AUTOMATION IN ELECTRONIC ASSEMBLY

Flexible Lighting Module for Advanced Substrate Imaging

Among the most essential components of today's advanced automated assembly equipment is machine vision. Machine vision is used for substrate recognition, component centering and inspection, and machine setup procedures. The primary task of machine vision is to distinguish features of interest from the background. This central task is made easier if the input image has a high degree of contrast. Of the individual parts that make up a machine's vision system, the lighting system has the most influence on image contrast.

Automated assembly systems must handle a variety of substrates, each with unique imaging properties. To handle the variety of substrates being used today, lighting systems must be versatile. Substrate types include FR4, flexible circuits, and ceramics of various colors and shades. This variety of substrates can challenge a relatively simple, monochromatic (single color) lighting system. To overcome this challenge, manufacturers should consider flexible lighting modules.

Features of a flexible lighting module

A flexible lighting module should address:

- Illumination wavelength
- Polarization
- Illumination angle, intensity, and symmetry

Each of these parameters is crucial for effective imaging.

Illumination wavelength

Each substrate type has unique optical properties. Two of the key parameters that describe the optical properties of a substrate are reflectivity and transmission. The values of these parameters are not constant: they change as a function of wavelength. In general, a monochromatic lighting module is not well suited for providing high-contrast images over a variety of substrate types. Wavelength flexibility allows the user to "tune" the properties of the lighting module to maximize image contrast.

Polarization

Polarized lighting is a very important tool in the imaging of certain substrates. Light-colored ceramic substrates tend to challenge machine vision systems due to the similar reflectivity of metal features and the bright background. For this important class of substrates, polarized illumination can be used as an effective "wedge" to distinguish features from the background.

Illumination angle, intensity, and symmetry

Substrate features have differing reflective properties. Therefore, it is important to have the flexibility to control the intensity of the incident light. Excessive light can lead to camera "blooming"; insufficient light results in poor image contrast. The angle of the incident light is also important. The character of the surface features may require either low or high-angle illumination. Finally, symmetric illumination is important in order to eliminate spatial distortion of substrate features.

A flexible module design

One such flexible lighting module* consists of a support structure that holds eight light-emitting diode (LED) petals and an inner LED ring. The petals are used for low-angle illumination, while the inner ring is user for higher-angle illumination. Each petal is a small printed circuit board containing 10 LEDs. The petals can contain LEDs of various wavelengths ranging from blue to red. Both the petals and the inner ring can be exchanged in a "plug-and-play" fashion. Petals are currently available in red (~660 nm), yellow (~595 nm), green (~525 nm), red/green, blue (~470 nm), and white. The design allows the illumination wavelengths of the module to be quickly and easily changed. In addition, the module can be equipped with a polarizer kit to extend its illumination capabilities.

The module is mounted to the housing that contains the substrate-imaging camera.

A schematic diagram of the lighting module is given in *Figure 1.*

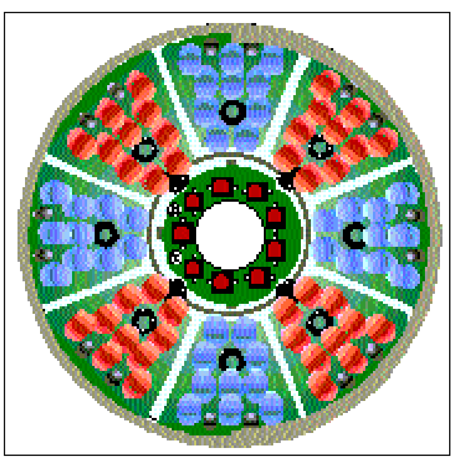

Figure 1a

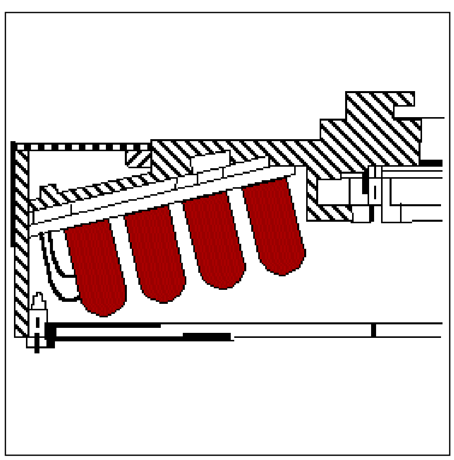

Figure 1b

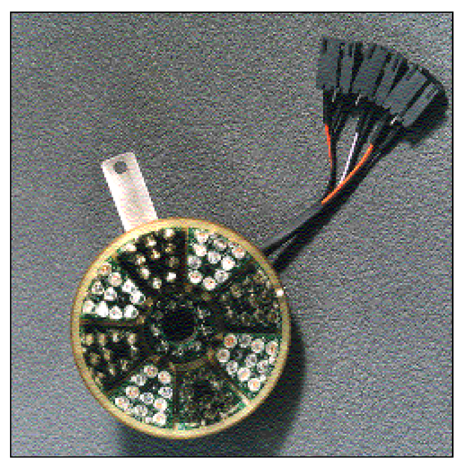

Figure 1c

Figure 1 - Schematic diagram of the illumination module. (a) View upward from the substrate showing the eight petals and the inner ring. The petals and the inner ring are replaceable in a "plug-and-play" manner. (b) Cross-sectional side view shows the angle of the petals. The angle was chosen to optimize the focus of the light on the substrate. (c) Photograph of the module. A polarizing film is mounted over four of the LED petals.

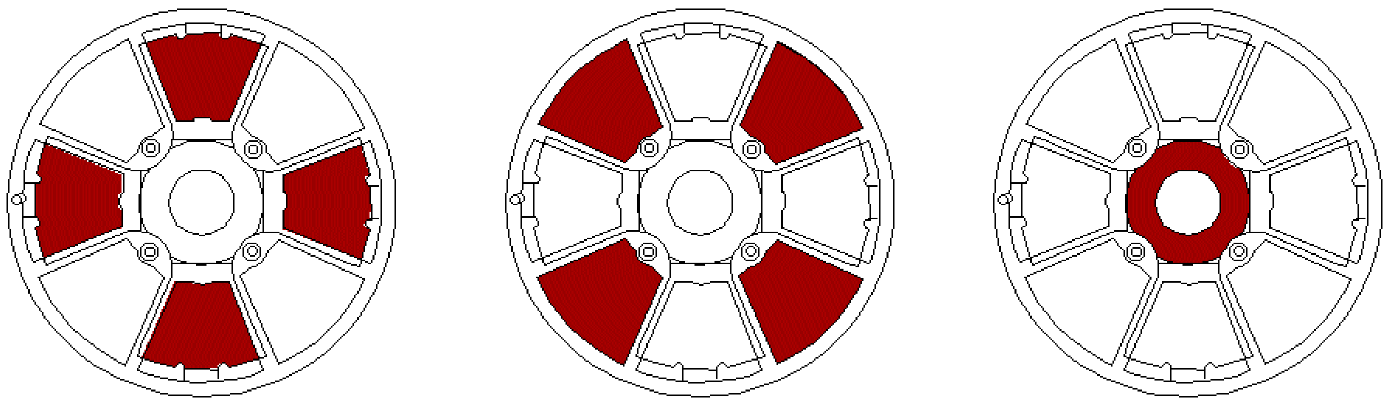

Figure 2 - Lighting zones of the module. An enclosed electrical bus situated in the rear of the housing provides voltage to all of the lighting elements.

The module has three lighting zones: Petal Zone I, Petal Zone II, and the Inner Ring. See *Figure 2*.

The following sections present imaging studies on two very different substrate types. The first study is with flexible circuits; the second involves ceramics. Although the substrates are different, both studies have a common theme: the key to effective substrate imaging is understanding the optical properties of the substrate and altering lighting parameters to leverage these properties.

Case Study I: Flexible Circuits

Flexible circuits typically consist of polyimide layers mounted on a metal stiffener. The polyimide layers contain copper or gold conductive traces that terminate at an IC pad site.

Flexible circuits present a significant imaging challenge to many machine vision systems.

To effectively image flexible circuits, one must gain an understanding of the optical properties of the constituent material, polyimide.

DuPont Corporation, a major manufacturer of flexible circuit material, assisted in this portion of the study. The following graph, based on experiments conducted at DuPont, plots the transmission of polyimide for wavelengths throughout the visible spectrum. To generate this plot, light of various wavelengths was directed through a thin film of polyimide. The transmitted light intensity was measured and compared to the incident intensity. *See Figure 3.*

The data shows that polyimide is almost transparent (transmission ≥80%) for wavelengths in the red portion of the spectrum (wavelength ~ 650 nm). Further, there is a dramatic reduction of the transmission in the 450 - 550 nm range. For wavelengths in the blue portion of the spectrum (wavelength ≤475 nm), polyimide is virtually opaque. This fact was used as a wedge to distinguish metal fiducials from the polyimide background of flexible circuits.

The following two images of a flex circuit pad site demonstrate this effect:

In the image of *Figure 4a*, obtained with a conventional monochromatic (~660 nm) lighting system, the metal traces of the pad site are virtually indistinguishable from the surrounding polyimide. This is because polyimide is very transmissive to the red light of the illumination module. In the background areas surrounding the metal traces and fiducials, the red light is transmitted through the polyimide and reflects from the metal backing of the circuit. This results in a bright background. The copper features on the substrate also reflect the red light efficiently. The result is a bright feature on a bright background - a low contrast image.

The image in *Figure 4b* was obtained with the new illumination module equipped with blue LEDs (~470 nm). Since polyimide strongly absorbs in the blue portion of the spectrum, the previously bright background is now dark. The copper features on the substrate reflect the blue

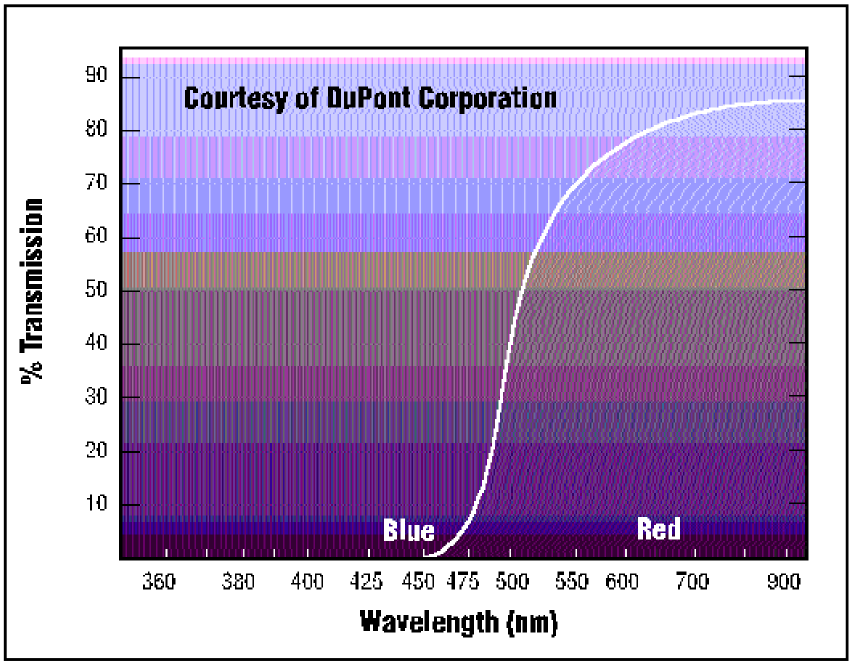

Figure 3 - Plot of the transmission of polyimide. The plot shows the drastic change in transmission from blue light (~450 nm) to red light (~650 nm).

light efficiently. The result is a dramatic improvement in image quality.

To quantify the improvement in image contrast, line scans were taken through a metal fiducial on the pad site. The line scans, displayed in the lower right corner of each image, plot pixel intensity versus pixel location across the fiducial site. The line scan in *Figure 4a* shows extremely poor contrast and little edge structure. In short, this is an unworkable image. The situation is reversed in *Figure 4b*. The line scan in *Figure 4b* shows excellent contrast and a marked reduction in the background.

In this case study, dramatic improvements in image contrast were made possible by understanding the transmission of the substrate and adjusting the lighting solution to take advantage of it.

Case Study II: Ceramic Substrates

Ceramic substrates are manufactured in a variety of shades and colors. This variability, coupled with different pad metallurgy, makes ceramic substrate imaging challenging. To make matters more complex, several component manufacturers using flip chip technology choose to image the pad site through a pre-applied film of flux. White or gray ceramics are particularly challenging because the metal pads and the ceramic background both reflect light efficiently. This makes it difficult for the vision system to distinguish the pads/fiducials from the background. A "wedge" is needed to distinguish the features. In the case of the polyimide of flexible circuits, the wedge was illumination wavelength. With light colored ceramic substrates, the wedge is polarized light.

The reason why polarized light is effective on this class of substrates is that metals and dielectrics reflect polarized light differently.

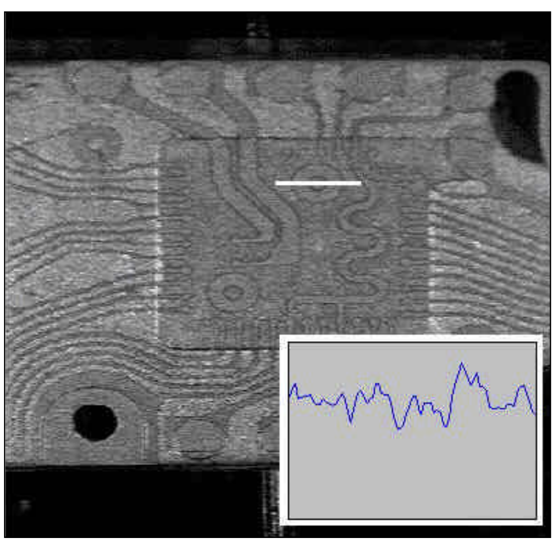

Figure 4a

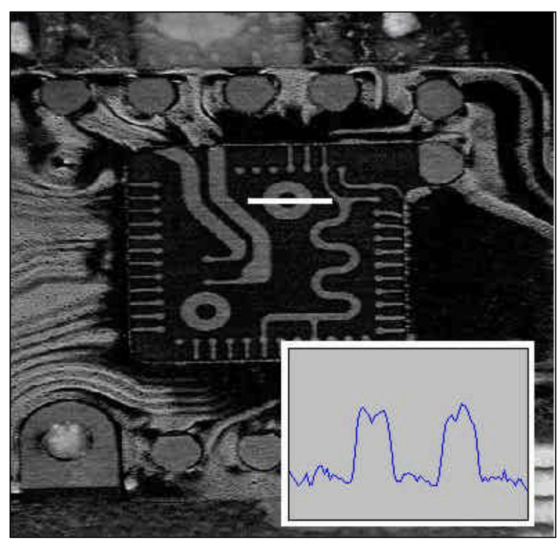

Figure 4b

Figure 4 - Images of a polyimide-based flexible circuit. (a) Image taken with a conventional monochromatic lighting system equipped with red (660 nm) LEDs. (b) Image of the same pad site taken with the new lighting module equipped with blue (470 nm) LEDs. In each image there are line scans plotting pixel intensity versus pixel location across the fiducial on the circuit. Circuits courtesy of ADFlex Solutions, Inc.

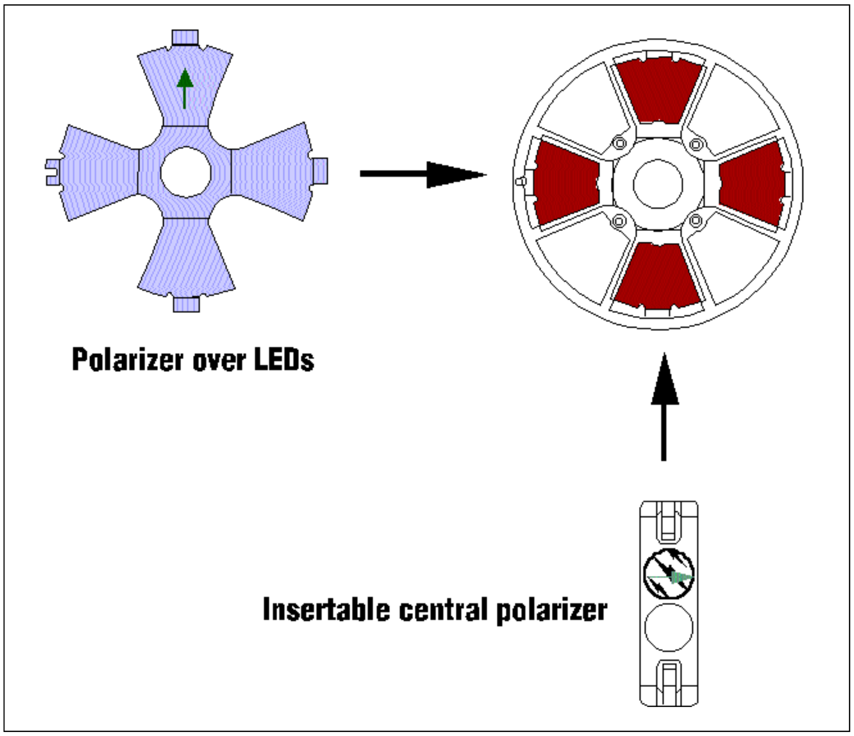

Figure 5 - Polarizing kit for the lighting module. A polarizing film covers four of the LED petals. A central polarizer can be inserted in the camera aperature. The polarizing films are oriented orthoganal to each other. This technique is called cross-polarized illumination.

When linear polarized light strikes a metal surface, the light is reflected with no net rotation of the polarization. This is the case since metals consist of free electrons. When polarized light interacts with the “sea” of free electrons in a metal, the electrons oscillate in the electric field of the light and re-radiate the light with no net change in the polarization orientation. This is not the case with the dielectric ceramic background that surrounds the feature of interest. Upon reflection, dielectrics tend to randomize the polarization of the light.

This behavior can be capitalized on by installing a polarizing kit on the lighting module and using a technique called cross-polarized illumination. *Figure 5* illustrates the polarization kit of the module:

The kit consists of two elements: a polarizing film that covers four of the eight illumination petals, and a metal slide that contains a second polarizer. The second polarizer is located in the camera aperture. The axis of this polarizer, frequently referred to as the “analyzer”, is orthogonal to that of the polarizer covering the LEDs. The combination of these polarizers on the module results in what is known as cross-polarized illumination.

The polarizer covering the LEDs ensures that the substrate is illuminated with linear polarized light. Recall that the metal features and ceramic background reflect polarized light differently. The light reflected from the metal has no net change in the polarization. Since the orientation of the polarizer located in the camera aperture is orthogonal to that of the LED polarizer, most of

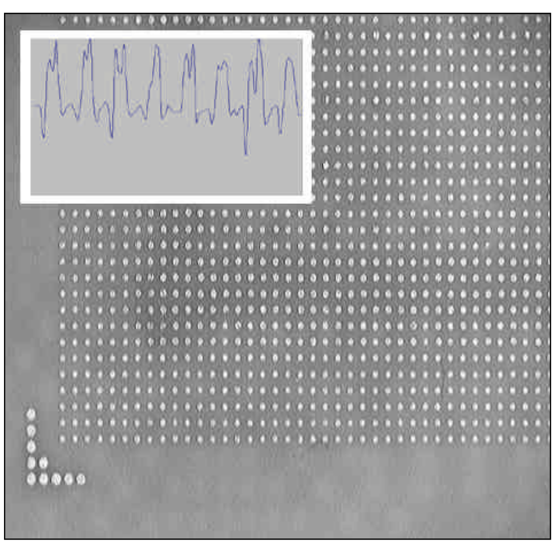

Figure 6a

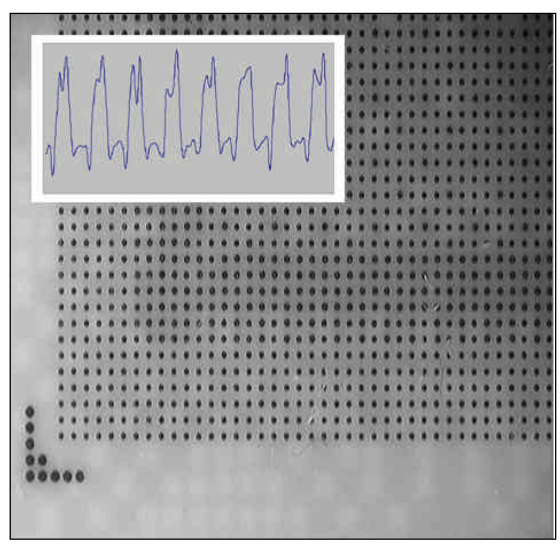

Figure 6b

Figure 6 - Images of a ceramic substrate for flip chip assembly. (a) Image obtained with unpolarized illumination. Note the bright metal features on a light background. (b) Image obtained with cross-polarized illumination. Metal features appear black on a gray background. Line scans taken through the same region of both images show markedly improved contrast with cross-polarized illumination.

the light reflected from metal features is blocked. Therefore, metal features appear dark on the camera.

In contrast, the ceramic surrounding the metal features randomizes the polarization upon reflection. Since the polarization is randomized, a portion of the reflected light can pass through the central polarizer and reach the camera. Therefore, the ceramic background appears as a shade of gray.

The following table summarizes the polarization effects on metals and dielectrics:

	Incident Polarization	Reflected Polarization	Central Polarizer Orientation	Intensity at Camera
Metal	↕	↕	↔	■
Ceramic	↕	✷	↔	▒

The images in *Figure 6* illustrate the effect of cross-polarization:

The image on the left was taken with unpolarized illumination. The flip chip pad appears as a bright feature on a light background. A line scan taken across a portion of a row shows a high noise level. The image on the right was taken with cross-polarized illumination. The metal features appear dark on a relatively light background. Line scans taken across the equivalent portion of the image show a 2x increase in contrast with cross-polarized illumination.

Conclusions

Manufacturers requiring advanced substrate imaging should consider utilizing flexible lighting modules on their assembly equipment. In evaluating lighting modules, one should seek a module that offers flexibility in illumination wavelength, polarization, and angle. It should be effective on flexible circuits and ceramics, two substrate technologies that have traditionally been challenging for machine vision systems. Although only these two substrate types were highlighted in this article, the module should also be capable of imaging a variety of other substrates. In short, the module should provide the tools to allow a much more systematic approach to substrate imaging.

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* *The module referenced in this article is the UniversaLight™ illumination module from Universal Instruments Corporation.*