

# Automatic Optical Inspection of Ceramic Thick Film, Thin Film Hybrids and LTCCs

Sabine Miksa, Stratus Vision GmbH, Lochhamer Schlag 17, 82166 Gräfelfing, Germany  
Tel. +49 (0)89-829989-0, Fax +49 (0)89-829989-99, sabine.miksa@stratusvision.com

## Abstract

*Automatic Optical Inspection (AOI) is becoming a very important aspect in the production of hybrids and LTCC. The substrate size of hybrids and LTCC is getting bigger and, at the same time, the structures of the layers and defect sizes are getting smaller. Therefore visual inspection is getting more and more time-consuming and unreliable.*

*Transmission, reflection and absorption of materials are dependent on the wavelength of the incoming light. Therefore different materials require different lighting solutions in order to highlight all defects.*

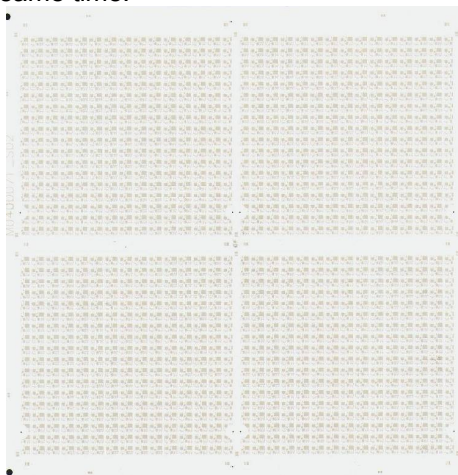
*The presented patented AOI technique uses multiple lighting solutions from UV to IR which can also be combined if needed to meet the requirements. But not only is the wavelength of the lighting critical, the structure of it is just as important. Inspection of highly reflective material like wet print needs a different approach than dry print. An extremely inhomogeneous reflective material like the polycrystalline silicon of solar cells requires a different structured light than a textured silicon surface.*

*A fast area-scan camera is used which acquires images on the fly reducing inspection time and keeping up with increasing production rates. Sophisticated image processing software delivers repeatable results and helps to find production errors.*

*This work presents various defects on different materials and their detection with a patented AOI technique which is reliable and highly flexible.*

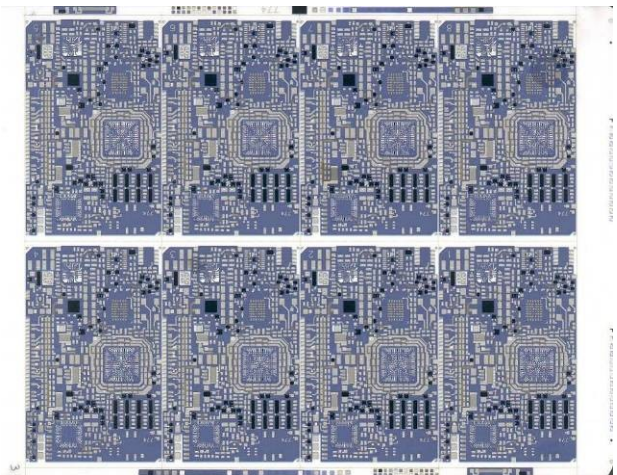
## 1. Motivation

Conductor prints of 50  $\mu\text{m}$  are already in production and smaller structures are in development and testing phase. Inspection by people with microscopes is not only unreliable, it is simply impossible with structures that small, or even smaller. Another aspect is the cycle time of modern screen printers. They can print a complex layer on a LTCC (Low Temperature Cofired Ceramic) with 220mm x 220mm within 3-5 seconds. There is no way that one person can inspect such a structure in the same time.



**Fig. 1: LTCC foil with fine print. Size: 220 mm x 220 mm**

To make things even more complex for human inspectors, modern hybrids in automotive electronics often have up to 40 layers, printed on top of each other.



**Fig. 2: Hybrid with 6x8 inch, 40 layers**

It is very important to have a defect-free layer # 36, before layer # 37 will be printed. If there is no inspection, then the entire production may have to be scrapped. The reject rate will be very high and the delay in production may have consequences with the customer.

The production of a hybrid requires as many cycles through the screen printer as layers need to be printed. Once the substrate (maybe 10.000 of them) has passed through the drying oven, nothing can be done anymore. They cannot be repaired, they have to be scrapped. Therefore the most important location for an AOI system is between the screen printer and the drying oven. This is called wet inspection.

## 2. Optical Background

The most important optical properties of materials are transmission, absorption and reflection. Each material has its own specific spectral abundance which results in the human colour impression. This section gives a short overview of the basics.

When a radiation beam of spectral radiance  $L_\lambda$  passes through a material, it is attenuated by extinction along the path  $\Delta s$  by the amount of  $\Delta L_\lambda$ . Extinction includes both scattering and absorption. The attenuation is proportional to the incoming spectral radiance  $L_\lambda$  (the wavelength and radiant flux of the illumination) and the path length (thickness of the layer)  $\Delta s$ . Extinction is also dependent on the type of the material. These properties can be described by a proportionality factor  $\mu_\lambda$ . Therefore the law can be expressed as

$$\Delta L_\lambda = -\mu_\lambda \cdot L_\lambda \cdot \Delta s$$

In integral form:

$$L_\lambda = L_{0,\lambda} \cdot e^{-\mu_\lambda \cdot s}$$

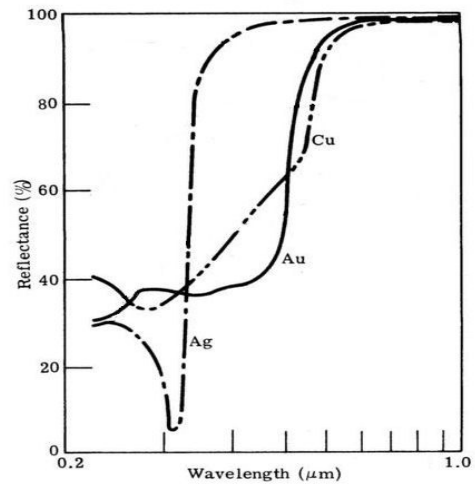
The term  $e^{-\mu_\lambda \cdot s}$  describes the transmission  $t_\lambda$  of a layer of thickness  $s$

$$t_\lambda = e^{-\mu_\lambda \cdot s}$$

The law of extinction is also called the Lambert or Lambert-Beer law.

The product  $\mu_\lambda \cdot s$  is called extinction or attenuation coefficient. It has the dimension 1/length.

The radiation that is not absorbed or transmitted is scattered back to the observer which results in the colour impression of the material. Some spectral curves of these wavelength dependent reflectances are shown in fig. 3.

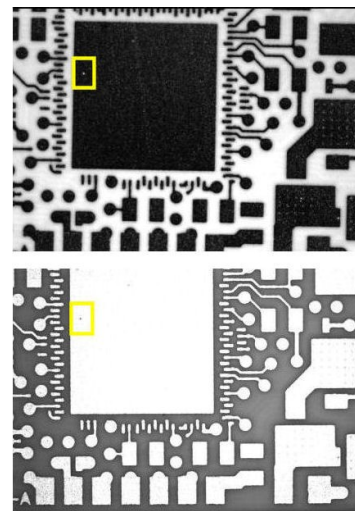


**Fig. 3: Reflectance spectra of some materials (gold, silver and copper).**

If we take a closer look at the reflection curve of gold in fig. 3 we see that up to a wavelength of 600 nm the reflectance is below 80%, for higher wavelengths the reflectance rises nearly up to 100%.

It is clear what happens when gold is illuminated with light of different wavelengths. If the colour of the light is blue (about 450nm) then more than 60% is absorbed and below 40% is reflected. This means we will get a dark image of the gold. If the colour of the light is IR (880nm) then nearly 100% is reflected and we will get a very bright image of gold.

The images in fig. 4 show that this is indeed the case.

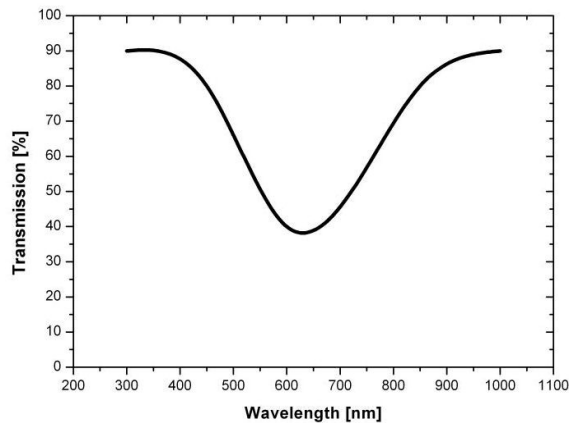


**Fig. 4: Example for wavelength dependency of reflectance on gold. In the upper image the illumination was blue light (450nm) and in the lower image IR (880nm).**

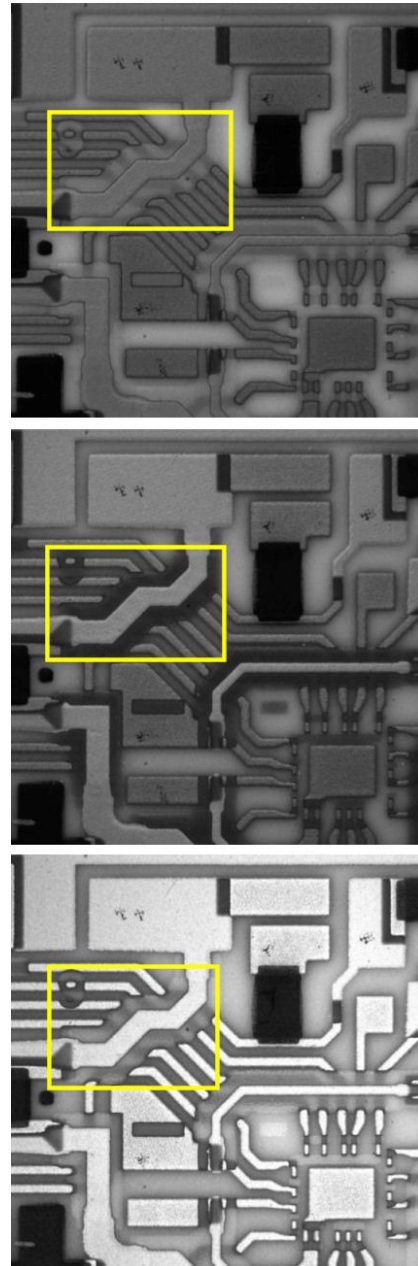
Sometimes not only scattering and absorption are important factors but also transmission. For

some materials the transmission at certain wavelengths is dominating.

Fig. 5 shows a spectral curve of a dielectric material. The transmission wasn't measured so it is only qualitative. The effect of this spectral abundance is shown in fig. 6. The dielectric layer is transparent in blue and IR illumination but it absorbs red light.



**Fig. 5: Transmission curve of a dielectric material. The material is absorbent in the red region of the visible spectrum and transparent everywhere else.**



**Fig. 6: The dielectric layer separating two conductor layers (yellow box) illuminated with different wavelengths. In the upper image, the part is illuminated with blue light (450nm) and the dielectric is transparent. In the image in the middle, the illumination is red light (600nm) and the dielectric is absorbing. The bottom image the dielectric is transparent again using IR illumination (880nm).**

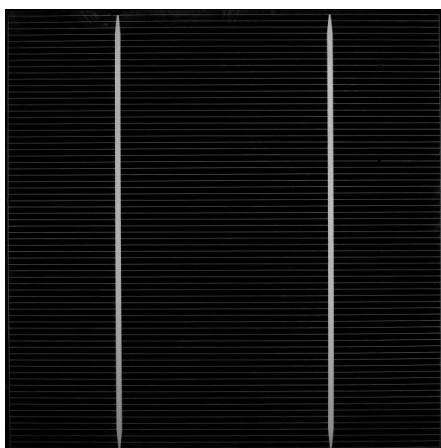
Therefore different illuminations in different wavelengths help to discriminate materials and defects on the inspected substrate. If structural differences have to be detected where the material of the defect is the same as the underlying material like dips and bumps, then different wavelengths are of no use. Both defect and surrounding material will look the same. Here a different light structure is needed.

Another problem arises if the inspected material is very inhomogeneous like polycrystalline solar cells (fig. 7).



**Fig. 7: If polycrystalline silicon is illuminated with direct light the grain boundaries are visible and dependent on the angle of the light the grains are highlighted.**

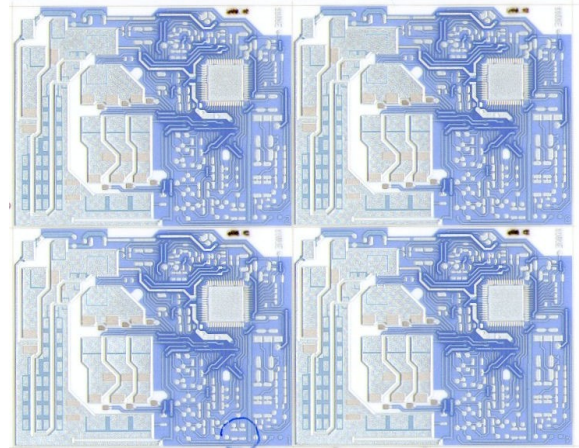
Here the light has to be very diffuse to suppress the reflective grains (fig. 8).



**Fig. 8: Image captured in diffuse light with a monochromatic camera. No grain reflections are visible. Any print defects would be clearly visible.**

### 3. Defect Detection

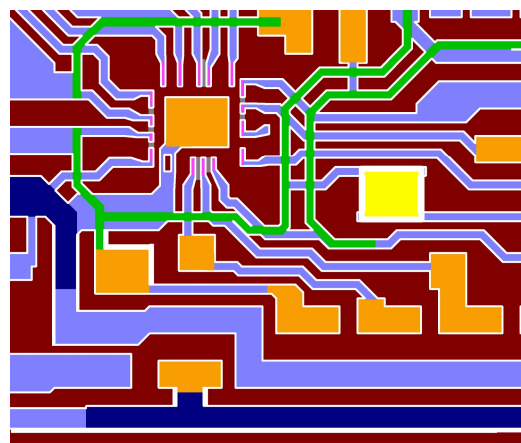
A modern AOI system can inspect all layers like conductor lines (silver palladium), dielectric, resistors, glass (overglaze), gold, adhesive, copper.



**Fig. 9: Typical hybrid product**

The AOI system will find all defects that are caused by screen (hole in mesh), screen shift, excess or missing paste, contamination, particles, running out paste, etc.

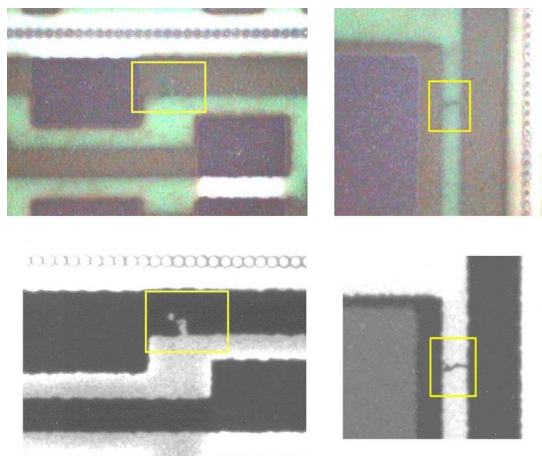
First the CAD data of the layer that will be inspected will be downloaded to the AOI system, which will automatically develop its own bitmap and practically makes a copy of the layer. Then the system will automatically develop a tolerance table, which means, it will apply to larger structures a different accuracy level (less accurate) than to smaller structures.



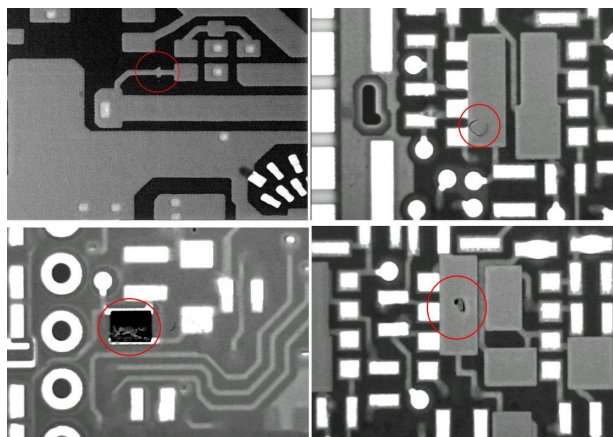
**Fig. 10: Example of tolerance settings for different areas in a product. Each colour illustrates a separate setting.**

The system will then use strobed colour LEDs for the exposure of the image in the 4 or 16 megapixel camera. The LEDs have a wavelength that is defined by the material that needs to be inspected and the defects that have to be found as described in the previous section. The wavelength can go from deep UV into the high IR. Sometimes polarization filters are used.

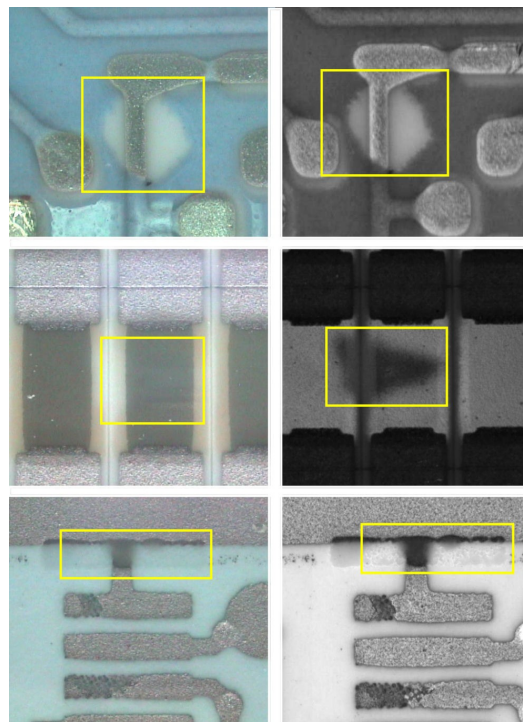
The following images show the importance of good illumination to see all defects.



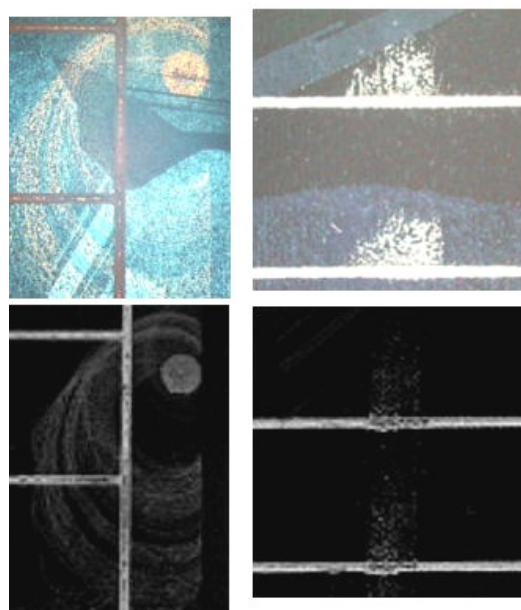
**Fig. 11: Printing defects. Upper row: microscope images, lower row: AOI**



**Fig. 12: Other typical defects on hybrids as seen with AOI: excess paste, particle, contamination, hole**



**Fig. 13: Defects in overglaze. Left column: microscope images, right column: AOI**



**Fig. 14: Defects on solar cells. Top row shows microscopic images, lower row AOI images. The illumination must suppress grain reflections in order to get a reliable and repeatable contrast for defects.**

By running fast across the substrate in a serpentine mode, the camera takes images and compares them to the CAD data. Any deviation will be found and detected. The size of the defects found depends on the pixel

size of the camera. The camera pixel size depends on the optics and is usually set between 5  $\mu\text{m}$  and 20  $\mu\text{m}$ .

In some projects two cameras are used and there are two reasons for doing that: For making the system faster and for inspecting the substrate with two different resolutions. Gold pads are usually inspected with higher accuracy than relatively wide conductor layers or dielectric layers.



**Fig. 15: AOI image head with two cameras**

#### **4. Conclusions and Outlook**

Illumination technique is the first step to reliably detect defects on ceramic thick film and thin film hybrids, LTCCs and solar cells. Sophisticated software is needed to help optimizing the production process.

Many Stratus Vision AOI systems are either inline systems, integrated into the production line with the screen printer. Other systems are automatic AOI lines where from four or more magazines, substrates are automatically loaded into the AOI system and then unloaded into magazines on the other side. Laser marking, inking or labelling is available upon request.

The cycle time of a substrate with 100 mm x 100 mm in size depends on the resolution of the camera optics but can be estimated around 3-5 seconds.

The AOI system works with high resolutions up to 2  $\mu\text{m}/\text{pixel}$  or 3  $\mu\text{m}/\text{pixel}$ , using fast CMOS cameras or big CCD cameras up to 16 Mega Pixels.

In future high intensity lights have to be developed to keep up with the speed of the camera and software.