



TECH BULLETIN

COLOR STABILITY of
Vikuiti™ Dual Brightness Enhancement Film MF1-650 (DBEF/MF1-650)
Vikuiti™ Dual Brightness Enhancement Film D550 (DBEF-D550)

CONTENTS

INTRODUCTION	2
LCD-TV WAVELENGTHS	3
MEASUREMENT OF UV INTENSITY	4
SPECTRAL DEPENDENCE OF DISCOLORATION – YELLOWING VS. PHOTBLEACHING	5
TEMPERATURE DEPENDENCE OF AGING	6
INTENSITY DEPENDENCE OF AGING	7
DIRECT COMPARISON OF VIKUITI™ DBEF/MF1-650 AND DBEF-D400 FILMS	8
ACCELERATED TESTING	8
SUMMARY	9

INTRODUCTION

Vikuiti™ Dual Brightness Enhancement Film D400 (DBEF-D400) was developed for the monitor market, in which it has performed well for many years. Vikuiti™ Dual Brightness Enhancement Film MF1-650 (DBEF/MF1-650) and Vikuiti™ Dual Brightness Enhancement Film D550 (DBEF-D550) were developed for application in LCD-TVs, which have higher brightness targets and operating temperatures. This document will give background information on polymer aging, and describe the increased color stability that Vikuiti DBEF-D550 and DBEF/MF1-650 films will exhibit relative to Vikuiti DBEF-D400 film.

CCFL bulbs emit UV wavelengths which (if high enough in intensity or especially in combination with higher temperature) can cause visible aging in organic polymers. This aging is influenced by the temperature of the film and the UV spectrum and intensity impinging on the film in a given display.

LCD-TV WAVELENGTHS

The emission spectrum of a CCFL of the type commonly used in LCD television is shown in Figure 1. Emission peaks include 313, 335, 365, 436 and 550nm. LCD televisions typically have a fairly thick diffuser plate, usually polycarbonate or acrylic, placed between the lamps and the brightness enhancement films, to provide uniform illumination. This diffuser plate will typically filter out wavelengths below 350nm. This effect is shown in Figure 2, which compares the UV light emission of a) a TV back-light unit with plate and all films removed b) the same BLU with diffuser plate and diffuser sheet only and c) the same BLU with plate, diffuser sheet and Vikuiti DBEF-D400 film. Wavelengths between 350 and 380nm are passed by (non-UV protected) diffuser plates and sheets and will be absorbed by the Vikuiti DBEF film. If the intensity of these wavelengths and the temperature of the Vikuiti DBEF film during display operations are high enough, discoloration can occur. Vikuiti DBEF/MF1-650 and DBEF-D550 films contain an adhesive that was selected to be more color stable than the adhesive used in the monitor product, Vikuiti DBEF-D400 film. UV-protected diffuser plates and sheets will also extend the lifetime of a Vikuiti DBEF film product by absorbing light from 350 to 380nm.

Figure 1.

Spectrum of Typical LCD-TV CCFL

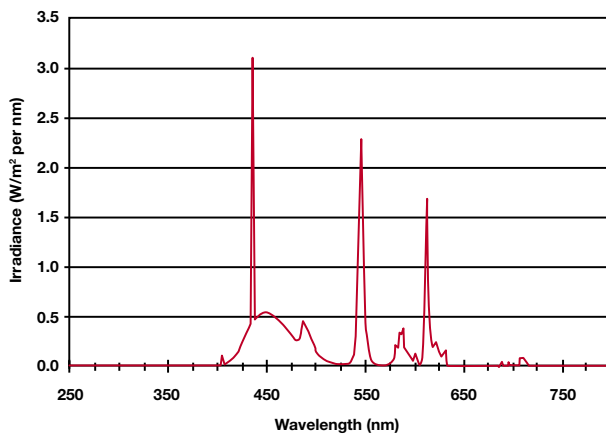
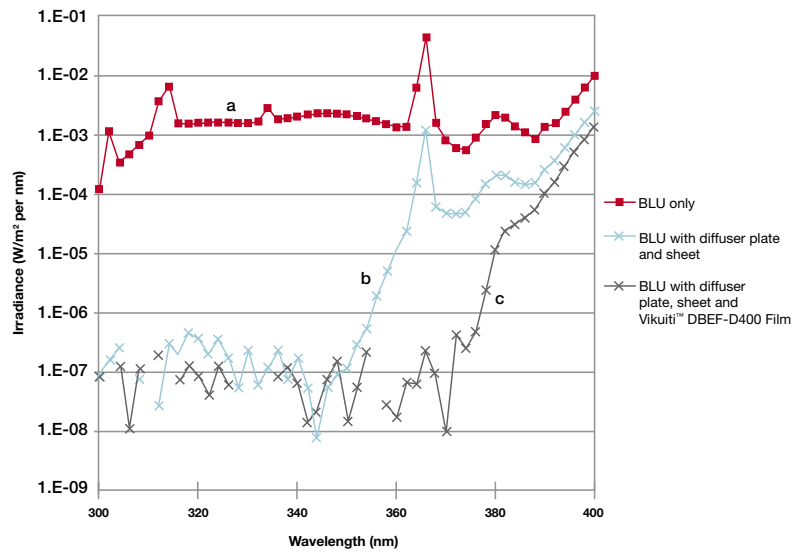


Figure 2.

LCD Television Back-light Unit Spectra



UV region comparison of a) lamp emission spectrum with spectrum of light b) impinging upon and c) transmitting through Vikuiti™ DBEF Film in a typical LCD television. The diffuser plate absorbs light <340nm. Vikuiti DBEF film will absorb light from 340 to about 380nm.

MEASUREMENT OF UV INTENSITY

It is important to know the UV intensity which will impinge upon a brightness enhancement film in a display. Intensity should be known in W/m² of film area, integrated over a specified range of UV wavelengths. UV intensity numbers in this document are in W/m² from 340-400nm.

The UV content for many LCD televisions has been measured at 3M. Values, shown in Table 1, range from 0.0049 to 0.0381 W/m² of 340-400nm light impinging on the Vikuiti™ DBEF Film. As will be described further below, televisions at the lower end of this range will provide many more lifetime hours before a polymer film such as Vikuiti DBEF film reaches a specific dy, dYI or db* value.

Table 1. Typical UV intensities impinging upon Vikuiti™ DBEF Film in LCD televisions.

	<u>Date measured</u>	<u>Diagonal (in)</u>	<u>W/m² 340-400nm</u>
TV1	March 2004	42	0.0381
TV2	February 2005	30	0.0228
TV3	July 2005	32	0.0220
TV4	March 2004	42	0.0196
TV5	July 2005	26	0.0177
TV6	February 2005	30	0.0167
TV7	July 2005	32	0.0057
TV8	July 2005	37	0.0049

It is important to realize that the magnitude of UV light which can cause aging of polymer components can sometimes be undetectable with standard instrumentation. For example, in Figure 1 (a typical plot of a lamp spectrum on a linear scale) the importance of the UV wavelengths can be overlooked. Figure 2 uses a logarithmic scale and focuses on the 340-400nm range. The UV peaks at 313, 335, and 365nm will be very important to polymer aging. Peaks of this magnitude require specialized high resolution equipment to detect, but it can indeed be these small amounts of UV light which are the cause of visible aging in polymer films.

SPECTRAL DEPENDENCE OF DISCOLORATION – YELLOWING VS. PHOTBLEACHING

In studies of UV exposure of polymers, it is common that there are two competing reactions: a photobleaching reaction which requires oxygen, and a yellowing reaction which does not require oxygen. Figure 3 shows a spectral activation curve measured for Vikuiti™ DBEF-D400 Film using sharp wavelength cut-off filters. This data was obtained at a temperature of 84°C and the UV intensity was many times the level of an LCD-TV, so a measurable shift in b^* was observed after a few hundred hours. This curve shows that the wavelengths of <370nm cause yellowing, and wavelengths between 370 and 450 cause much higher photobleaching. Light >550nm has no effect; the b^* occurring with these filters is believed to be thermal-induced ($\Delta b^* < 0.4$ after 96 hrs at 84°C). The performance of Vikuiti DBEF-D film in a display or test will depend greatly on the balance of yellowing (<370nm) vs. photobleaching light (>370nm).

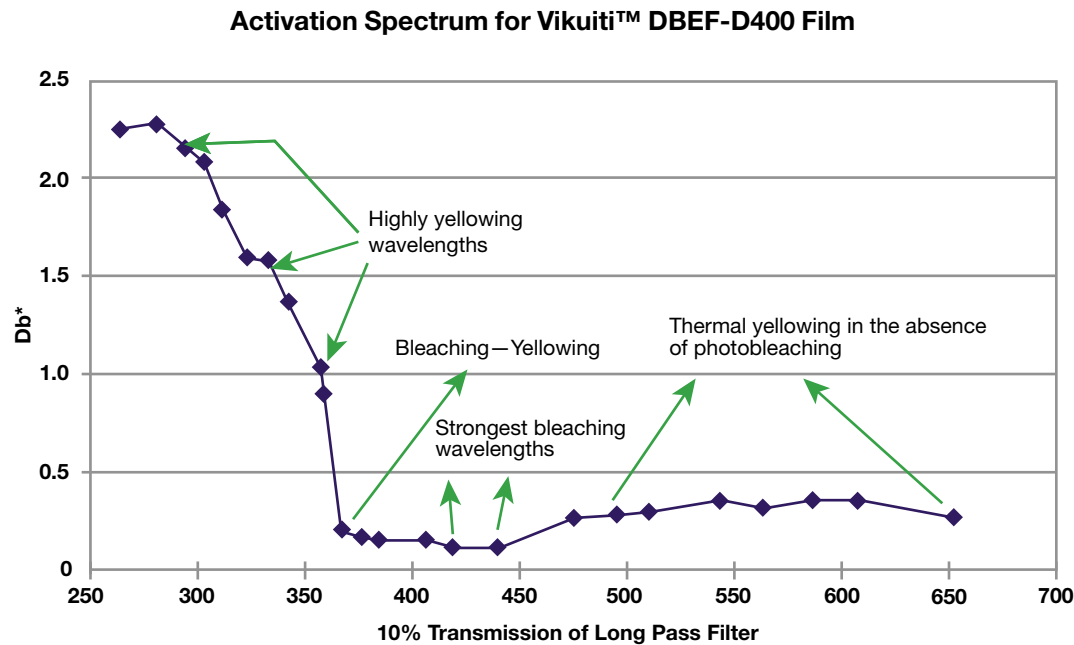
The rate of observed color change will be the rate of yellowing minus the rate of photobleaching:

$$\text{Change in } \Delta y, \text{ YI or } b^* = f(k_{\text{yellowing}} - k_{\text{photobleaching}})$$

The relationship between photobleaching rate, yellowing rate and the diffusion rate of oxygen into the film is very important. Accelerated aging in which the UV dose is applied too fast for oxygen diffusion will result in extremely fast yellowing because the competing photobleaching reaction will be eliminated.

The results discussed in this document are all assuming a spectral distribution typical of LCD-TV, shown in Figure 1. If testing is performed with other lamps with a significantly different distribution of intensities, aging can occur faster. For example, UV-B bulbs contain more low wavelength light relative to the visible light than do LCD-TV CCFLs. These lamps will cause more visible yellowing, because the yellowing (UV) wavelengths are less balanced by photobleaching (visible) wavelengths.

Figure 3.

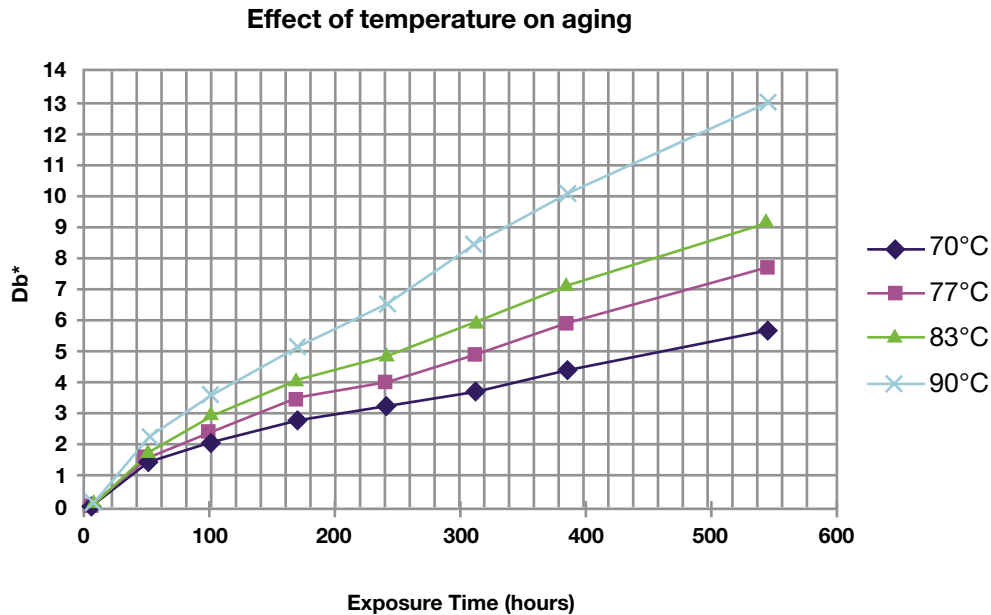


Much more yellowing is caused by light 365nm and less. (Large shifts in b^* were obtained during this experiment as both UV intensity and temperature are much higher than seen in operating LCD televisions. UV intensity was approximately 150 times normal TV levels and temperature was about 30°C higher.)

TEMPERATURE DEPENDENCE OF AGING

The temperature of a display will have a large effect on the discoloration rate. Figure 4 shows typical b^* changes occurring at high UV light intensity. Cooling a display by even a few degrees can greatly extend the lifetime of brightness enhancement films. This data was taken at very high UV intensity, 1.71 W/m^2 (340-400nm), but the same dependence of aging on temperature would occur at typical LCD television intensities.

Figure 4.



UV intensity is 1.71 W/m^2 from 340-400nm, much higher than in actual LCD televisions. (Large shifts in b^* were obtained during this experiment as both UV intensity and temperature are much higher than seen in operating LCD televisions. UV intensity was approximately 150 times normal TV levels and temperature was about 30°C higher. No diffuser plate was between the lamps and the films, resulting in exposure to much more short wavelength UV light. As a result, a very high rate of discoloration was observed.)

INTENSITY DEPENDENCE OF AGING

The rate of aging of film increases drastically with intensity of the UV wavelengths known to cause yellowing. Typically, aging rate (the reciprocal of the time required to reach a specific dYI, dy or db*) can be fitted to an equation:

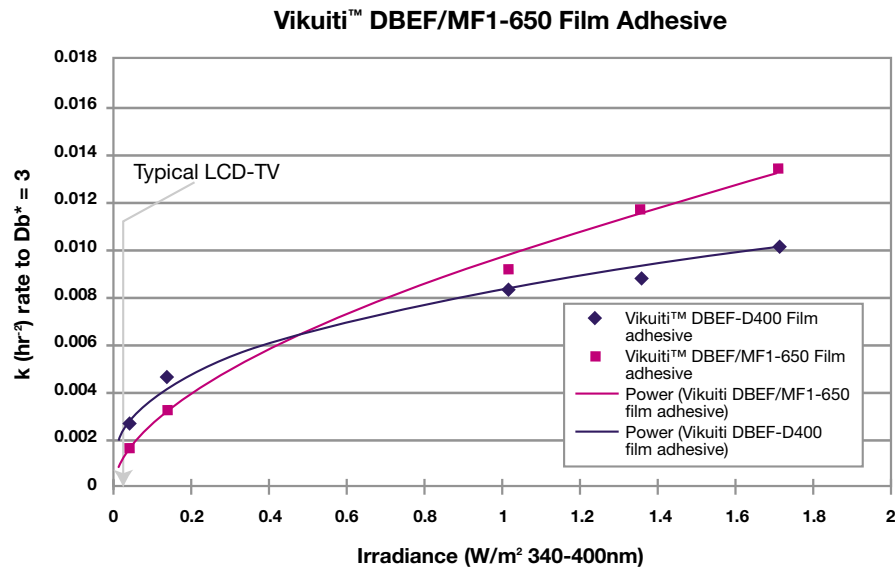
$$\text{Rate (h}^{-1}\text{)} = b + aI^x$$

The constants a and x describe the material's response to UV intensity, while the constant b is predictive of the rate of discoloration in the absence of light (thermal aging). Determination of these constants requires aging of films at many light levels. The constants for the adhesive used in Vikuiti™ DBEF-D400 Film and the adhesive used in Vikuiti™ DBEF/MF1-650 and Vikuiti™ DBEF-D550 Films are shown in Table 2. Figure 5 shows the relative rates of discoloration of Vikuiti DBEF-D550/MF1-650 and DBEF-D400 films laminate over a wide range of intensities. The plot shows the actual data taken to calculate b , a , and x , and the fitted line. Tests at six intensity levels were used to obtain these curves (0, 0.05, 0.14, 1.02, 1.36 and 1.72 W/m² 340-400nm). Comparing these numbers with Table 1 shows that these are much higher intensities than are seen in LCD televisions. The Vikuiti DBEF-D550/MF1-650 film adhesive, with larger a and x values, is much more variable in aging rate as a function of UV intensity. At low UV intensity, typical of LCD televisions, Vikuiti DBEF-D550 and DBEF/MF1-650 film will show much slower aging than Vikuiti DBEF-D400 film, while at extremely high intensities, Vikuiti DBEF-D550 and DBEF/MF1-650 films will age faster than Vikuiti DBEF-D400 film.

Table 2. Constants for comparing intensity dependence of aging for Vikuiti DBEF-D400 and Vikuiti DBEF-D550 and Vikuiti DBEF/MF1-650 film.

Vikuiti™ DBEF Film	b	a	x
Vikuiti™ DBEF-D400 Film	0.000165	0.0082	0.3662
Vikuiti™ DBEF-D550 or DBEF/MF1-650 Films	0.000117	0.0096	0.5949

Figure 5. Comparison of discoloration rate (h⁻¹) Vikuiti DBEF/MF1-650/DBEF-D550 films and Vikuiti DBEF-D400 film laminates at 84°C and a wide range of intensities.



DIRECT COMPARISON OF VIKUITI™ DBEF/MF1-650 AND DBEF-D400 FILMS

Figure 6 shows a direct comparison of aging data for Vikuiti DBEF-D400 film adhesive vs. Vikuiti DBEF-D550/MF1-650 film adhesive. In this accelerated aging experiment (0.05 W/m^2 at 340-400nm and 84°C), laminates made with the adhesive used in Vikuiti DBEF-D550 and DBEF/MF1-650 films took about three times as many hours to reach a db^* value of 6 as did the Vikuiti DBEF-D400 film adhesive laminates. Also note that in the first 200 hours of this test, there was not much difference in the performance. It requires many hours of aging to see the improvement.

Some recent LCD televisions, which have shown UV intensity levels close to 0.01 W/m^2 and lower (see Table 1), should show an even greater advantage of Vikuiti DBEF-D550 or DBEF/MF1-650 films over DBEF-D400 film, as the benefit is greatest at low intensities (see Figure 5). Results in LCD television models will depend upon the specific UV content and operating temperature of the LCD television.

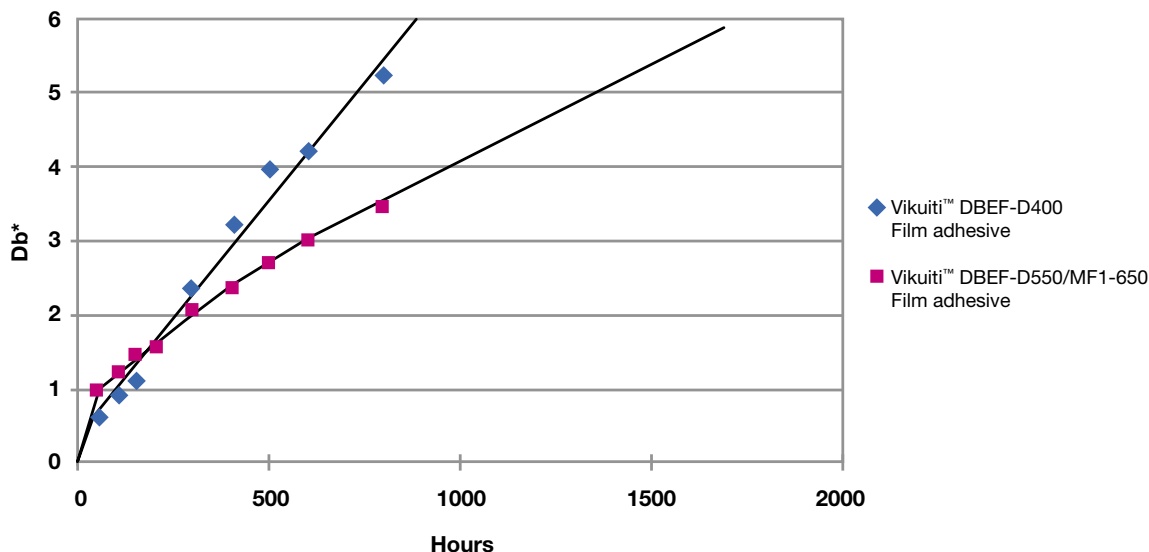
ACCELERATED TESTING

3M testing is done with increased UV and temperature, causing measurable discoloration to be observed after several hundred hours. Acceleration beyond these levels to exposures which cause discoloration in less than an hour is not recommended as it can lead to erroneous conclusions about the relative stability of Vikuiti DBEF-D400 film compared to Vikuiti DBEF-D550 and DBEF/MF1-650 film, for several reasons discussed above. First, very high acceleration can apply the UV dose too fast for oxygen diffusion, and the photobleaching reaction that normally competes with yellowing will be eliminated. Second, the improvement of Vikuiti DBEF-D550 and DBEF/MF1-650 film relative to Vikuiti DBEF-D400 film is highest at low UV intensities typical of LCD televisions, not at extreme UV intensities (see Figure 5). Third, application of high UV dose in a short time typically causes heating of the sample, and it is difficult to separate the contribution of UV vs. thermal aging.

Figure 6. Direct comparison of color shift for laminates made with Vikuiti DBEF-D550/MF1-650 film adhesive vs. Vikuiti DBEF-D550 film adhesive. In this accelerated aging experiment, Vikuiti DBEF-D400 film reached a db^* of 6 after about 500 hours, while Vikuiti DBEF-D550 film or Vikuiti DBEF/MF1-650 film required about 1700 hours.

Comparison of Aging Rate for Vikuiti™ DBEF-D550/MF1-650 Films and Vikuiti™ DBEF-D400 Film

UV intensity = 0.05 W/m^2 (340-400nm) Temp = 84°C



Large shifts in b^* were obtained during this experiment as both UV intensity and temperature are higher than seen in operating LCD televisions. UV intensity was 0.05 W/m^2 (340-400nm) and temperature was 84°C . Normal TV UV levels are lower than this (see Table 1) and operating temperatures are normally around 45°C . No diffuser plate was between the lamps and the films, resulting in exposure to much more short wavelength (highly yellowing) UV light. As a result, a very high rate of discoloration was observed.

SUMMARY

Vikuiti™ DBEF/MF1-650 and Vikuiti™ DBEF-D550 Films will provide enhanced color stability relative to Vikuiti DBEF-D400 film. Actual results will depend on the UV content (wavelengths and intensity) hitting the Vikuiti DBEF film and the operating temperature of the display. Color stability can be increased by reducing the UV intensity and operating temperature of the display. UV-stabilized diffuser plates and sheets can also enhance stability by absorbing light between 350 and 380nm.

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