Reliability Tests on SpatiaLight's LCOS Microdisplays

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Abstract

We report the recent reliability test results of SpatiaLight's liquid crystal on Silicon (LCOS) microdisplays. Two different types of reliability tests have been performed: 1) thermal and 2) thermal with high intensity UV light. Various important device parameters were regularly monitored including the contrast ratio, color uniformity, and switching time. The test data shows that there are no degradations that fail the pass criteria. Lifetime estimations are given from the test data.

1. Introduction

Liquid crystal on Silicon (LCOS) microdisplays have received much attention recently due to their high-contrast, high-resolution display capability [1]. LCOS microdisplays have many important application areas including rear projection TVs, which is the main focus of SpatiaLight's LCOS device [2]. The LCOS device that we consider here has vertically aligned nematic (VAN) mode with normally black state, enabling very high contrast ratio (>2000:1) for f/2.8 systems. Dielectric thin films are used to align the liquid crystal (LC) into the VAN mode. Fig. 1 shows the SpatiaLight's LCOS display device.

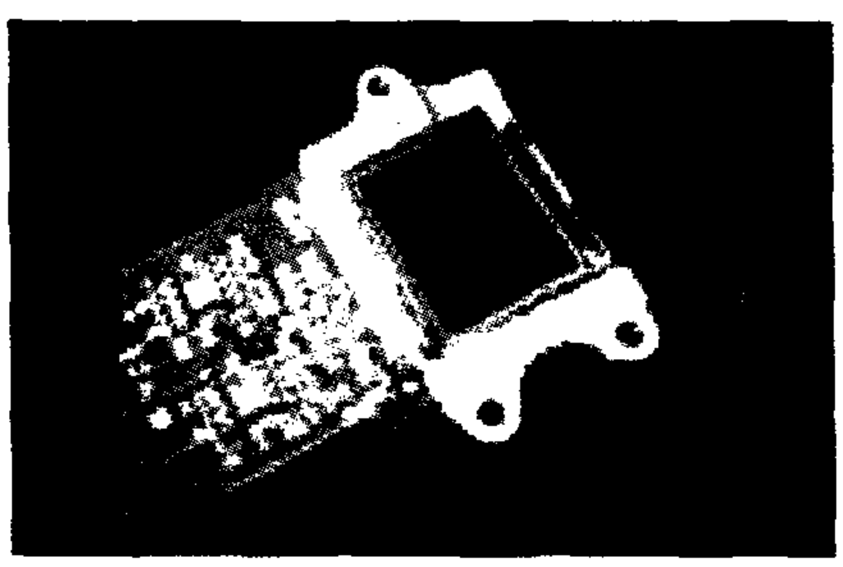

Fig. 1 SpatiaLight's LCOS display device.

One of the questions that need to be answered for the LCOS device is about the long-term reliability. In order to clarify the reliability issue, we have conducted reliability tests at elevated temperature and with high intensity UV light to accelerate the degradation and estimate the lifetime.

2. Reliability Tests

We selected two different tests to examine the reliability of our LCOS device. The first test (thermal test) was high temperature storage to accelerate the degradation of the LC material, LC alignment, cell gap, the LC response to the electric field, the glue, etc., which all contribute to the degradation of the LCOS device. We used 85 °C as a storage temperature and monitored the various device parameters including the contrast ratio, color uniformity, switching time, and reflectivity. In another reliability test (UV-thermal test), we shined the high-intensity UV light on the LCOS devices stored at high temperature (85 °C). The effect of UV will be further acceleration of the degradation. We monitored the same device parameters as mentioned above in this high-temperature storage test with UV light.

In a third test, we stored the devices at higher temperature (105 °C) for a year. We didn't regularly monitor the device parameters, but took the devices out after 1 year and examined the above parameters for the devices. We will call this test as long-term storage test.

3. Test Results

The monitor parameters were observed at regular time intervals for the thermal and UV-thermal tests. The tests showed that the measured parameters were not really changing in both tests for over 1500 hours. No device failed during or after the tests (test cell size: thermal = 12, thermal with UV = 6).

In case of the long-term storage test, still none of the devices failed after the test. The test cell size was 12.

3.1 Thermal Test

Figure 2 shows the change in the pretilt for the thermal tests. The change for individual device is within 20% of the initial value. With the uncertainty due to the measurement error, it can be considered that the pretilt is very stable over the test time.

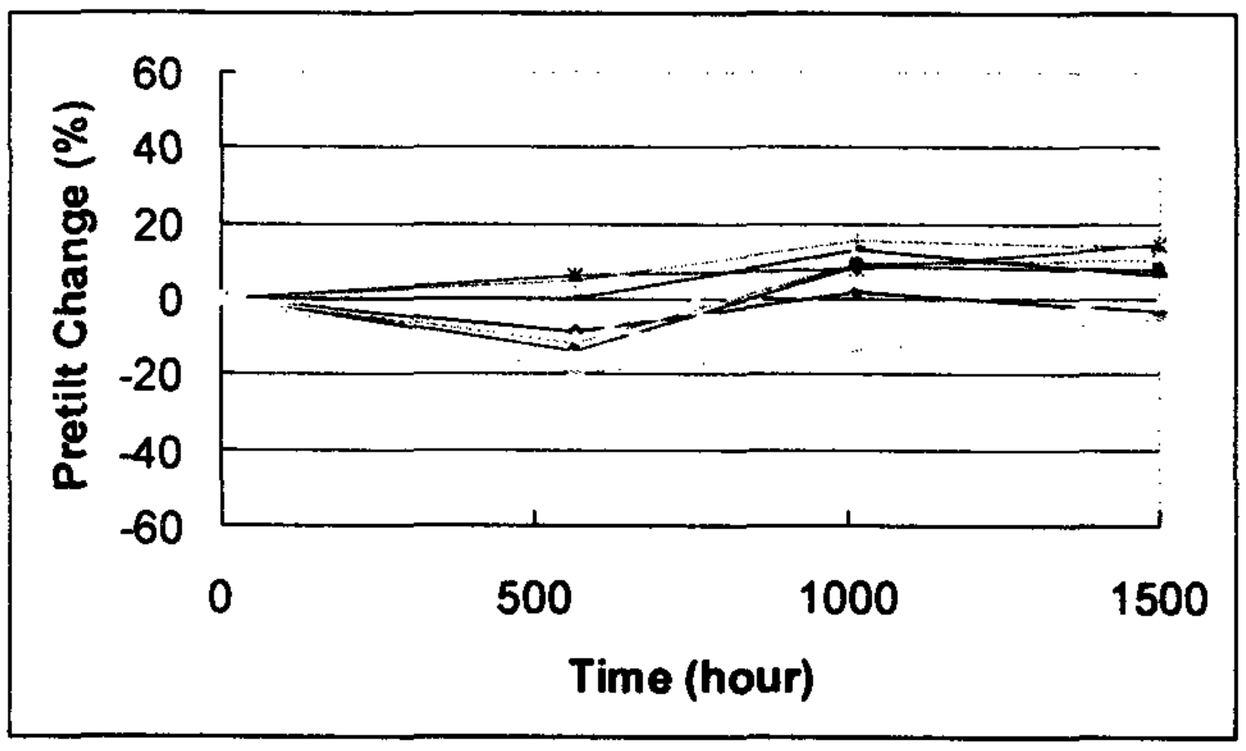

Fig. 2. Pretilt change over test time for the thermal test.

The contrast ratio data is shown in Fig. 3. The data was taken using the f/2.8 on-axis optical system (Fujinon light engine). It is seen that the contrast ratio is all over 2000:1 over the test time.

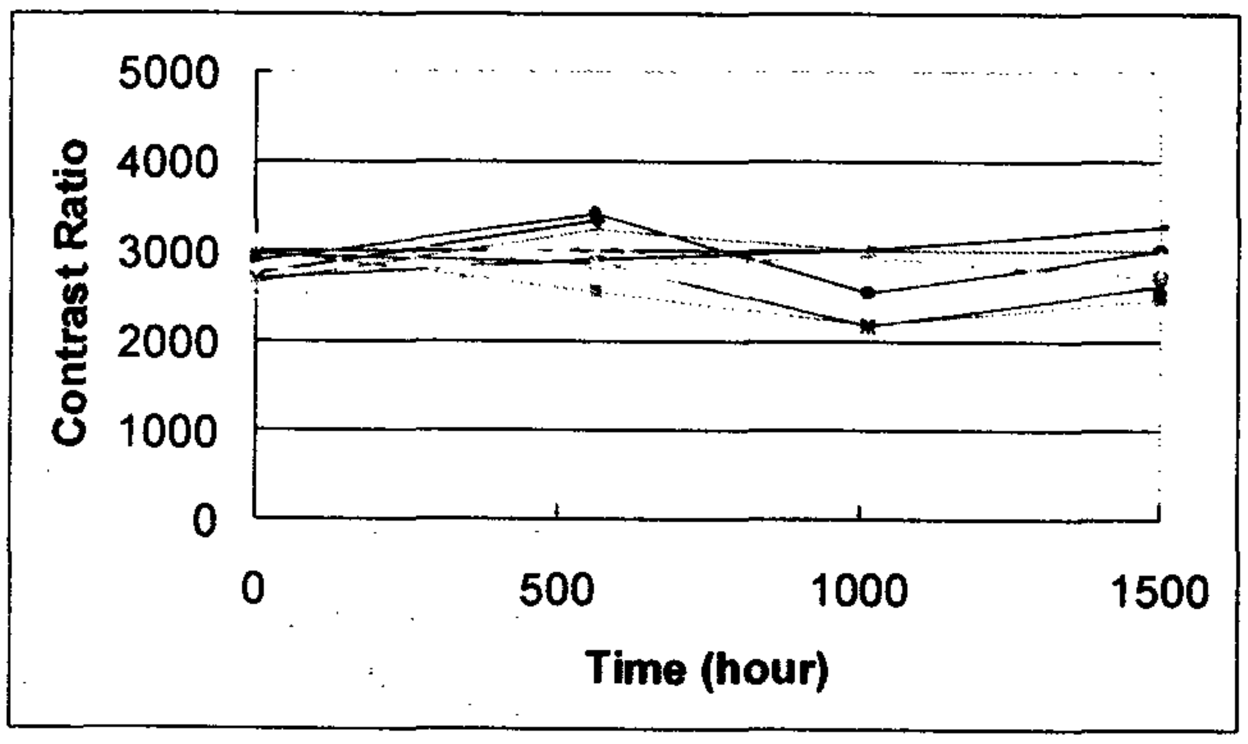

Fig. 3. Contrast ratio change over test time for the thermal test.

Color uniformity (Δu′v′) was measured at full modulation with the other two (reference) LCOS devices that did not undergo the reliability test. Three devices were put in each color channel of the Fujinon light engine. Since the green channel is the most dominant in determining the total color uniformity, the nine out of twelve LCOS devices under the reliability tests were put in the green channel and the other reference devices were put in blue and red channels in the light engine. The remaining three devices were put into red, green, and blue channels, respectively, to see the degradation in the color uniformity as a color set. Eight ANSI points were measured with respect to the center and the worst uniformity data is shown in Fig. 4. For over 1500 hours, the measured color uniformities were all well below 0.01 (5 JNDs), which is a commonly used criterion. Since the color uniformity reflects the uniformity in the cell gap, it can be said that the uniformity in the cell gap of the device is very stable.

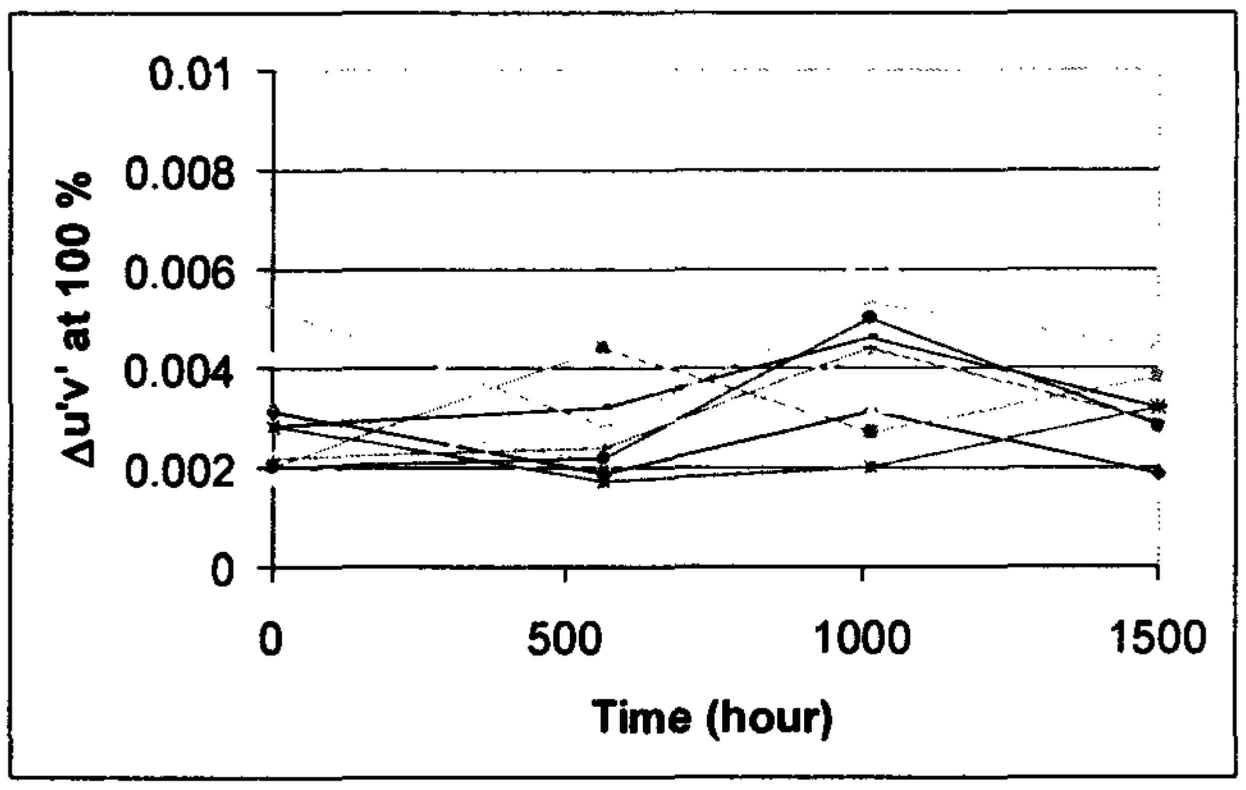

Fig. 4 Color uniformity change over test time for the thermal test.

The third parameter monitored was switching time, which was defined as the sum of rise and fall times when the device was modulated from full dark to full white and vice versa. The switching time over the test time was all ~15 ms, indicating that the devices' response to the applied electric field did not change much due to the reliability tests. As a reference, the cell gap of the device was ~4 μm. Fig. 5 shows the data for the switching time.

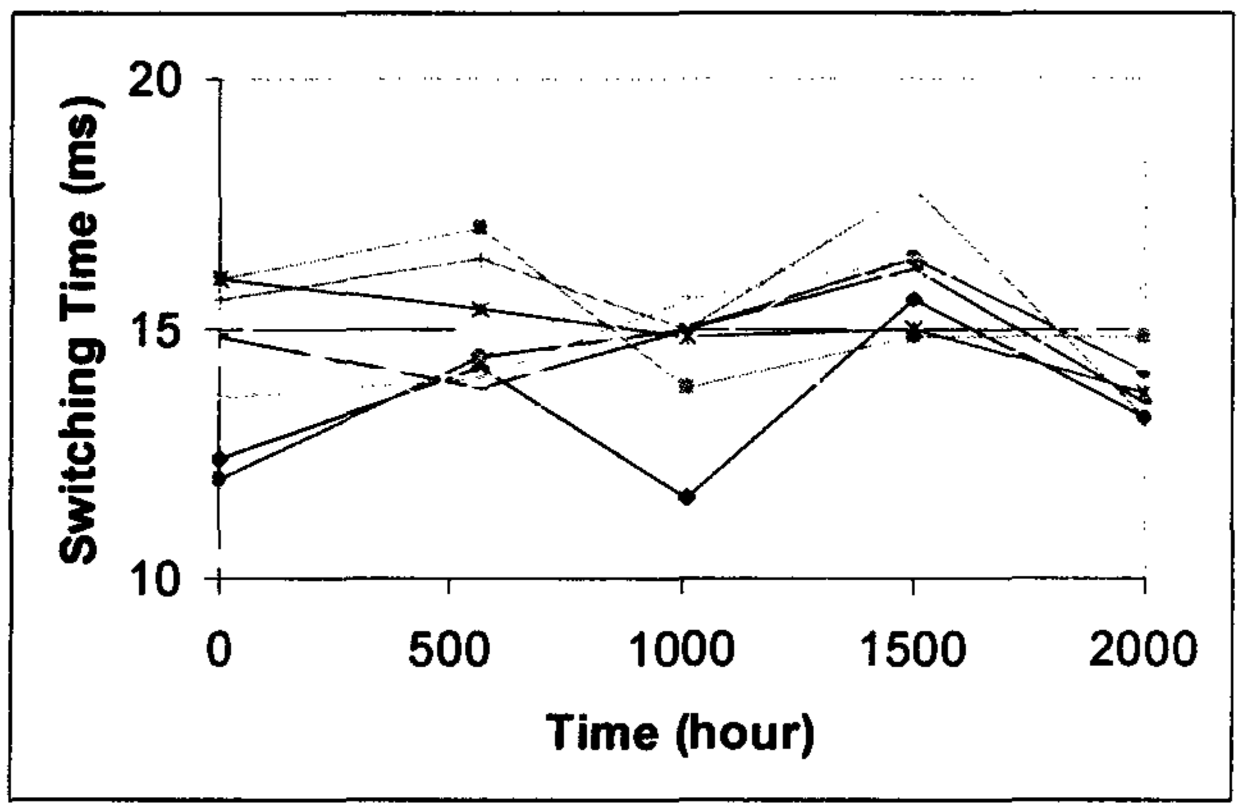

Fig. 5. Switching time over test time for the thermal test.

Finally, reflectivity data is shown in Fig. 6. Reflectivity was measured at the center of the display with respect to a reference mirror. There can be a measurement error depending on the angle and the position of the display and the data point that shows the reflectivity below 70% is considered due to this error. Overall, the reflectivity is almost constant, which implies that the brightness reflected by the display is almost constant over the test time.

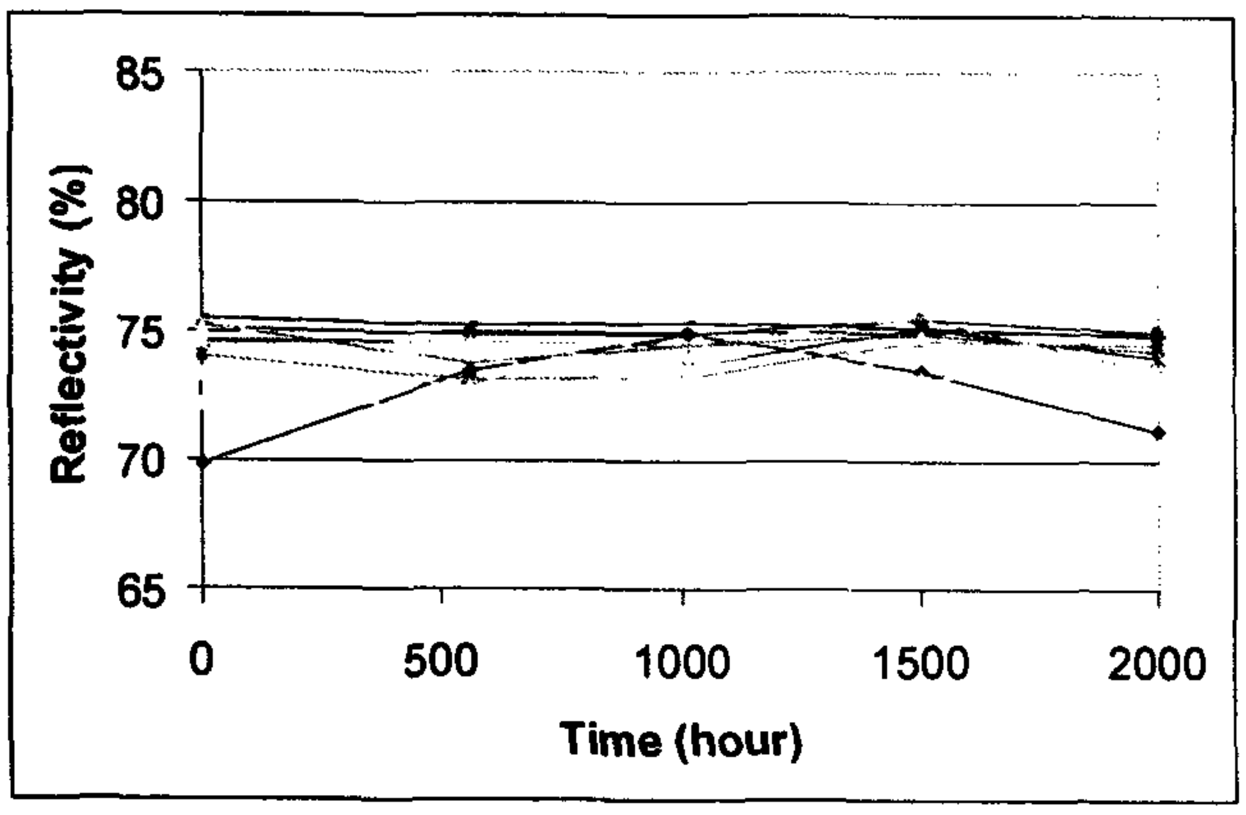

Fig. 6. Reflectivity over test time for the thermal test.

3.2 UV-Thermal Test

The intensity of the UV light used was measured as ~0.35 mW/cm^2 at 310 nm and ~3.6 mW/cm^2 at 365 nm. Same parameters were monitored as in the thermal test, i.e. pretilt, contrast ratio, color uniformity, switching time, and reflectivity. Each data is shown in figures below.

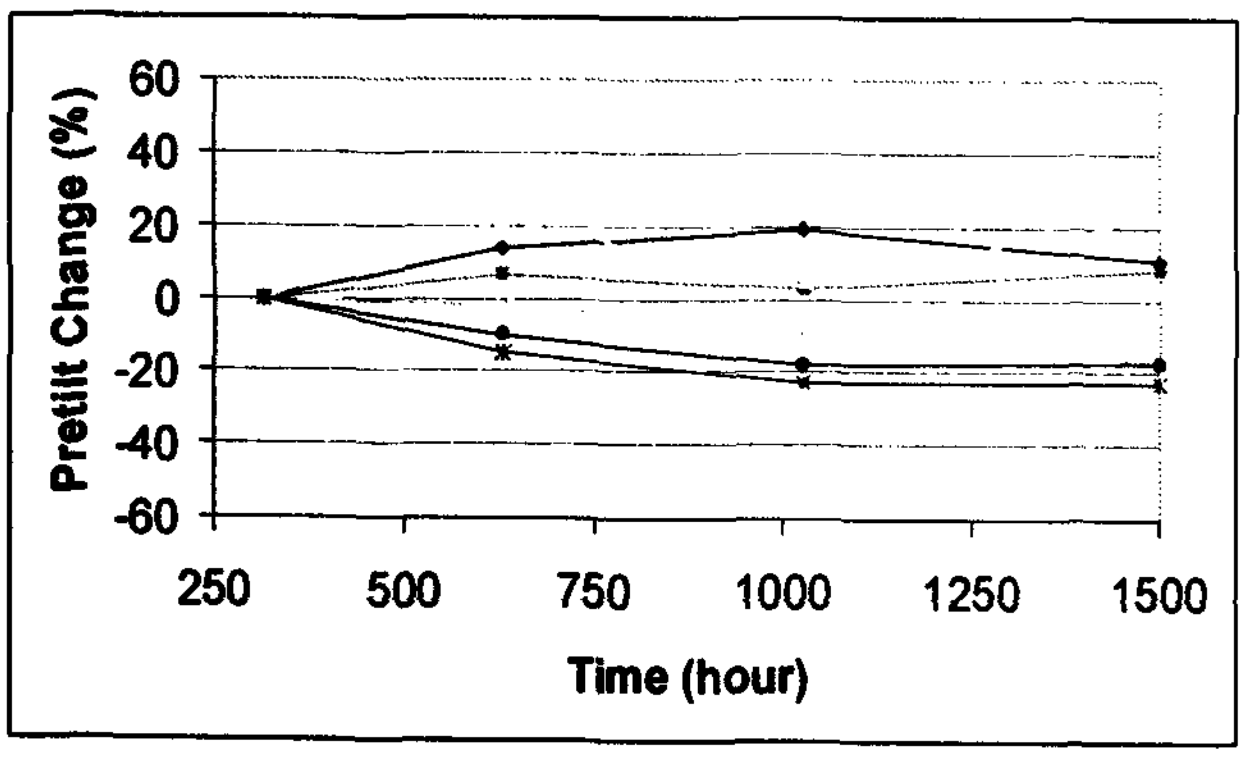

Fig. 7. Pretilt change over test time for the UV-thermal test.

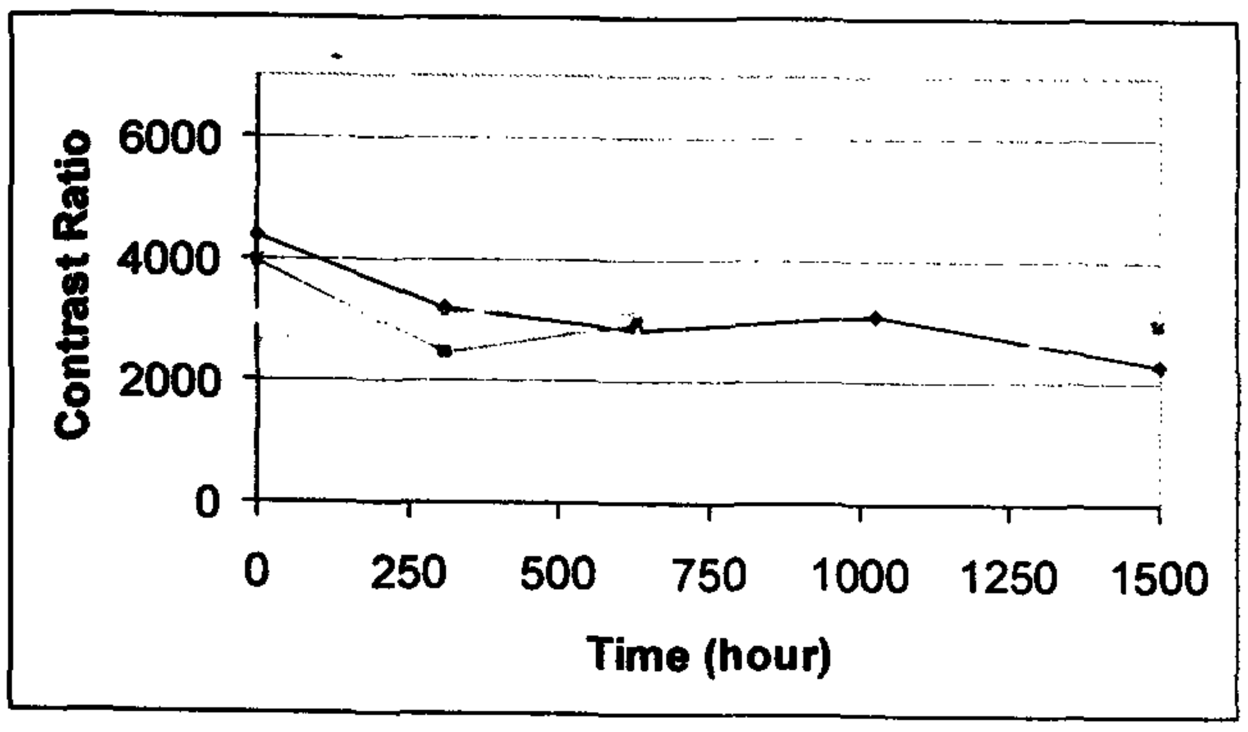

Fig. 8. Contrast ratio change over test time for the UV-thermal test.

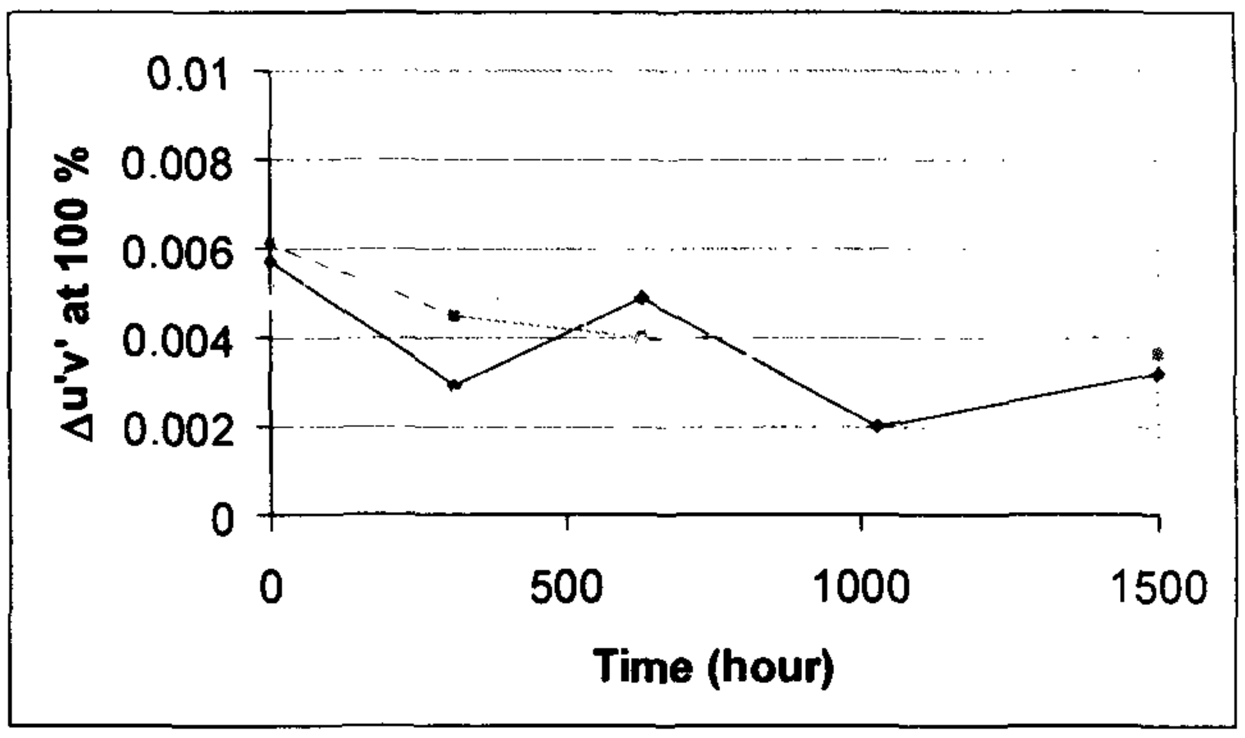

Fig. 9. Color uniformity change over test time for the UV-thermal test.

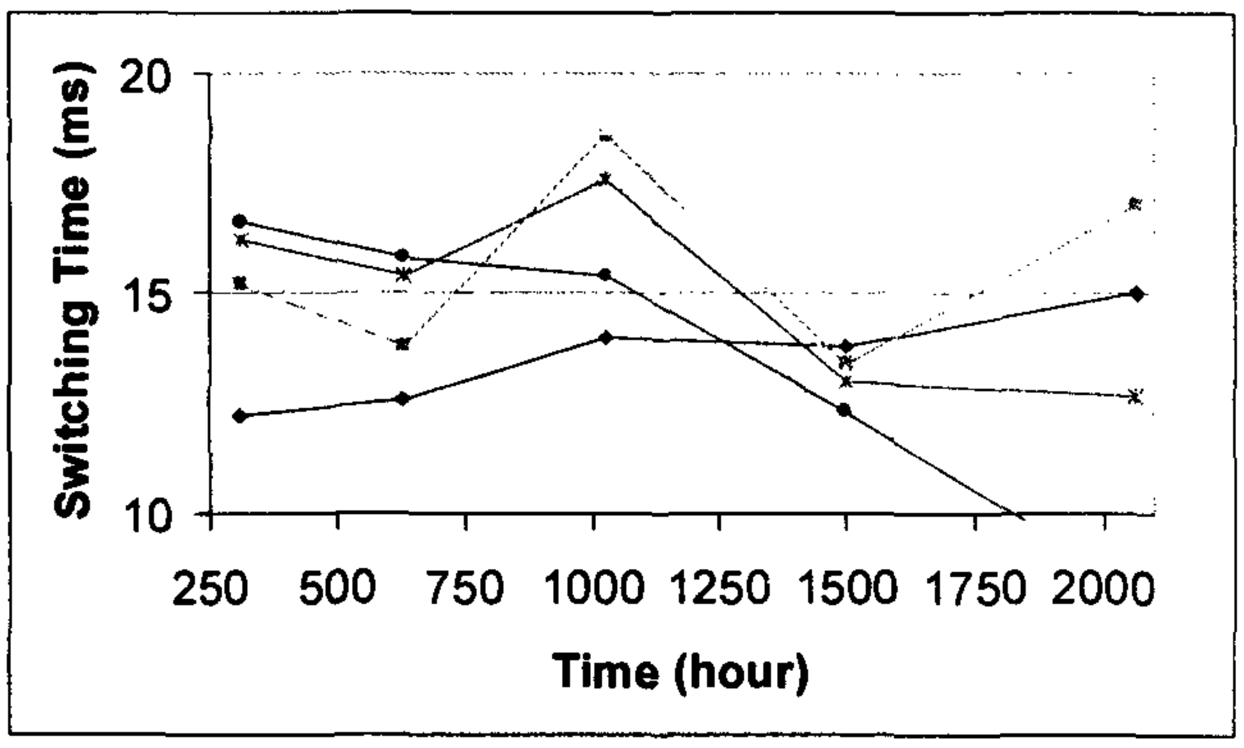

Fig. 10. Switching time change over test time for the UV-thermal test.

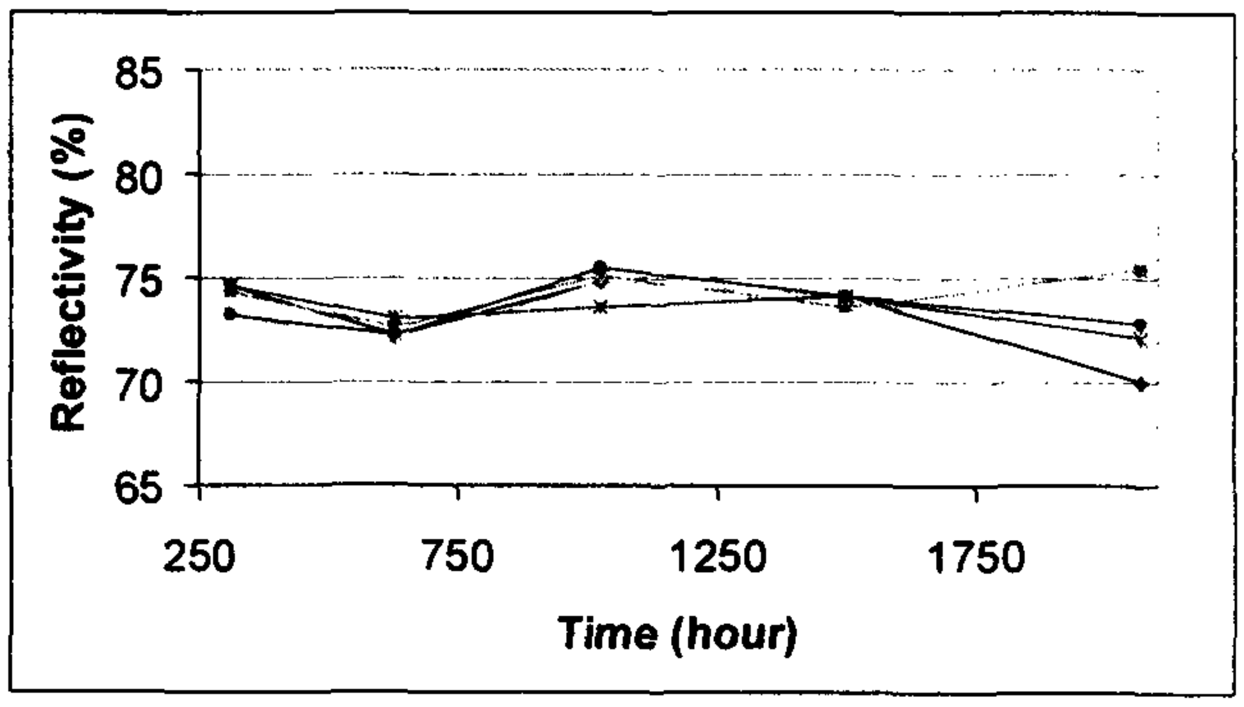

Fig. 11. Reflectivity change over test time for the UV-thermal test.

3.3 Long-Term Storage Test

All the devices in the long-term storage test showed reflectivities of 65 – 70%. The switching times for these devices were still ~15 ms. The contrast ratios were still >2000:1 when they were measured using f/2.8 light engine. Four color sets were matched from these devices and the color uniformities were checked. All the sets had the uniformities less than 0.009 at full modulation.

4. Lifetime Estimation

Lifetime can be estimated from the test data presented above. For the thermal test, the acceleration factor is ~3.4 with the assumption that the activation energy for the failure is 0.5 eV. Since there was no failed device for 1500 hours of testing, it can be said that for these test devices, the estimated lifetime is at least ~5100 hours. For the UV-thermal test, the acceleration factor is ~68, so the estimated lifetime is at least ~100,000 hours. If we assume the typical usage of 10 hours a day, then ~100,000 hours is equivalent to ~27 years of operation.

The long-term storage test adds another vindication that these LCOS devices are very reliable over the harsh reliability test. If we use this data for the reliability estimation, the acceleration factor is ~8.0. For the typical usage of 10 hours a day, the data will give the lifetime of ~19 years.

5. Conclusion

During the lifetime tests, the devices all performed in reliable and stable manner. Particularly, the pretilt was stable, which is consistent with contrast ratio, brightness (reflectivity) measurements. From this, we expect that these devices will show performance similar to the initial one over the lifetime.

We believe therefore that our reliability test data answers one important question about the LCOS device reliability. This test data is very timely as the industry is seriously considering utilizing the high-performance LCOS devices for next-generation high-definition projection TV applications.

6. References

[1] S.-T. Wu and D.-K. Yang, Reflective Liquid Crystal Displays (John Wiley & Sons, New York, NY), 2001.

[2] E. H. Stupp and M. S. Brennesholtz, Projection Displays ((John Wiley & Sons, New York, NY), 1999.