Choose the Right Lighting for Inspection

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Choosing the proper lighting for an inspection system may look like a black art because many people rely on guesswork. They point lights at a product and try to determine whether or not the lighting is adequate. There is a better approach. You can take some of the “mystery” out of selecting the right lighting by taking time to learn about the available methods. One thing you need to know is how the different forms of lighting interact with different surfaces. You also need to learn about the different forms of light and lighting techniques.

When you design lighting for an inspection system (usually a camera and a computer) you must consider what the inspection system should do—look for a defect in a part, measure a part's dimensions, or just determine the presence or absence of a feature. Then, you must think of the optical components that make up the inspection system.

You may not think of it as such, but the part you want to inspect is an optical component because it reflects or scatters light and helps form an image in the camera. In fact, it is the most important optical component because it has the greatest effect on the light in your inspection system. So, you must take into account a part's optical properties such as its surface reflectance, its geometry, and even its color so you can devise lighting that works properly.

Start at the Surface

The surfaces on your product have optical properties that fall into one of three general reflectance categories: specular, diffuse, or directional (Fig. 1). The individual components in your product often incorporate several surface types, so you should understand how light interacts with them:

Specular surfaces are mirrorlike—smooth and highly polished. They reflect light at an angle equal and opposite to the incident angle.

Diffuse surfaces are rough and have a dull luster, so they scatter light in all directions, an effect called diffuse reflectance.

Directionally reflective surfaces typically contain fine grooves that reflect light generally in a preferred direction depending on the incidence angle.

In addition to a part's reflective properties, you must also consider the surface's geometry and whether it is flat, curved, or prismatic. A flat surface is self-explanatory, and achieving uniform illumination across it is typically easier than other geometries. The changing slope of a curved part can often pose a lighting problem that manifests itself as uneven illumination across the part. If the curved surface is specular or directionally reflective, glinting can occur, too.
Prismatic parts contain sharp edges or steep slopes, and such parts can be difficult to illuminate because lighting can produce shadows or glints. Assemblies with prismatic characteristics include PCBs with ICs mounted on them.

Along with reflectivity and the shape of a part, you must also pay attention to a part’s color. Contrasting colors may help your inspection system distinguish parts from backgrounds. If contrast differences are small, you can use color filters or selective-wavelength illumination to enhance the contrast for your inspection system.

Figure 1. Three surface types predominate in electronic products, but most products’ surfaces are some combination of two or all three.

Select Areas to Light

As you work with the part or assembly you want to inspect, you'll have to think about the size of the area that requires illumination. For example, on a large PCB you may need to inspect only a few components, so only a small part of the PCB needs light. At first you might have thought about using a powerful (and expensive) flood lamp to light the entire PCB. A small quartz-halogen or fiber-optic light source, however, may suffice to illuminate a small area. If you must inspect a large PCB, sometimes it can be difficult to evenly illuminate the entire board even when using high-intensity light sources.

After you've considered the different effects of surfaces and the size of the area you want to illuminate, you'll have to choose from different sources of light (see "Choose a Light Type," at the end of this article). And, you'll have to select the lighting technique or techniques that will illuminate your product properly. For the most part, inspection systems rely on front, back, dark-field, and light-field illumination techniques.

Front illumination involves placing a light source and a camera on the same side of a product to provide overall illumination. The position of the light source can vary depending on what you want to
inspect (Fig. 2a). You can also position a light source to provide front illumination from only one direction. At a high angle, such directional lighting lets an inspection system measure shadows and calculate the heights of components. Placing a light source nearly perpendicular to a camera provides oblique illumination (Fig. 2b). Use this technique to find surface irregularities such as burrs.

\textit{Coaxial illumination}, another form of front lighting, directs light down a camera’s line of sight (Fig. 2c). Employ this lighting technique to shine light directly into a hole or a small subassembly. Because this technique provides uniform illumination across your field of view, it can reduce shadows and some glinting.

Light can also illuminate a product from behind. Back lighting is often ideal for making dimensional measurements or checking for the presence or absence of components (Fig. 2d). Back lighting a translucent PCB lets you locate components and find holes unoccupied by a lead or solder. A variation of back lighting uses collimated light to produce images with sharp edges, even for curved surfaces such as those on a cylinder or ball (Fig. 2e).

**Figure 2.** You can choose from six types of lighting techniques to best illuminate the product you want to inspect. Some inspection systems may use a combination of the techniques above.

Both dark-field and light-field illumination techniques provide high-contrast images that can highlight specific components or defects. Dark-field illumination directs most reflected light away from a camera so surface variations or features appear brightly on a dark background field (Fig. 3a).

Under light-field illumination, defects or components appear as dark features on an otherwise bright image (Fig. 3b). You can use either front lighting or back lighting to produce dark-field or light-field images for your camera. Typically, inspection systems use back lighting to highlight cracks,
Particles, and air bubbles in translucent or transparent parts.

![Figure 3](image)

**Figure 3.** Both dark-field and light-field lighting provide high-contrast images that let you quickly detect defects or areas of interest.

**Put Lighting to Work**

Now that you better understand the choices of lighting and lighting techniques available to you, three brief examples will show you how to put lighting techniques into practice.

**Inspect**

**Printed Information**

**Problem:** Your manufacturing process prints white characters on black plastic cases that will enclose small circuit modules. You must inspect the printing to be sure it is properly positioned and undamaged.

**Solution:** The black plastic provides a dull opaque surface, so there is already a high contrast between the black plastic and the white ink. Two lighting techniques will properly illuminate the cases so you can inspect the printing. First, you can use a circular fluorescent ring light ([Fig. 4a](image)) that produces uniform diffuse front illumination. You could also use polarized lighting from a fiber light guide ([Fig. 4b](image)). The polarized light helps reduce any small bright glints on a case’s surface. In this example, the light simply maintains an already high-contrast image across the part’s entire surface.
**Read Etched Data**

**Problem**: Your inspection system must accurately read characters that have been etched into the surface of a silicon wafer.

**Solution**: Under normal lighting conditions, the characters are almost indistinguishable from the wafer’s highly polished metallic surface. The wafer has a specular and opaque metallic surface. The two best solutions require light-field or dark-field illumination. Both techniques take advantage of the disruptions caused by the characters on the specular flat surface of the wafer. The characters appear bright on a dark background under dark-field illumination or dark against a bright background under light-field illumination.

Collimating the light from a red LED produces light-field illumination (Fig. 5a). Or, you can use two rectangular banks of LEDs to provide the illumination for dark-field images (Fig. 5b).
Monitor Solder Deposition

**Problem:** You must inspect through-hole PCBs for solder defects such as missing material, unfilled holes, and solder bridges.

**Solution:** Keep in mind that the PCB is a complex "optical component." And surfaces on the board include flat, prismatic, and mixed. Solder joints, on the other hand, range from smooth, domelike structures to sharp cones. The solder joints are bright gray, but the PCB is a dark green with white silk-screened legends printed on it. The PCB's surface is highly specular and opaque, and objects can appear bright or dark, depending upon the angle of incident light.

This application requires that the inspection system acquire two images, each of which has its own lighting requirements (Fig. 6). Because the solder joints have various shapes, diffuse illumination will best light them. When you illuminate the PCB with diffuse light, the inspection system acquires an image that lets it detect empty holes and missing solder.

*Figure 6. A combination of diffuse light and directional polarized light produced in the same housing lets a camera obtain two images of a PCB. The inspection system combines images to extract useful information.*

Next, you should illuminate the PCB with directional polarized light that enhances the silk-screened legends and blocks specular reflections from the solder. The inspection system can then acquire a second image and subtract it from the first. The image processing effectively "removes" or de-emphasizes silk-screened legends so the inspection system doesn't confuse them with solder bridges. In this example, the difference in reflectivity between the solder and the legends produces a high-contrast image.

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Choose a Light Type
Light can come from various types of sources, and knowing what light can do will help you select the best source for your inspection job. You should also know about the techniques you can use to light a product. The most popular light sources used for inspection are described below.

Fluorescent lamps provide a highly diffuse, cool, white source of light.

Halogen lamps furnish a high-intensity light source that has a broad spectrum. Halogen light sources may provide a fiber-optic cable that directs light to specific points for front and back lighting. Fiber-optic lamps can shape light into slits, rings, and other forms.

Light emitting diodes, or LEDs, supply monochromatic light that you can pulse or strobe.

Xenon lamps, or flash lamps, provide high-intensity sources that find use primarily when you have to momentarily "stop" a moving part or assembly.

Other Lighting Techniques
Lighting requires that you pay attention to various techniques:

Coherent illumination arises from a laser, and it finds use in applications that require intense monochromatic light for bar-code scanning, targeting, and aligning. Coherent light can have some disadvantages such as causing speckling and diffraction, and lasers have stringent safety requirements.

Diffuse illumination comes from multiple directions and provides uniform illumination across the field of view. You use it to illuminate reflective or shiny parts because it produces little, if any, glinting, and it reduces shadows. A fluorescent lamp is an example of a diffuse light source. Spheres and domes can also provide diffuse light.

Directional illumination comes from a localized source. Collimated light and light from lasers are highly directional because the light rays propagate parallel to one another. You can also obtain directional light from LEDs and fiber-optic sources. Directional lighting produces shadows that can help locate surface defects such as burrs or pits.

Polarized light helps reduce glints from shiny or highly reflective parts. In many inspection systems, glints result in "noise" in an image and make the image difficult to process.

Strobed illumination lets an inspection system "freeze" or stop the motion of a part so a camera can obtain an unblurred image of the part. Strobe lights can be monochromatic (LEDs) or white light (xenon), depending on your requirements.

Structured illumination finds use in inspection systems that need to obtain 3-D information about a part. A line of light, perhaps supplied by a laser, is an example of a structured light source.

Unpolarized illumination is typical of lighting found in offices or factories, and it is useful for lighting diffuse parts.

The types of lighting described above are not mutually exclusive. For example, you could use strobed directional light to detect pits on a production line of fast-moving PCBs.—Carl H. VanDommelen