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Light Emitting Diodes as an alternative ambient illumination source in photolithography environment

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Abstract: We explored an alternative light emitting diode (LED) - based solution to replace the existing yellow fluorescent light tubes (YFT) used in photolithography rooms. A no-blue LED lamp was designed and a prototype was fabricated. For both solutions, the spectral power distribution (SPD) was measured, the colorimetric values were calculated, and a visual comparison using Gretagmacbeth colorcharts was performed. The visual comparison showed that the LED bulb was better to render colors despite a low color rendering index (CRI). Furthermore, the LED bulb was tested in a photolithography room and there was no exposure to the photoresist even after 168 hours illumination.

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1. Introduction

Photolithography is a key pattern-transfer process that is used in fabrication of microelectronic-chips, microoptichips e.g. laser diodes and LED etc. It consists of three main steps: Photoresist spin, exposure and developing. Usually a photomask is used during the exposure. The goal of photolithography is to transfer a specific geometrical pattern from a mask to a photoresist material using UV light to change the solubility property of the resist. Afterwards specific parts of the resist is removed after the developing step [1]. Photoresist is a material that is very sensitive to light in the lower spectral range of the visible spectrum and the UV spectrum.

When working with photoresist it is extremely important that it is not exposed to light containing wavelengths in the sensitive range of the photoresist, before the appropriate exposure moment in the fabrication process. This put limitations on the light sources used for ambient illumination in photolithography rooms. The current solution to this problem is to use yellow fluorescent light tubes (YFT), which filters out all light components with wavelengths below 500 nm. This light source appears yellow, therefore photolithography rooms are also often called yellow rooms. One such room can be seen in figure 1 [2]. YFT have some problems rendering colors, for instance when bringing a blue box into the yellow room, it turns green. People may also experience problems, when working with multi-mask alignment where the color difference corresponding to different mask layer degrades in the yellow room. Furthermore, people that have been working in a yellow room for several hours, may also have issues readjusting to normal illumination when departing.

A potential alternative to the YFT based approach is to use LED based light sources. LED light sources are very energy efficient, have a long lifetime and are environment friendly. UV LED arrays are already used in some cleanrooms as an alternative cheap exposure source as a replacement for the mercury lamp [3]. In addition to that, another big advantage of a LED-based light source is the design flexibility. In this paper, we utilised this and characterized, designed and fabricated a LED-based white light source that can be used in photolithography rooms. It was demonstrated that this LED solution renders more colors than the YFT solution.

2. Design

Table 1 summarizes the wavelength sensitivity of several different photoresists available on the market today [4-16]. These sensitivities have been examined in order to determine the desired properties of a LED light source that can be used in a yellow room.

As seen in the table, all of the photoresists are sensitive only to wavelength below 460 nm, it should be mentioned that the sensitivity of the photoresist does not end abruptly at the maximum wavelength. There might be a small tail going towards higher wavelengths. Normally



Fig. 1. A typical photolithography room illuminated by a yellow fluorescent light tube [2].

Table 1. Different types of photoresists and their wavelength sensitivity [4-16].

Photoresist	Wavelength sensitivity range		Photoresist	Wavelength sensitivity range	
	Min [nm]	Max [nm]		Min [nm]	Max [nm]
AZ1505	310	440	ma-N405	<300	360
AZ1518	310	440	ma-N415	<300	360
AZ1529	310	440	ma-N420	<300	360
AZ4533	310	440	ma-N440	<300	360
AZ4562	310	440	ma-N490	<300	360
AZ4620	310	440	ma-N1410	<300	410
AZ5214E	310	420	ma-N2403	<225	325
S1805	350	450	SU8-2002	<320	400
S1818	350	450	SU8-2005	<320	400
S1828	350	450	SU8-2050	<320	400
SPR 220	200	460	SU8-2100	<320	400
KMPR 1000	350	400			

when creating white light sources based on LEDs, blue LEDs are among the utilized LEDs, however this would not be appropriate in this case, since the blue LEDs usually have a peak wavelength around 460 - 470 nm and a tail going well below 450 nm as seen in figure 2.

Figure 2 shows the relative spectral power distribution (SPD) of some of the LEDs that are commercial available on the market today. It is seen that the full width at half maximum (FWHM) of the LEDs ranges from 20 nm - 40 nm. It should be noted that the peak wavelength of the LEDs, even, within the same colors varies a lot primary depending on which batch and supplier they are from. The LED bulb has been designed using additive color mixing, excluding blue LEDs [17]. In order for a light source to be perceived as white its chromatic coordinates must be located very close or on the planckian locus in a chromaticity diagram [18]. This property is used when creating white light sources based on LEDs. The present study introduces a LED based light bulb, which was designed not to emit any wavelengths below 440 nm and to have its chromatic coordinates located as close to the planckian locus as possible. The properties of the LED bulb were compared to the properties of a YFT typically used in cleanrooms. A prototype of the bulb is shown in figure 3.

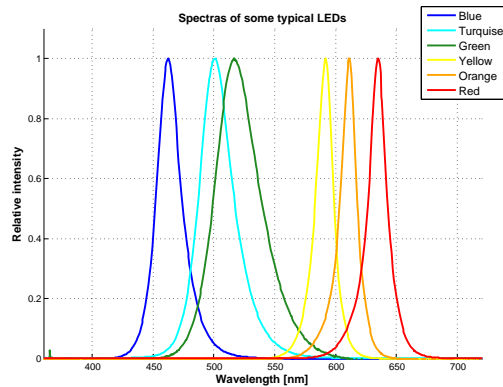


Fig. 2. Some typical LED spectra, the spectral bandwidth ranges from 20 nm (Red LEDs) to 40 nm (Green LEDs). The LEDs measured are from the supplier "KingBright".



Fig. 3. The LED Bulb prototype used in the experiments, it was created by RGB Lamps.

3. Experiments

To ensure that all the collected data came from the bulb, all the SPD measurements, were done inside a dark room at a constant room temperature of 25°C. This ensured that there were no reflections or contributions from outside sources. The total spectral flux was measured in a forward flux setup using an integrated sphere with a diameter of 1 m [19, 20] that was fiber-coupled to a spectrometer (Andor Shamrock SR-303i with an IDus DV-420A camera). Figure 4 shows a sketch of the setup. The forward flux measurement setup was calibrated using a standard spectral irradiance lamp (OL FEL-C S/N F-911 from Optronic Laboratories), and corrections for the absorption changes in the sphere setup was made using auxiliary lamps.

The input port of the sphere was 7.62 cm (3") in diameter and the LED bulb was mounted just inside the sphere: to ensure that all the light emitted from the bulb was collected. The spectrometer used a 300 l/mm grating yielding a spectral measurement range from 270.6 nm to 838.7 nm, with a resolution of 0.5570 nm. The measured SPD of the LED bulb was used to calculate the total luminous flux and colorimetric data e.g. color coordinates, correlated color temperature and color rendering indices.

The yellow fluorescent tube used in this study is the "TL-D 36W/16 yellow" from Philips. The tube was too large to be fixed inside the integrated sphere; hence it was not possible to measure the total flux. Instead the tube was mounted just outside the input port, to measure the SPD of the tube which was used to calculate the colorimetric values, such as the chromatic coordinates and color rendering indices of the tube.

To visually compare the color rendering of the LED bulb and the YFT tube, they were both

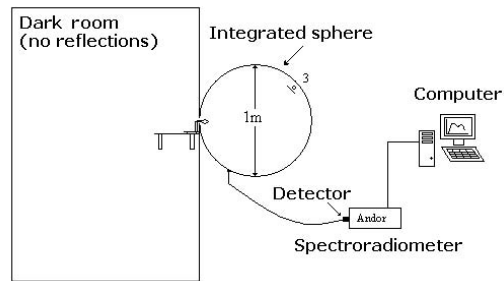


Fig. 4. The measurement setup; The LED bulb were located inside the darkroom, the spectra were collected by an integrated sphere and transferred to the spectrometer. The spectrometer used a 300 l/mm grating yielding a spectral measurement range from 270.6 nm to 838.7 nm, with a resolution of around 0.6 nm.

mounted above a color chart from Gretagmacbeth [21]. As reference source a normal 60 W incandescent light bulb was used. The three illumination sources were mounted in such a way that the illuminance level received at the charts from the three sources were the same. Pictures of the color chart illuminated by each light source, were taken using a Nikon camera mounted on a tripod 1 m away from the color chart, they can be seen in figure 10. A picture of the Gretagmacbeth chart can be seen in figure 5. This chart is computer animated to give as clear color representations as possible.



Fig. 5. A simulated "ColorChecker" chart from Gretagmacbeth, typically used when comparing different illumination sources with each other. [22]

4. Results and discussion

The results of the SPD measurements and the calculation of the colorimetric properties for the LED bulb and the YFT are presented in the following. Furthermore, the results of the Gretagmacbeth charts for the two light sources are presented and compared to the reference light source.

4.1. SPD Measurements

4.1.1. LED bulb

The SPD of the LED bulb was measured at a steady state and is shown in figure 6. The bulb has a continuous spectrum ranging from around 440 nm to around 700 nm and has four main peaks

around 500 nm (turquoise), 600 nm (yellow), 620 nm (orange) and 650 nm (red). Because of the lower boundary in the spectrum of this bulb, it can be used as an ambient illumination source for photoresists where the maximum sensitivity wavelength is less than 440 nm.

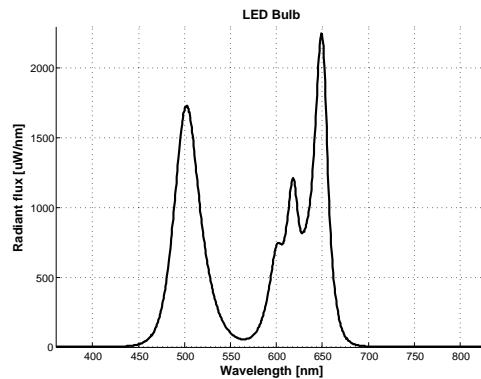


Fig. 6. The spectral power distribution of the LED bulb, measured at a steady state.

4.1.2. Yellow fluorescent tube

The SPD of the YFT is shown in figure 7 where it is seen that the majority of the energy is allocated in the yellow spectral range. The spectrum of the YFT was also measured at a steady state. The tube has two peaks. One sharp peak at 546 nm and one broad peak at 578 nm with a full width at half maximum of around 75 nm. The tubes spectrum is continuous and ranges from 500 nm to 700 nm.

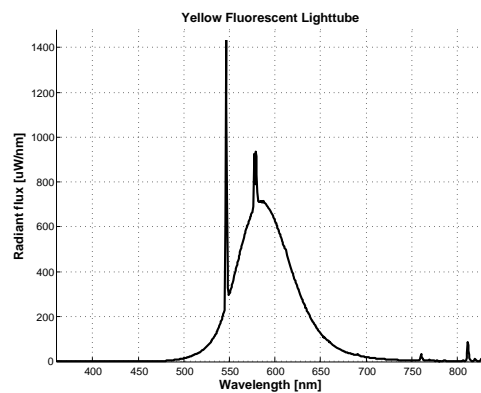


Fig. 7. The spectrum of the yellow fluorescent light tube, measured at a steady state.

4.1.3. Comparison

In order for a light source to be perceived as white, its chromatic coordinates must be very close to the planckian locus in the chromaticity diagram. Exactly how close can be discussed. In the uniform chromatic coordinate system it is said that, the distance between the chromatic coordinates of the light source and the planckian locus should be no more than 5.4×10^{-3} , also

called the chromatic deviation (DC) [18]. To give an idea of how close the two light sources lies to the planckian locus figure 8 shows their chromatic coordinates plotted in the uniform chromatic coordinate system. The LED bulb lies relatively close to the planckian locus (DC of 0.009) whereas the YFT lies at the periphery of the chromatic coordinate system (DC of 0.0186). Both light sources are too far away from the planckian locus to be perceived as white. For the LED bulb this can be corrected by modifying the SPD of the bulb, for instance by inserting some more yellow/orange/red colors or by removing some green.

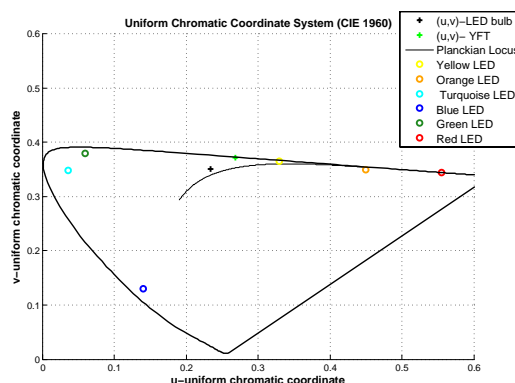


Fig. 8. The CIE 1960 (u,v)-uniform chromatic coordinate system including the uniform chromatic coordinates of the LED bulb, the yellow fluorescent light tube, the planckian locus and some typical LED locations.

4.2. Colorimetry

The colorimetric properties of the light sources, i.e. the chromatic coordinates, uniform chromatic coordinates, correlated color temperature (CCT), color rendering index (CRI) and the luminous flux was calculated and is shown in table 2, together with the radiant flux of the LED bulb. The method used to calculate these properties can be found in [17, 18].

As mentioned earlier the radiant and luminous flux of the YFT could not be calculated, since it was not possible to measure the total SPD of the tube.

Table 2. The colorimetric values of the LED bulb and the yellow fluorescent light tube.

	LED Bulb	YFT
(x,y)-chromatic coordinates	(0.4219, 0.4209)	(0.5174, 0.4780)
(u,v)-uniform chromatic coordinates	(0.2342, 0.3504)	(0.2687, 0.3724)
DC	0.0092	0.0186
Correlated color temperature (CCT)	3400	2490
Color rendering index (CRI)	12.7	29.8
Luminous flux [lm]	36.6	-
Radiant flux [mW]	150	-

Generally a light source should have a CRI of at least 70-90, in order to be used for general illumination. The table shows that neither the LED bulb or the YFT have a CRI close to that both of them would be classified as light sources unsuitable for general illumination. The low CRI is exactly what was expected, since neither of them were designed with a high CRI in mind. Both light sources were designed not to have any light below a certain wavelength and

thus the color rendering index would be very low. The specific color rendering indices for a normal incandescent light bulb, the LED bulb and for the yellow fluorescent light tube can be seen in figure 9.

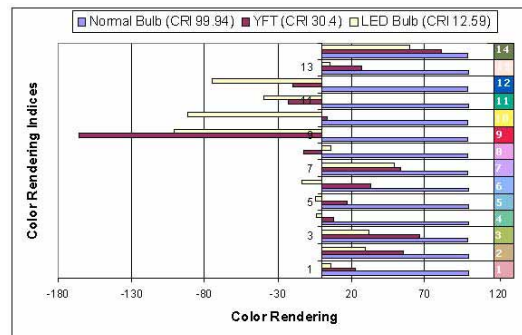


Fig. 9. The color rendering for the 14 different Color rendering indices used when calculating the color rendering index, for a normal incandescent light bulb (CRI 99.9), the YFT (CRI 30.4) and the LED bulb (CRI 12.59).

The figure shows how "well" the different illumination sources render the eight test colors used in the calculation of the general color rendering index, together with the six supplemental test colors compared to a reference source (an incandescent light bulb). As seen in the figure the YFT has higher color rendering than the LED bulb in all but two of the test color samples (8 and 9). Furthermore the general color rendering is higher for the YFT than that of the LED bulb. This could lead to the conclusion that the YFT would be better to render colors than the LED bulb would. This is not the case though, as will be discussed in the next section. CRI can be a bit misleading; a higher CRI does not necessarily lead to a better color rendering. For none white light sources, like the YFT, CRI does not give that much information being that CRI is reserved to describe the color rendering of white light sources. Instead the Gretagmacbeth color charts can be used to visually compare the two.

4.3. Gretagmacbeth color charts

An alternative way to compare the two light sources is by using the Gretagmacbeth color charts. This gives a more visual approach to see the difference between the two solutions by looking directly at their color rendition of certain physical colors. The color charts can be seen in figure 10.

To easier identify and compare the colors in the chart they have been numbered from top left to bottom right. By comparing the chart of the YFT, figure 10b, with the one from the incandescent bulb, figure 10a, it is seen that there is a huge difference between the way the colors are rendered by the two. It is seen that the tube have a major problem presenting any of the blue colors (3, 8, 13, 18) they are just squares with different shades of gray. When looking at the spectrum for the YFT in figure 7, it is seen that the tube does not emit any light in the lower range of the visible spectrum, so it is expected that the tube cannot render any blue colors. The white square (19) and two of the gray squares (20, 21) looks very yellow, actually there is almost no difference between the white square (19) and the yellow square (16). When looking at the color chart for the YFT it is like looking through a yellow piece of glass or a pair of yellow-sunshades, every color has a yellowish hue.

When looking at the color chart for the LED bulb, figure 10c, and comparing it with the one from the incandescent bulb, figure 10a, it is seen that the LED bulb render the majority of the

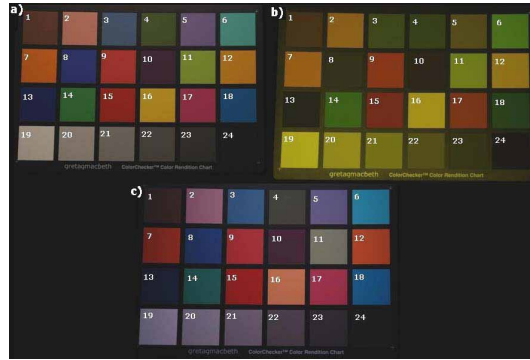


Fig. 10. Photographs of the Gretagmaboth color rendition chart illuminated by a) an incandescent light bulb, b) the yellow fluorescent light tube and c) the LED bulb.

colors fairly well. Some of the blue colors gets a bit more turquoise than blue (4 and 6) and the dark green square becomes brown (5). Furthermore the "light" orange square (12) becomes a darker shade of orange when illuminated by the LED bulb compared with the incandescent light bulb. Beside these, the rest is rendered fairly well. It should be mentioned, though, that the use of the color renditions chart from Gretagmaboth is a very subjective method; other people might have another opinion than the one given here by the authors. It is also important to note that color is, to some extent a very subjective quantity and that the transition between the difference colors is continuous [17]. The two main reasons that the LED bulb is better to render colors than the YFT is that its SPD is broader and that its uniform chromatic coordinates is located closer to the planckian locus.

In order to show that the LED bulb does not affect the photoresist, it was brought into a photolithography room and was used to expose Si wafers.



Fig. 11. A microscope image of a fraction of the patterns used on the mask.

Our home-made setup consists of a 4" inch Si wafer, a 5 inch quartz mask, and the LED bulb. On the wafer a $2\ \mu\text{m}$ thick photoresist of the type SU8-2005 was spun. A quartz mask, a fraction of the patterns shown in figure 11, was placed very closely on top of the Si wafer. The LED bulb was placed 10 cm above the mask. It was positioned so that the light was directed toward the top surface of the wafer, through the mask. This setup was placed inside a black tube in order to ensure that no outside sources could influence the experiment and that the LED bulb

could not affect other people's work. A couple of wafers coated with resist were prepared for different illumination time (24, 72 and 168 hours) test. After each illumination period, the Si wafer was baked and developed in a SU8 developer for 2 minutes. Afterwards, each Si wafer was examined using a microscope. The examinations showed that no patterns appeared on the photoresist even after 168 hours illumination, which means that the resist was not affected by the LED bulb.

4.4. Cost comparison

In the following the cost of the LED solution is compared with the current YFT solution. Given that the LED solution is a prototype it is not possible to get a purchasing price for the LED bulb. Instead their luminous efficacy is compared. According to the datasheet for the YFT, it has a luminous flux of 1580 lm and a energy usage of 36 W. Due to the fact that that the tube has a 360 degrees emission angle,, some of the light is lost due to reflections in its socket, under the assumption that this loss is 30 %, the luminous efficacy of the YFT is $1580 \text{ lm} / 36 \text{ W} * 0,7 = 30,7 \text{ lm} / \text{W}$. In comparison the LED bulb has a luminous efficacy of $36,6 \text{ lm} / 1,6 \text{ W} = 22,8 \text{ lm} / \text{W}$. The calculations show that the energy efficacy of the YFT is better than the one of the LED bulb. However, the LED bulb was not designed with high energy efficiency in mind; first and foremost it was designed not to emit any light below a certain wavelength and to emit white light. There are more energy efficient LEDs on the market today than the ones used in this design.

Another application for the bulb could be to use it as a general illumination source for people suffering from a very rare skin disease called Porphyria. People suffering from Porphyria cannot tolerate light in the lower range of the visible spectrum, meaning that they cannot use normal incandescent light bulbs or fluorescent tubes as a light source. This bulb would be an excellent choice as an illumination source for people suffering from this disease [23].

5. Conclusion

The goal of this work was to examine whether or not it was possible to create a LED-based white light source, which can be used in photolithography rooms. It was shown that this could be achieved. The conventional colorimetry calculations, such as the chromatic coordinates, CCT, DC and CRI, showed that both the YFT and the LED-bulb had a low CRI implying that both of them would be poor at rendering colors. By using Gretagmacbeth color charts, it was demonstrated that the LED prototype gave a better color rendition than the YFT. The chart showed that the LED bulb rendered the majority of the colors in the chart fairly well. The reason for this is that the LED bulb's SPD is broader and its uniform chromatic coordinates is located closer to the planckian locus than the YFT's. Although the LED bulb was not exactly white, in the sense that it was not located close enough to the planckian locus, this could be improved by changing the spectral distribution of the LED bulb (i.e. change the LEDs composition). The lower boundary of the prototype is around 440 nm, thus it can be used as an illumination source for the majority of the different photoresist that is on the market today. The bulb was used to expose the photoresist SU8-2005 for 24, 72 and 168 hours in the Danchip cleanroom of DTU and it was shown that it did not affect the photoresist in any way.

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