Acoustic imaging reveals die stack layers

By Ann R. Thryft, Contributing Technical Editor

Acoustic microscope imaging is commonly used along with x-ray inspection during semiconductor production and failure analysis to reveal internal flaws such as cracks and voids. Until recently, however, acoustic microscopy was not good at finding and analyzing defects on specific layers of a stacked die assembly. Ray Thomas, manager of Sonoscan’s SonoLab division, described new software algorithms that his company developed to improve the use of this imaging technique for nondestructive, offline examination of stacked die.

Q: What are the main challenges that engineers face when inspecting stacked die assemblies using acoustic microscopic imaging?
A: The process engineer needs to know where defects are located in a die stack, along with their size, extent, and type, such as a crack on the third die layer, or a delamination between the fifth and sixth layers. In a semiconductor package containing a single die, acoustic imaging technology propagates ultrasound into the package to make an image of its internal features, such as cracks, delaminations, or voids, which can then be inspected. While ultrasound penetrates solid materials, it is reflected by the interface of two different materials, such as mould compound and the die. These reflections produce an image of the interfaces.

The additional die layers and die attaches in a stacked die configuration create complexity. Reflections from the interfaces on each layer merge with the reflections from interfaces at other levels in the stack and can’t be separated, creating a composite image that’s difficult to interpret. Sorting out this mess is nontrivial, but it must be done to assess stack reliability.

Q: What other technologies can be used for stacked die inspection?
A: The alternatives are destructive physical analysis techniques. No other nondestructive evaluation method is used to separate out the layers so you know where defects are located. The fact that ultrasound can bounce off of the layers is a strength of that technology. The complication of reflections from so many layers merging together in an image is the difficulty.

Q: What advancements have you made in acoustic imaging and how do they help solve the inspection problem?
A: Our new proprietary software capability gives us a level of detail where you can see individual layers with some accuracy and assign defects to specific layers. What we’re changing is the ability to correctly interpret the signals. There was a great deal to learn about how the reflections from multiple interfaces interact with each other. Also, not every part configuration is inspectable. For example, when die in the stack are roughly the same size, you tend to have better access throughout the stack’s thickness, but when one die overhangs another, access becomes limited.

Materials also affect accuracy. For example, mould compound is a composite material so it scatters ultrasound. If we can inspect a stack of bare die that has not yet been overmoulded, we can use a higher frequency to get better accuracy between layers. Typically, we’re looking for cracked die, or delaminations and voids between layers. But some of the other things we detect along the way include nonuniformities in the die-attach material, which may be caused by incomplete curing or incomplete mixing. □
Recovery? Vision gives mixed signals

By Ann R. Thryft, Technical Editor

Although some pundits are talking about an economic recovery, reading the tea leaves for machine vision produces mixed results. Research firm Strategies Unlimited predicts that once the final numbers are in, worldwide image sensor shipments will have experienced an unprecedented 30% downturn during 2009, an indication of what happens in vision when the whole world stops buying products that must be manufactured and inspected. Although the firm forecasts a return to growth in 2010, this sharp decline occurs after more than a decade of continuous growth.

But machine vision is expanding into new areas. In photovoltaic crystalline-silicon solar manufacturing, the economic downturn has spurred competition among both wafer fabs and solar-cell manufacturers to produce higher-quality, more efficient products, instead of focusing mainly on getting volumes out the door. Since solar-cell manufacturing hasn’t depended much on automation, machine vision, or metrology and yield-management tools, there’s room for expansion to help boost product quality. And more and better inspection will be needed for newer processes such as multilayer screen printing, while more intelligent use of data can help improve and refine processes. Meanwhile, the glut in solar panels is lifting and growth continues, which should mean more opportunities for machine-vision and inspection technologies.

Highlights

Wafer-inspection system detects macro defects

Microelectronic device manufacturers can use the Iris wafer-inspection system from SemiProbe to detect flaws in the wafer circuit pattern as well as contamination or process damage. Depending on the choice of optics, the Iris inspection system is able to identify defects as small as 3 μm.

The system is suitable for examining optical components, double-sided devices, photovoltaics, MEMS, and other microelectronic devices. Iris can find visual defects such as probe marks, thru-silicon vias, bumps, incomplete etch, scratches, large-scale contamination, and passivation. Configurations are available for performing manual visual inspection or automated inspection.

Once a defect is identified, its failure code is noted on the wafer map. Wafer maps are fully exportable in a variety of formats for offline analysis or downstream processing.

Halcon Embedded runs on the Beagle Board

MV Tec Software reports that it has taken initial performance measurements with its Halcon Embedded 9.0 machine-vision library running on the Beagle Board using Angstrom Linux as the operating system. The Beagle Board single-board computer is based on the OMAP35x processor from Texas Instruments.

From the results of its tests, MV Tec said that image-processing algorithms such as filtering or blob analysis can be performed on the Beagle Board running Halcon in milliseconds. The company added that subpixel-precise measurements are possible in less than 1 ms.

Market for image sensors dips in 2009, should rebound in 2010

By Ann R. Thryft, Contributing Technical Editor

Research firm Strategies Unlimited has predicted that once final figures for 2009 are available, the overall market for image sensors worldwide will show a decline for the first time since 1997, when the company began tracking this market. Although growth is expected to return in 2010, revenue will increase at a lower, single-digit rate compared to the double-digit revenue growth the market experienced over the last decade, said Tom Hausken, director of the firm’s photonics and compound semiconductors research.

Unit shipments of the image sensors used in machine vision will generally follow the same curve, said Hausken. In 2008, shipments of machine-vision image sensors grew only 8% to 256,000 units compared to the 238,000 units that shipped in 2007. For 2009, Hausken expected a 30% drop from 2008 figures to 179,000 units. He predicted shipments of 188,000 units in 2010, an increase of only 5%.

Hausken called the 30% drop in growth in 2009 “huge,” and said it was due primarily to the global recession. Although the 30% decline last year is not as big a drop as, for example, the decline in shipments of semiconductor manufacturing systems, it’s larger than the drop in cellphone shipments, which only took a 10% hit, said Hausken. “Going forward, we see about 5% to 11% growth over the next few years starting in 2010 in unit shipments of these sensors. Since machine vision is still expanding, this is a common growth rate for that business.”
The amount of image data generated in some machine-vision applications is growing rapidly as camera resolutions increase, panels and wafers get bigger, and the features to be inspected shrink even further. In semiconductor wafer and mask inspection, as well as in FPD (flat-panel display) inspection, the board-level or multi-board vision processors and blade servers traditionally used to process this data are running out of steam.

Some vendors of vision processors, such as Matrox Imaging, are creating systems that build upon HPC (high-performance computing) architectures to process the growing data that must be handled as it comes into the system via an external interface adapter and moves among multiple processors.

**Larger wafers mean more data**

In semiconductor inspection, wafer sizes are moving from 150 mm to 300 and even 450 mm, while at the same time the features on the wafer that must be examined are shrinking, said Pierantonio Boriero, product line manager for Matrox Imaging. “3-D x-ray systems can generate 0.5 Tbytes to 9 Tbytes per scan,” he said. “Compounding the challenge is the increase in dynamic range from 8 bits to 12 bits per pixel.”

In the FPDs manufactured today, the substrate glass measures 2.16x2.4 m, so there are roughly 80 Tbytes of data to inspect per panel. In the near future, the imaging of larger panels, with substrate glass measuring 2.88x3.13 m, will result in about 140 Tbytes of data per panel.

“Not only is this an enormous volume of pixels to inspect, but throughput must remain high, since this is in-line processing equipment,” said Boriero.

Traditional vision-processor boards were based on a DSP (digital signal processor) or a microprocessor and also included custom ASICs for the image processing, said Boriero. “With a single expansion board that performed all the necessary data-acquisition and processing functions, increasing the processing power was a problem because of the much higher power consumption and heat-dissipation levels,” he said.

Blade server systems do offer greater computational power per processing node but suffer from limited I/O bandwidth between blades, commonly provided by Gigabit Ethernet and sometimes Infiniband. They also lack a spare slot for a frame grabber or other specialized I/O expansion board, resulting in inadequate external I/O expansion for getting data into and out of the whole system.

“We could have solved the problem by employing multiple host PCs with vision-processor boards, but that would exceed most production floor space requirements,” Boriero explained. He added, “Once we got beyond what one board or one standard PC can do, we started thinking about multiple processors running concurrently, sharing data among them all via a switched-fabric backplane. That’s when we looked at high-performance computing, which is a broad concept of how to make multiple computer systems work together.”

The Matrox Supersight system, which consists of up to four system host boards in one box with a high-speed fabric interconnect, tailors HPC technology for image-processing applications. The rack-mounted system includes a PCIe (PCI Express) 2.0 backplane, quad-core Intel Xeon CPUs for image processing and analysis, FPGAs for image preprocessing, and GPUs (graphical processing units) for accelerated image processing.

To maximize computing resources by increasing I/O throughput, Matrox chose PCIe x16 Gen 2, at 8 Gbytes/s bidirectional, to interconnect boards and nodes within the system, said Boriero. The PCIe switched-fabric backplane is packet-based, so it enables developers to segment the data and move it around more efficiently among the different processing elements. “Developers can create clusters, or little work groups made up of different technologies, each working on a portion of the data set,” he said. The point-to-point, full-duplex nature of PCIe lets developers isolate bus traffic within the compute clusters, which helps optimize performance, especially as the number of processing elements increases.
Although thin-film and crystalline-silicon PV (photovoltaic) solar wafers and cells share some similar defects, they require different manufacturing and inspection techniques. Crystalline-silicon solar cells are based on wafers, so software tools used for machine vision, inspection, metrology, and yield analysis of regular semiconductor wafers are being applied to high-volume manufacturing of silicon solar wafers and cells. Thin-film solar cells, on the other hand, are created with substrate materials such as glass or stainless steel, and thus require different inspection techniques.

The main differences between semiconductor and crystalline-silicon PV solar-cell manufacturing are volumes and cost, according to Mike Plisinski, VP and GM of Rudolph Technologies’ Data Analysis and Review business unit. “A large, first-tier semi fab has about 100,000 wafer starts a month, versus a first-tier crystalline-silicon PV fab with about 500,000 starts a day,” he said. In the semiconductor world, manufacturers depend on metrology and analysis data after most process steps. Unlike a high-value semiconductor wafer, “a PV cell or wafer is worth maybe a couple of dollars,” said Plisinski. So, manufacturers do not need as much data after each step to ensure wafer quality.

The current state of wafer-based solar-cell manufacturing resembles semiconductor wafer manufacturing in the early 1970s, said John Petry, manager of marketing for vision software at Cognex. At that time, traceability was first introduced and individual wafers were still handled by technicians. Similarly, in most solar-wafer production, people still handle wafers, geometries are coarser, and precise registration is not nearly as important.

But Petry said Cognex is seeing changes in crystalline-silicon solar-cell manufacturing, which is beginning to employ procedures used in today’s 300-mm semiconductor wafer fabs, where wafers are tracked throughout production and handling is completely automated. Petry noted that solar-cell manufacturing techniques such as multilayer screen printing and thinner solder fingers on wafers need highly precise alignment, and thus must be automated.

The primary uses for machine vision in solar-wafer production are checking for edge chips and sorting and grading by color, said Petry, fairly simple applications for today’s vision systems. “The other commonly requested test today is to detect non-penetrating microcracks,” he said. “Unfortunately, no one’s yet found an efficient in-line solution because the necessary imaging techniques—thermal sensors, for instance—are fairly slow. Given a good image, the visual inspection task isn’t actually that hard.” At present, manufacturers are solving the problem by handling the wafers more gently throughout production.

The need for machine vision in crystalline-silicon solar-wafer inspection is growing for a couple of reasons, said Petry. In the industry’s early years, manufacturing processes were simple and fabs could sell wafers as fast as they made them, but since the recent downturn, fabs are competing more on quality. “Manufacturing processes are becoming better understood, so fabs are better able to correlate wafer appearance to efficiency,” he said. “Newer processes are also becoming more demanding, so you’ll need more wafer inspection, for example, to confirm the alignment in a multilayer screen-printing step.”

For simpler tasks such as wafer handling, said Petry, solar-cell manufacturers use vision software tools such as Cognex’ VisionPro Solar Toolbox, which includes preconfigured tools for standard wafer alignment, edge and print inspection, and color checking. For key OEMs, Cog-
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nex also produces custom solar-cell inspection tools. “For example, we have high-speed inspection software for screen-print registration that includes optical distortion correction for high-resolution linescan cameras,” he said. (See “Machine vision in solar-cell fabrication,” below.)

Cognex is working with wafer foundries on new algorithms to detect dislocations in polycrystalline wafers, since inconsistent crystal formation can lead to less efficient electrical conduction, said Petry. The company is also developing more complex pattern-recognition algorithms. “Foundries are just now beginning to understand the relationship between these pattern characterizations and wafer performance,” he said. “But we expect that eventually these algorithms will also be useful for incoming inspection at some solar-cell fabs to ensure good-quality wafers from the foundry.”

The need for solar metrology tools

Increased competition is driving manufacturers of both crystalline-silicon and thin-film PV solar cells to look for improvements through more intelligent use of data to make their lines more productive, said Rudolph’s Plisinski. “In addition to differentiating on efficiency and in cost per watt, they are now trying to differentiate on product quality,” he said. “With the long, 20- to 30-year warranties on PV panels, they need complete traceability.”

Plisinski sees two types of yield- and quality-improvement issues in PV cell manufacturing: those at the factory-management level and those at the equipment level. Most manufacturers have not used data-management systems for monitoring factory-wide processes, due to limitations in existing software. At the equipment level, wafer breakage caused by manufacturing tools is still a big problem. Because of lack of traceability at the tool level, manufacturers can’t put pressure on vendors to address the problem. “One use for Rudolph’s Discover Solar fab-management software is to add that traceability,” he said.

A big factor in PV cell efficiency is the quality of incoming materials, according to Plisinski. “You might have 10,000 samples in a batch, and some or all of that batch could be bad because of a material problem from one supplier,” he said. That problem could cause a drop in overall PV cell efficiency that triggers process engineers to spend time looking for process or equipment problems. “Customers require systems that can identify these issues instantly and that allow manufacturers to trace these problems back to the supplier,” Plisinski explained. (See Fig. 1.)

The much larger volumes in silicon PV fabrication vs. semiconductor fabrication strains databases that were designed for fewer samples, and also strains data-collection and yield-management systems, said Plisinski, “so we had to design a yield-management system specifically for [the solar] industry.” To create its Discover Solar fab-management system, Rudolph re-engineered its Dis-

### Machine vision in solar-cell fabrication

Cognex says that machine-vision systems and software are now being used for these tasks in solar-cell fabrication:

- **Back-print registration inspection**: Measuring the position, width, and distance between the bus bars and checking the continuity of finger lines.
- **Cell-defect detection**: Inspecting cells for chips and cracks to ensure any defective cells are rejected prior to processing.
- **Cell-orientation detection**: Monitoring solar cells to ensure correct up-right orientation prior to the dopant application phase.
- **Color cell sorting**: Inspecting and sorting solar cells by slight color variances and grading the cells based on inconsistencies in color.
- **Front-print registration inspection**: Inspecting lines for contour breaks, continuity, and excess solder and ensuring that traces are parallel and correctly registered.
- **Laser edge isolation**: Aligning cells and inspecting the edge groove cuts along the wafer edges to isolate the emitters from the back sides of the cells.
- **Robot guidance**: Transmitting placement information for robot-guidance applications used throughout the solar-panel manufacturing process.
- **Screen-print alignment**: Aligning solar cells for screen printing.
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“First, we redesigned the underlying database structures so they could handle and display such huge volumes of samples quickly,” he said. “Next, we modified the analysis engine. In PV solar manufacturing, there’s not much metrology data available. Although thin-film panel manufacturers have some useful metrologies, a lot of analysis is still done by examining electrical test results and tool and sensor data. We needed domain-specific algorithms that would automate a process engineer’s basic analysis to dramatically improve the time required to identify and resolve problems.”

As PV manufacturers bring new technologies into pilot production and then strive to ramp quickly to high-volume production, they will continue to tighten process windows, said Plisinski. “We see customers looking to further improve line performance by using run-to-run control technologies to compensate for the variability of tools and materials over time,” he said. “We also see PV manufacturers pushing process equipment vendors to make a greater amount of process data available to the factory to enable predictive metrology.”

**Thin-film technology grows**

“While crystalline wafers constitute the vast bulk of solar-cell surface area manufactured today, many feel that the long-term trend is in thin-film, since they believe it will cost less and will be more flexible, both as a substrate and in the areas where it can be used,” said Petry of Cognex. According to a recent report from market research firm iSuppli, the proportion of solar cells created with thin-film technology, as measured by a percentage of total solar panel watts, is growing quickly (Fig. 2).

PV solar-cell manufacturing can be divided into three generations, said Darin Cerny, marketing manager at Cognex. “The first involves processing of mono- or multicrystalline wafers,” he said. “The second is thin-film deposition on glass or on a flexible substrate such as stainless steel.” In thin-film solar-cell fabrication, inspection is currently being performed on incoming substrates and thin-film coatings.

Although the third generation is still in development, most third-generation materials will be polymer-based. “The goal is lower-cost yet higher-complexity materials that will produce even higher efficiencies than either first- or second-generation solar cells,” Cerny said.

In wafer-based solar-cell fabrication, manufacturers have already learned much of what it is they want to measure, said Cerny. “But in thin-film solar, manufacturers are just starting to figure this out. They have some idea of what the defects are and what problems they cause. Now, they must concentrate on reliably and consistently finding these defects so that they can either adjust their processes to prevent them from occurring or decide whether to continue processing less-efficient material.”

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