Laser and Camera Inspection Technologies for On-Line Defect Detection

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ABSTRACT

Manufacturers of microelectronics media (ceramics, film, foil, etc.) are under enormous pressure to maximize throughput rates, while maintaining high quality and yield. Automatic inspection systems can achieve these objectives, concurrently, if the correct inspection system is installed. The difficulty is matching the inspection problem against a dizzying array of inspection system solutions.

Inspection system design represents the integration of four disciplines - optics, electronics, mechanical engineering and software. The disciplines must play together, as a system, like a symphony. And, like a symphony, there are lead disciplines and supporting disciplines.

This paper serves as a guide for MCM manufacturers who must address the issue of on-line inspection of base material, laminates and coatings. It defines the underlying principles behind the selection of an inspection system. The optical solution is presented as the critical issue. Laser and camera technologies are compared and guidelines for the selection are given.

Key Words: AOI, inspection, laser, camera, defects, divergent, telecentric

Introduction

Manufacturers are under increased pressure to meet a multitude of business demands:

+ Boost Production Rate

+ Increase Yield

+ Improve Quality

+ Expand Market Share

+ Reduce Operating Costs

Satisfying a single demand is a challenge. Pick two, and the difficulty increases dramatically. Today, businesses are expected to generate substantial progress in all five dimensions, **concurrently!** If this was a simple task, it would have been accomplished long ago. Hence, achieving simultaneous progress means a step change in the manufacturing paradigm; automatic inspection represents the means to achieve these goals.

Benefits of Automatic Inspection

An automatic inspection system creates a "window" into the manufacturing process, generating an information stream. This information stream flows in three directions, ***feedback*** (process control), ***feed forward*** (quality control) and ***feed upward*** (management information).

The inspection objectives will define the location of this "window"; if process control is the primary objective, the system will be located after a high value-added unit operation. If quality assurance is the driving force, the capability migrates to the end of the process train.

Some of the resulting benefits are well defined and quantifiable, while others are qualitative. Mapping the information streams onto the manufacturing challenges;

- **Boost Production Rate**
  Higher line speeds are possible, as the production rate will no longer be "inspection constraining."
- **Increase Yields**
  Immediate process ***feedback*** spurs corrective action, substantially reducing waste.

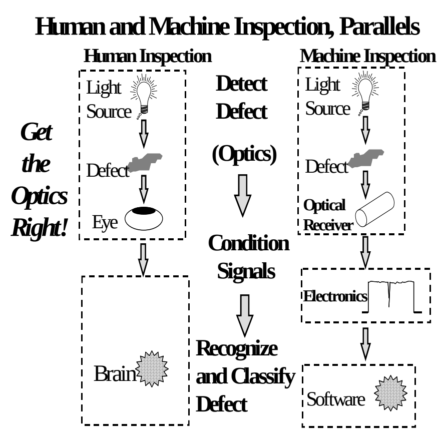
  After defects are created they may be removed in converting operations; the system records the type, size and location of defects to assist this process (***feed forward)***. Net results; **increased** total <u>and</u> **highest quality** yields.
- **Improve Quality**
  Quality improves at the point of manufacture <u>and</u> downstream. System provides the means to "100% certify" product quality.
- **Reduce Operating Costs**
  Manual inspection may be eliminated, on both the production line and converting operations.
- **Expand Market Share**
  Customer satisfaction and confidence is maximized. Sales may employ the "100% certified" capability to secure previously unattainable customers.
- **Management Information**
  The data stream may be analyzed for comparison of plant performance by shift, machine, product, etc. In addition, all process changes and improvements can be assessed quantitatively based upon their effect on yield, quality, etc. This utility complements all the benefits, above.

Defect Detection Overview - Rule #1; Get the Optics Right!

An automatic inspection system displaces or augments human inspection. The two inspection processes are very similar. A survey of manual inspection techniques, utilized in metals, film, paper, non-wovens, photosensitive media, display and storage industries revealed a common manual inspection algorithm, below:

1. The product and defects are illuminated. Companies expend considerable effort to define a light source, which will interact with the defect to make the defect "stand out" against the substrate. The universal goal is to provide a light source, which is ***safe for human use***, which allows an inspector to detect the visual defects, while acceptable product can be easily ignored. However, as human eyes can tolerate only very limited lighting conditions (wavelength and intensity), these systems are usually sub-optimal.
2. The trained inspector focuses on the visual anomalies, highlighted by the light source, ignoring the balance of the product; 99.9999% of the product is not inspected. Defects are sized and classified based upon agreed specifications.

Automating this inspection task requires a



fundamental understanding of the optics of defect detection, for a given application. The algorithms for human and machine inspection are very similar, with one notable exception. The light source, which can be employed in an automatic inspection system, does not have to be viewed by a human. This means that the best light source can be employed; the constraint of "human-safe" can be removed.

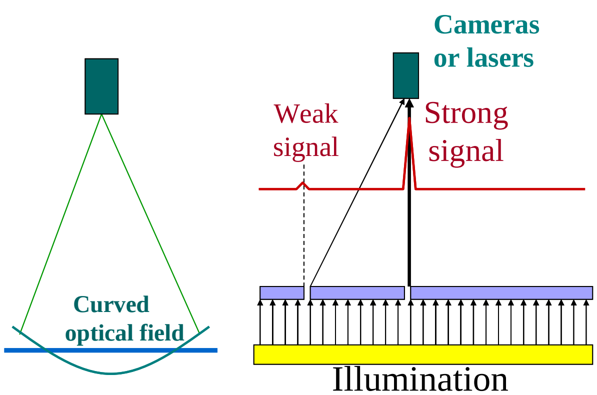
Rule #1, for both manual and machine inspection, is simply, "**Get the optics right!"**

Defect Detection; Divergent and Telecentric Systems

Divergent systems

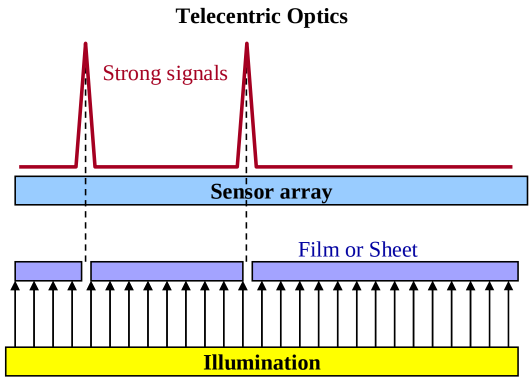
Optically divergent systems, e.g. line scan cameras and "fan scan" lasers typically utilize a continuous illumination source and a bank of cameras or a series of laser scanners and receivers. Each camera/laser is focused onto a section of the product, and each camera field of view overlaps its neighbors, Figure 1. The field of view is curved and herein lays one of the key problems, inconsistent detection across the field of view.

The problem is particularly evident when the defects are "small" ("small" is a relative term and depends on the application). The defect signal strength depends upon the position of the defect in the field of view. A simple illustration for pinhole detection, utilizing a camera, is shown below. As less light enters the camera from the side of the inspected width, this signal is less than that generated from pinholes in the middle of the field of view. This shortcoming is true regardless of the defect type and does not depend upon whether the defect is viewed in transmission, reflection, bright field, dark field, etc.



Telecentric systems

To solve the problem of inconsistent signals across the optical field, the optical field must be flattened. The most practical means is with a telecentric system. The array of active elements (camera pixels) spans the product.



Pinhole/void detection is INDEPENDENT of the cross-direction position of the pinhole.

Telecentric laser scanning; operation

Details of a telecentric laser scanner operation are given below .

1. A laser source, tuned to the application, is selected. Telecentric laser systems are capable of supporting four lasers (of different wavelengths). The most common wavelengths are red (632 nm) and infrared. Laser wavelength is normally driven by the spectral response of the product or coating.

2. The laser is directed to a rotating polygon (2), which creates the required "scanning" frequency to ensure 100% inspection (coverage of the product) at the highest line speed.

3. The beam is folded onto the plane of inspection by a spherical mirror (3). This mirror forces the beam to maintain a constant profile and orientation as it travels across the product with. This "telecentric" scanning feature is essential for reliable and repeatable results across the product.

4. 4. A lens (4) focuses the beam onto the plane of the product (5). This lens may also be used to normalize the beam for elimination of scan pitch caused by the pyramidal error of the polygon. The laser spot traverses the product, at speeds to 36 KHz (36,000 scans per second).

5. After interacting with the product, the laser light is transmitted and/or reflected and is then captured by special optical receivers. The receiver shown is a focused receiver and is a mirror image of the projection optics. The high-speed laser spot is "descanned" by the internal mirrors (6) creating a stationary laser spot, which is focused on the photomultiplier(s) (PMT's) (7).

6. The PMT's (7) convert the laser light energy into electrical video signals, which are processed in the

Telecentric Laser Scanner

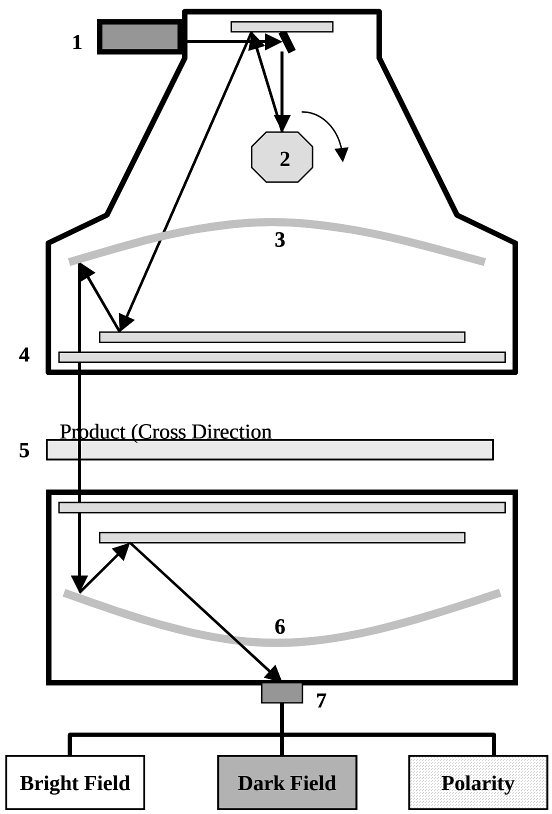


Figure 5

electronics and software of the system. Multiple optical fields (i.e., bright field, dark field, polarity shift, optical power, transmission, reflection, etc.) can be generated. These signals are analyzed by the system and images of each optical channel are produced. These images may be combined in order to view the totality of the defect, i.e., its size and extent in transmission dark field and reflection bright field.

Defect Classification, The Need for Multiple Optical Dimensions

Defect detection and sizing is only one problem. In order to correct process problems, production personnel need to identity (classify) the defect. Corrective actions for contaminants are different from that action taken due to scratches, coating defects, etc. To this end, the inspection system needs enough information for defect classification. A single optical field, which is most commonly employed, is grossly insufficient. Just as a human inspector will look at a defect from different angles, so must an inspection system. This is the second area of extreme deficiency in conventional divergent systems.

Divergent optical systems, particularly cameras, cannot produce coincident images. If multiple banks of cameras are used to capture the defect information from different angles, it is impossible to align the camera pixels, in each bank of cameras with those of the other cameras. The pixels overlap and project differently on the product, so the projected pixel size is different with each bank of cameras. Additionally, the defect image clarity depends on the nature of the optical divergence, defect image clarity changes across the scan line.

Only a telecentric laser system provides ever normal scanning, consistent detection/sizing/imaging and coincident imaging. The reason is simple; as the laser spot travels across the product, it is generating information in transmission and reflection, in bright field, near dark field, far dark field, polarity, etc. at that point on the product. The receivers process the information, at each point, so the resulting signals and images are perfectly coincident. No other system can do this.

10-micron Scratch in Display Glass

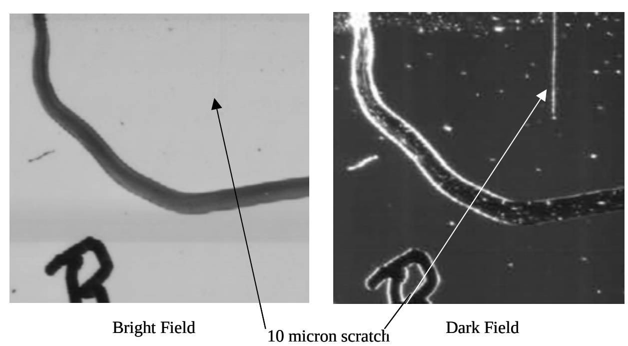
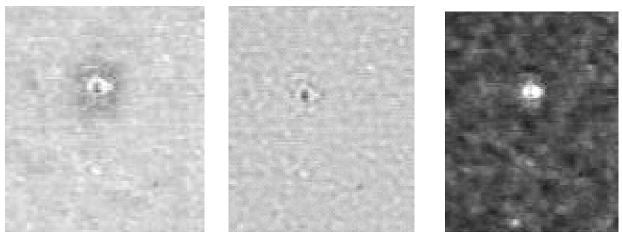


Figure 6

Examples are given below. Note the 10-micron scratch (scratch is 10 microns wide) on display glass, Figure 6. These images were generated by a telecentric laser scanner operating in transmission, with bright field and dark field optical channels. There was almost no signal in bright field. However, the system detected the scratch easily in dark field.

The use of multiple optical channels is further shown below. A coating defect, on display glass shows that the origin of the defect is a particulate (bright field image), but the total extent is much larger, as shown in the dark field and combined images, which show the total extent of the coating disturbance.

Coating Defect, Display Glass



Combined Image
Bright field and dark field

Bright field image

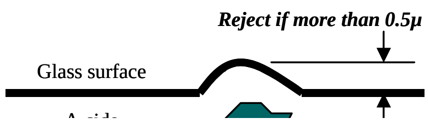
Dark field image

Figure 7

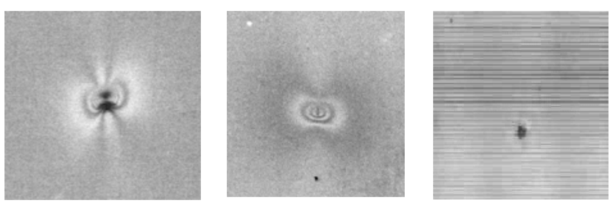
Protrusion Detection

Utilizing a telecentric laser scanner and receivers operating in bright field and dark field, small protrusions (bumps) on the surface can be detected. The example below shows the impact of an inclusion, near the surface of display glass. When this inclusion occurs near the A-side, even the smallest departure from flatness can cause a defective display.

Protrusions, Display Glass



Protrusion Detection, Telecentric Laser System



Protrusions larger than 1 micron

0.5 micron Protrusion

Figure 8

A range of protrusions is shown, in Figure 8. These were taken dynamically with a telecentric laser system.

References

[1] T. Potts and E. Cohen, “Coating Defects; Detection, Causes and Cures” AIMCAL Conference, October 2008

[2] T. Potts, W. Ullrich, "High-Resolution Laser Inspection of Low-E Glass" ICCG Conference, July 2004

[3] T. Potts, "Automatic Inspection Systems, Application Guide for Laser and Camera Systems”, AIMCAL Technical Conference, October 2003.

[4] T. Potts, “Laser Imaging and Detection of Coating Defects”, AIMCAL Technical Conference, October 2002.

[5] T. Potts, “Automatic Inspection of Coated Webs”, AIMCAL Technical Conference, October 2001.