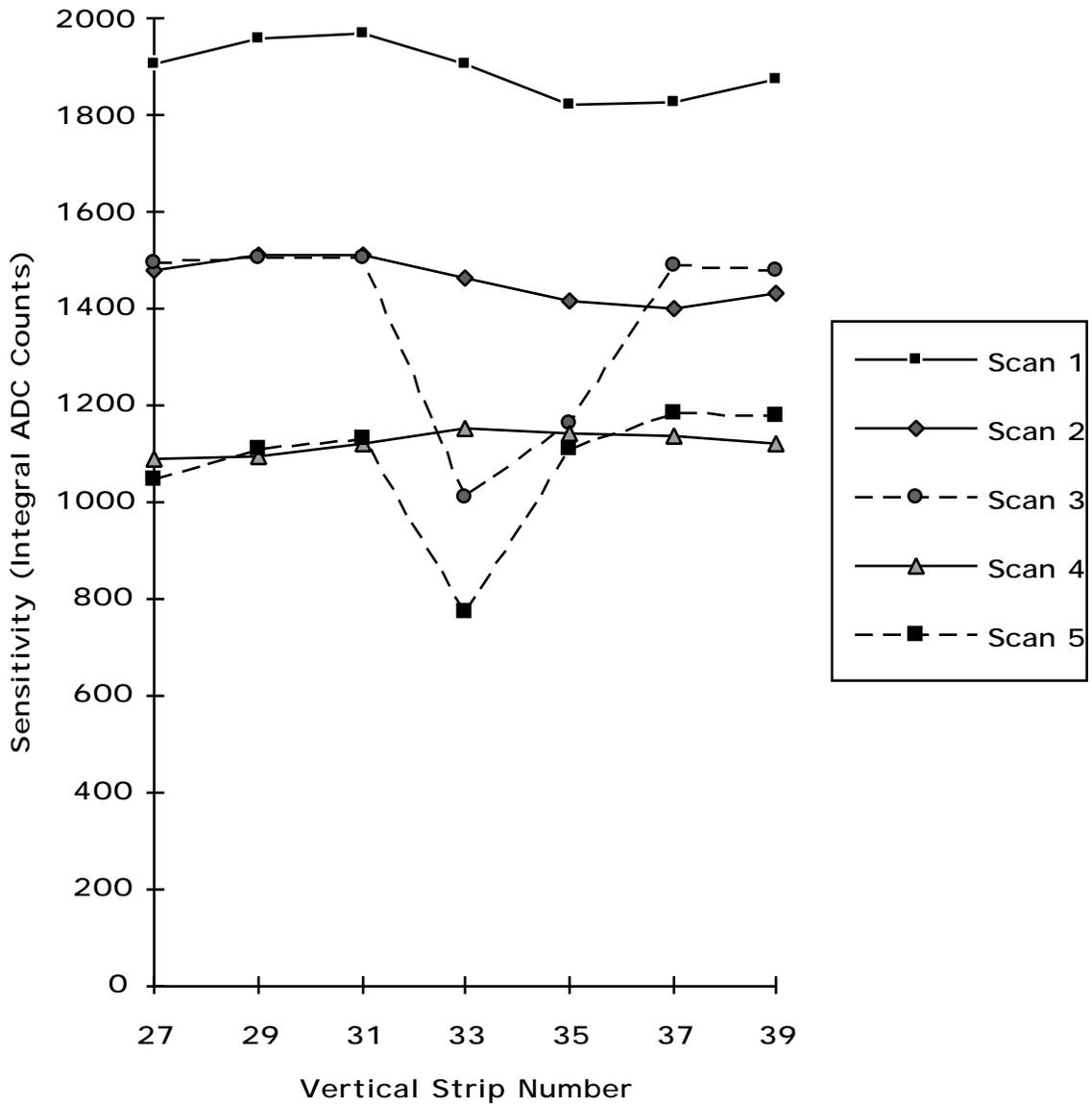


Figure 5: Sensor sensitivities recorded in Scans 1 through 5.

Conclusion

A 1-mW laser reduced the sensitivity of one of our ALMY sensors by almost 30% during a thirty-five day exposure. Afterwards, the sensor's

measurements were off by 60 μm at the edges of the exposed region. In an attempt to stabilize another of our sensors, we exposed it to 300 mW/cm^2 of white light for four days. Its sensitivity decreased by 50%. We exposed it to a red laser with intensity 60 mW/cm^2 for one day. The sensitivity dropped by another 30%. In short, we failed to stabilize our sensors.

Acknowledgments

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References

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