

Contrast Measurement System for Laser Marks

Field of the Invention

This invention relates to a technique for testing laser marks, and more particularly to an optical technique for testing laser marks.

Background

The use of laser for integrated circuit (IC) marking has become very popular mainly due to its flexibility and speed. In comparison to ink marking, laser marking does not need any dispensable medium such as ink. However, one major disadvantage associated with laser marking is its reduction in contrast. Unlike ink marking where inks are printed onto the IC surface, laser marking operates by removing materials from the IC surface and hence creates a groove-like depression. Materials are being burnt away by the striking laser beam. The roughness of the laser marked surface is different from that of the unmarked surface. The contrast generated by laser marking is a result of these two factors: depression and roughness. Another factor that affects the contrast is the remnant of the burnt compound which has a different reflectivity from the original material.

As far as the external factor is concerned, the apparent contrast of the laser mark is very much dependent on the lighting and the viewing geometry. In other words, the direction of the incident light and the viewing direction determine how well the laser mark can be seen. Usually the depth of a laser mark is about few tens of microns and its roughness is rougher than that of the unmarked surface. In general, one would view the IC marking directly from the top. In this case, the lighting must be set to an oblique angle in order to highlight the contrast of the laser mark. If the lighting is cast from a direction more or less the same as the viewing direction, the laser mark can hardly be seen. The entire IC surface will be brightened up instead.

There have been many attempts to improve the contrast of the laser mark. For example, new molding compound which reacts to laser and produces a contrast between the unmarked and marked surface have been experimented. Another example is the use of different surface glazing material from that of the matrix compound. The laser beam removes the surface material and exposes the underlying matrix compound and hence produces a high contrast mark. However, all these attempts have not been able to fully commercialize due to factors such as cost, etc.

Descriptions of the accompanied drawings

- Figure 1 A cross-sectional view of a laser marked surface.
- Figure 2 A surface reflection model which consists of three components: diffuse lobe, specular lobe and specular highlight.
- Figure 3A Laser mark contrast measurement system configuration.
- Figure 3B Embodiment of a laser mark contrast measurement system according to the present invention.
- Figure 4 A typical image acquisition system flow.
- Figure 5 A laser mark character "B".
- Figure 6 An image of the ANSI traceable KODAK "Gray Scale Card".

Summary

In one aspect, the present invention provides a method and a system for testing laser marks in a manner which reduces the need for subjective judgment.

In an embodiment, a method of testing a laser mark applied to a surface of a semiconductor device includes the steps: illuminating the laser mark to be tested and the adjacent unmarked surface of the semiconductor device; determining the intensity

of light reflected from a portion of the laser mark (I_M); and evaluating the determined intensity value to assess the acceptability or otherwise of the laser mark.

Preferably, the evaluation step involves determining the intensity of light reflected from a portion of the adjacent unmarked surface (I_U) and comparing the value of (I_M) with the value (I_U) to obtain a value of the contrast between the portion of the laser mark and the portion of the adjacent surface. In a more preferred embodiment, the contrast (Con) is obtained according the equation:

$$\text{Con} = | \text{Log}(I_M) - \text{Log}(I_U) |$$

In the equation, Log represents the logarithmic value. The present invention also provides, in another aspect, an apparatus for testing a laser mark applied to a surface of a semiconductor device. In an embodiment, the apparatus includes a light source for illuminating the laser mark and the adjacent surface of the semiconductor device; image sensor to detect light reflected from a portion of the laser mark and an adjacent portion of the unmarked surface; and a processor to determine a measure of contrast between the portion of the laser mark and the adjacent portion. In a preferred embodiment, the processor calculates the contrast according to the above equation:

$$\text{Con} = | \text{Log}(I_M) - \text{Log}(I_U) |.$$

Using the present technique for inspecting laser marks, laser marks can be consistently determined with high-speed, even in an application for on line inspection.

Detailed Description of Specific Embodiments of the Invention

Generally, the reflection produced by a ray of light striking on a surface can be modeled as having three components: diffuse lobe, specular lobe and specular

highlight. Figure 2 illustrates the surface reflection model. The ratio of these three components are largely determined by the roughness of the surface. When a surface is smooth, the diffuse lobe and specular lobe are rather small and the specular highlight dominates. For example, a mirror which has a very smooth surface displays such characteristics. On the other hand, a piece of white paper which is uniformly rough would have small specular highlight but displayed stronger diffuse lobe and certain extent of specular lobe.

In the case of an IC with laser mark, there are two types of surfaces: marked surface and unmarked surface. The laser marked surface is rougher than the unmarked surface. As noted above, a smooth surface exhibits a stronger specular highlight and specular lobe than a rough surface. Since the material remains the same in the marked and unmarked surfaces, the surface have the same albedo, which can hence be ignored in the following description.

In order to measure the contrast of the laser mark objectively and consistently, a controlled lighting and viewing environment should be established. A specific embodiment of a system for measuring contrast for laser marks according to the present invention is illustrated in Figure 3A and Figure 3B. This embodiment includes an image processor system 1, light sources 61. A holder 2 is used to hold the object 5 in place. The image processor 1 further includes a video camera 50, lens 51, frame grabber 55, and a processor 57. In general, the video camera 50 includes a high grade CCD (charge coupled device) image sensor 50a. The contrast measurement system is properly enclosed by a light shield 60 to shield off ambient light. The contrast measurement system is illustrated in Figure 3.

In this specific embodiment, the frame grabber 55 and the video camera 50 of the image processing system 1 are monochromatic. Typically, a 8-bit gray scale representation is used. A typical image processing system 1 is shown in Figure 4. The lens 51 further has an aperture 51a that is adjustable. An image of the object 5 which is a laser marked IC is focused by the lens and impinged onto the CCD sensor 50a of the video camera 50. The CCD sensor 50a produces an analogue video signal which is fed to the frame grabber 55. The frame grabber 55 digitizes the video signal into 8-bit digital signal which is equivalent to 256 gray level. The digital image is a 2D (two dimensional) array of 8-bit data which can be processed by a computer.

Many variables can affect the final contrast measurement result. Given that the light sources 61 are well controlled, one first adjustable parameter is the lens aperture 51a. The diameter of the lens aperture 51a controls the amount of light that can pass through the lens 51 and be collected by the CCD sensor 50a. The aperture 51a setting is represented by F-number. A large F-number means that the diameter of the aperture 51a is small and hence cut off a large portion of light. A small F-number, on the other hand, will admit more light. The F-number also determines the depth-of-field of the image acquisition system 1. A first step is to ensure that a proper F-number is selected and locked. The amount of light impinged onto the CCD sensor 50a should not be too strong to cause saturation. The light should not be so weak that the signal to noise ratio becomes poor.

Once the F-number of the lens 51 is fixed, the next adjustable parameter is associated with the video camera 50. The video gain of the video camera 50 should be set to a fixed gain level. The video output from the video camera 50 is fed to the frame grabber 55, which has several adjustable parameters. A frame grabber 55 normally has a video amplifier, a sync stripper, and a flash A-to-D converter. The A-to-D

converter converts analog signals from the camera into digital signals. The user accessible parameters are gain and offset of the A-to-D converter. The gain and offset for the entire measuring process should be set. The adjustment of the gain and offset of the frame grabber 55 is carried out during the calibration process.

The calibration process can be achieved by the use of a standard gray scale card 30 as the test object. The standard gray scale card 30 has a series of known optical density steps. Such gray scale cards are known in the art and commercially available. One such gray scale card is the KODAK gray scale cards produced by KODAK Co. for photographer. The KODAK gray scale card 30 is used by the present invention as the standard gray scale reference. The KODAK gray scale card 30 is easily available to both the end user and the IC manufacturer. The KODAK gray scale card 30 has a tightly controlled specification and is traceable to ANSI standard. The original purpose of the KODAK gray scale card 30 include the following:

- 1) Compare the tone values of reflection originals with the tone values of their reproduced image.
- 2) Compare exposure and processing in a photographic (marking) environment so that changing conditions can be identified, measured and controlled .
- 3) Balance positive and negative in a color reproduction process that requires the use of masks, separation films, and filters.
- 4) Determine values for tone-reproduction curves.

The KODAK gray scale card 30 is composed of twenty optical density steps; step aims are 0.10 density increments and relative density values from a nominal "white" of approximately 0.05 to 1.95. Density increments are tightly controlled and will vary only slightly from the nominal density value. Neutrality and uniformity are also

tightly controlled. The background approximates an 18% neutral gray to neutralize flare and adjacency effects.

In an illustrative embodiment, the image acquisition system 1 of the present invention is calibrated according to the following steps:

- 1) Establish the lighting and viewing environment of the contrast measurement system according to the requirement. For the case of measuring the contrast of laser mark, oblique front lighting technique is used.
- 2) Position the medium gray scale (optical density equals to 0.9) of the KODAK gray scale card 30 in the field of view of the video camera 50.
- 3) Capture the image of the medium gray scale.
- 4) Measure the mean intensity of the image of the medium gray scale.
- 5) Adjust the aperture 51a of the lens 51 such that the intensity of the medium gray scale to be approximately 80 (based on a 8 bit image acquisition system).
- 6) Position the gray scale with optical density of 0.4 of the reference gray scale card 30 in the field of view of the camera 50.
- 7) Capture the image and measure the mean intensity of the gray scale of 0.4 optical density.
- 8) Adjust the gain and offset of the image acquisition system 1 such that the mean intensity of the 0.4 optical density gray scale is close to the upper limit of the image acquisition system 1 but ensuring no intensity saturation. For example, intensity level equals to 250.
- 9) Position the gray scale with optical density of 1.4 of the KODAK gray scale card in the field of view of the camera.

- 10) Capture the image and measure the mean intensity of the gray scale of 1.4 optical density.
- 11) Adjust the gain and offset of the system such that the mean intensity of the 0.4 optical density gray scale is close to the lower limit of the image acquisition system 1. For example, intensity level equals to 25.
- 12) The parameters of the image acquisition system 1 including the camera lens 51 are now calibrated.

Contrast can be defined as

$$\text{Contrast} = (I_{\max} - I_{\min}) / (I_{\max} + I_{\min}),$$

where $I_{\max}$ is the maximum intensity of the region of interest, and $I_{\min}$ is the minimum intensity in the region of interest.

Following the above contrast definition, the laser mark contrast is computed by

$$\text{Contrast} = (I_M - I_U) / (I_U + I_M),$$

where I_M is the intensity of the laser mark 12 and I_U is the intensity of the background which is the unmarked IC surface 11. It should be noted that the intensity of the background 11 is sampled from the immediate neighborhood of the laser mark 12.

The contrast value is normalized from 0 to 1.0. For example, if I_U is zero while I_M is non-zero, contrast would be equal to 1.0. If I_M is equal to I_U , then contrast is 0.

According to the present invention, an optical system such as one described above (e.g., one shown in Fig. 3) can be used to measure the intensity values I_U and I_M and a processor (e.g., a computer such as a desk-top personal computer, a minicomputer, or a mainframe computer) can be used to calculate the contrast according the contrast equation above. A computer program can be written to implement the algorithm according to the equation in the computer. The result of the calculation can then be communicated to a typical output units to a user. For example, the result can be broadcast in a CRT monitor display, printer, relayed to another computer, stored in a storage device such as a hard disk, floppy disk, tape, compact disk, and the like. Furthermore, the algorithm can be stored in an article of manufacture, such as a computer, disks, and the like such as the above-mentioned.

Although the above equation can be used to calculate contrast of laser marks, according the present invention, a more preferred way of calculation can be used. One reason is that the above contrast measurement is non-linear and there is no objective way of communicating the contrast value.

In another embodiment, the present invention provides a new way of computing contrast after the image acquisition system has been calibrated according to the above mentioned procedure.

$$\text{Contrast_new} = | \text{Log}(I_M) - \text{Log}(I_U) |$$

Contrast_new is also a normalized value with a scale of 0.0 to 1.0. Using the KODAK gray scale card 30, the user can simply specify an acceptable contrast value based on the difference in the density steps provided. The measured contrast value

(Contrast_new) will then be compared with this user defined value to determine whether the laser mark contrast is acceptable or not. In other words, by this technique, the present invention uses video imaging to measure the optical density of the laser marks.

According to the present invention, in order to measure a laser mark contrast, the system first segments the laser mark 12 from the background 11 and further extracts their respective intensity values. The uniformity of the marked area and that of the unmarked areas are computed as well. Due to the variations in the laser beam energy, the amount of material removed from different areas may be different and hence the laser mark will appear uneven. The present invention also measures the evenness of the laser mark in addition to the contrast itself.

In summary, the present invention provides an improved technique for inspecting contrast of a laser mark (e.g., a logo). An illustrative procedure is as follows:

Measure the optical density of the laser mark 12 and the unmarked surface 11 under a controlled illumination environment;

Compute the contrast of the laser mark based on the optical density measurement;

Compare the contrast of the laser mark with a pre-defined reference which is preferably the KODAK gray scale card 30 to determine whether the contrast is acceptable or not. Preferably, the comparison is based on the contrast calculation using the equation: $Con = | \text{Log}(I_M) - \text{Log}(I_U) |$.

Compute the contrast for each of the character of laser mark (e.g., logo) and also calculates the deviation of contrast over the entire laser mark on an IC 5; this is again compared with a pre-defined value to determine whether it is acceptable or not.

Measure the uniformity of the optical density within each of the character and compare with the pre-defined value.



CLAIMS:

1. A method for testing a laser mark applied to a surface of a semiconductor device, comprising:

illuminating the laser mark I_F and unmarked surface I_B adjacent to the laser mark on the surface of the semiconductor device;

determining the intensity of light reflected from the laser mark or a portion thereof (I_M); and

evaluating the determined intensity value (I_M) to assess the acceptability or otherwise of the laser mark I_F .

2. A method according to claim 1 wherein the step of evaluating comprises the further steps of determining the intensity of light reflected from a portion of the adjacent unmarked surface (I_U) and comparing the value I_M with the value I_U to obtain a measure of contrast between the portion of the laser mark I_F and the portion of the adjacent surface I_B .

3. A method according to claim 2 wherein the measure of contrast (Con) is obtained according to the equation:

$$\text{Con} = | \text{Log}(I_M) - \text{Log}(I_U) |$$

4. A method according to any of claims 1 to 3 wherein the measure of contrast is determined by reference to a gray scale.



5. A method according to any of claims 1 to 4 wherein the laser mark I_F has a number of portions and the method further comprising obtaining the measure of contrast for each of the number of portions and calculating the deviation of contrast over all the portions to determine the acceptability of the semiconductor device.
6. A method for testing a laser mark applied to a surface of a semiconductor device, comprising:
 - determining the intensity of light reflected from the laser mark I_F or a portion thereof (I_M) and determining the intensity of light reflected from a portion of unmarked surface I_B adjacent to the laser mark (I_U);
 - comparing the intensity of light reflected from a portion of the laser mark I_F with the intensity of light reflected from the portion of surface I_B adjacent to the laser mark to obtain a measure of contrast between the portion of the laser mark I_F and the adjacent surface I_B ; and
 - evaluating the measure of contrast with reference to a gray scale to assess the acceptability or otherwise of the laser mark I_F .
7. A method according to any of claims 7 wherein the measure of contrast (Con) is obtained according to the equation:
$$\text{Con} = | \text{Log}(I_M) - \text{Log}(I_U) |$$
8. A method according to any of claims 7 wherein the determining of intensity step employs an image sensor 50a and the evaluating step uses a processor 57, the method further comprising an initial step of calibrating the image sensor 50a with respect to the evaluation step by the processor 57 using a reference gray scale.



9. An apparatus for testing a laser mark applied to a surface of a semiconductor device, comprising:

light source 61 for illuminating the laser mark I_F and unmarked surface I_B adjacent to the laser mark I_F on the surface of the semiconductor device;

image sensor 50a for determining the intensity of light reflected from the laser mark I_F or a portion thereof (I_M); and

processor 57 for evaluating the determined intensity value (I_M) to assess the acceptability or otherwise of the laser mark I_F .

10. An apparatus according to claim 10 further comprising image sensor 50a for determining the intensity of light (I_U) reflected from a portion of the adjacent unmarked surface I_F and wherein the processor 57 calculates the measure of contrast (Con) between the portion of the laser mark I_F and the portion of the adjacent surface I_B according to the equation:

$$\text{Con} = | \text{Log}(I_M) - \text{Log}(I_U) |.$$