Wireless wafer-like vibration sensor for diffusion furnaces

When a manufacturer has yield problems sometimes finding the cause can be as challenging as the solution. **Allyn Jackson, Field Application Engineer at CyberOptics Semiconductor** discusses how a wireless wafer-like vibration sensor helped a diffusion furnace team identify vibration sources and subsequently increase their yield.

A 200mm fab diffusion furnace group with a total of 13 tools was fighting low wafer yield for months. While some tools performed to standard, others were missing the mark, with four tools in particular experiencing low yields due to the following problems:

- Random broken wafers
- Scratched wafers
- Abnormally high wafer defect rates downstream
- Excessive particle counts

To resolve these issues, the diffusion team initially conducted various trouble shooting steps such as parts replacement, complicated and time-consuming partitioned particle checks, and various tool parameter adjustments. These randomly conducted, trial-and-error efforts, however, provided unverifiable or inconsistent results that contributed little to finding the primary cause of tool yield issues.

Next, the team sought to test a theory that differing and/or indiscriminate vibrations and/or misaligned tools for wafer handling leveling were affecting performance with some tools. Traditional wafer vibration and level test methods such as attaching wired accelerometers to wafers or running dummy wafers through a tool and listening with stethoscopes for abnormal noises proved difficult, inconsistent and ultimately inaccurate as such crude methods are not repeatable. The diffusion team wanted a more accurate, comprehensive and repeatable test method that could assess the whole tool while providing reliable data to quantify results with the ultimate goal of documenting and incorporating new maintenance procedures to prevent such problems in the future.

A wireless, wafer-like vibration sensor offered the capability to travel through tools to monitor three-axis accelerations and vibrations and transmit real-time vibration exposure data for analysis. By filtering out acceptable vibration frequencies produced by regular, slow-moving equipment or high-frequency noises between 1 to 200 Hz, the sensor could help identify vibration anomalies during wafer processing.

As the sensor operates in unison with its own vibration monitoring software, data could be viewed and manipulated to identify problems and predict equipment failures to improve process yield and cycle times.

Diffusion tool characterization goals

The fab chose to use the auto vibration sensor with an auto levelling sensor to characterize all 13 of its tools to determine if wafer handling and excessive vibrations were a contributing factor to these yield issues. A comprehensive test plan was formulated with the following primary goals:

- Establish a baseline levelling standard for all wafer transport or process positions in the tool. Of particular note were wafer

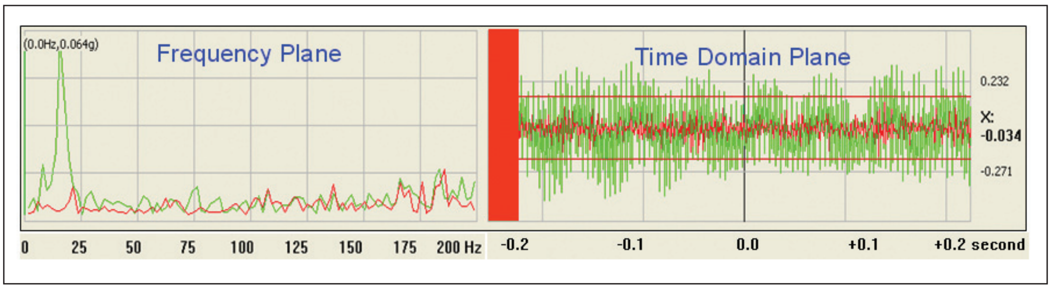

Figure 1

handling, storage cassettes and the setups inside the vertical furnace where access was particularly difficult.

- Identify wafer transport and process locations that do not meet the level standard and those that are level to standard to assure that all wafer handoffs and wafer processing are uniformly administered on all tools.
- Using the highest yield tool as the "golden reference", establish a baseline vibration signature for all wafer movements within the tool and use that baseline signature as a comparison reference for all similar moves on all other tools, with particular attention given to the lowest yield tools.
- Test all tools and identify locations where wafer movement does not conform to the established standard for vibration.
- In cases where wafer movements in "test" tools exceed the "reference" signature standards, determine the root cause of that excursion and correct it.
- White-paper or document as Best Known Method the newly established levelling and vibration test standards and schedule the levelling and vibration testing into the all ongoing routine tool PM activities.

Vibration characterization tool

Placed either in standard cassettes, storage cassettes or in wafer boats that typically hold 150 wafers, the wireless vibration sensor moved through the entire diffusion tool, monitoring three-axis accelerations and vibrations at all locations in the tool in which the wafer travelled. Using Bluetooth technology, the wireless sensor provided wireless real-time data on tool vibration as it moved through the process.

With companion software displaying data on a GUI, engineers were able to overlay vibration fingerprints and analyse vibration data. After carefully recording known good tool and using those golden move vibration signatures as a "reference" for all other tools, it was ultimately determined that there was no one specific cause, but rather many cumulative effects that contributed to poor yield in some tools in the diffusion department.

Results

Problem 1: Some robot moves exhibited excessive vibration.

Action: Perform routine maintenance such as lead-screw lubrication or identify and replace failing component.

Example 1 – Red trace reference signature of good wafer movement, green trace test signature: Shown above (Fig 1) are two overlaid vibration signatures of a stage move. Frequency is shown in the left plane and Time Domain on the right. The red trace is the reference signature and the green trace is the test signature. The two red lines and the red bar are the go no/go threshold.

Results show that the stage move on the test tool clearly failed, indicating possible defect sources and required maintenance. Also, note

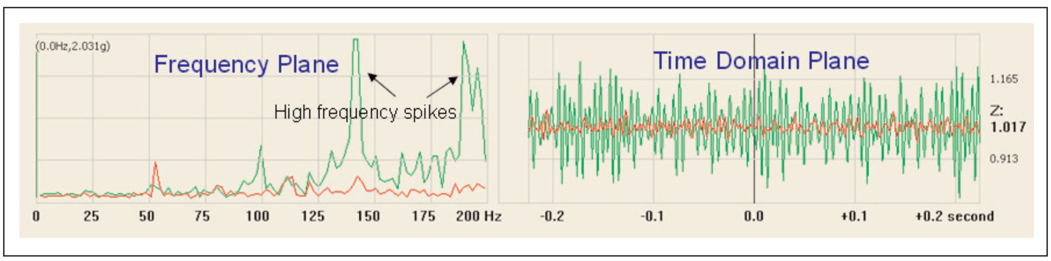

Figure 2

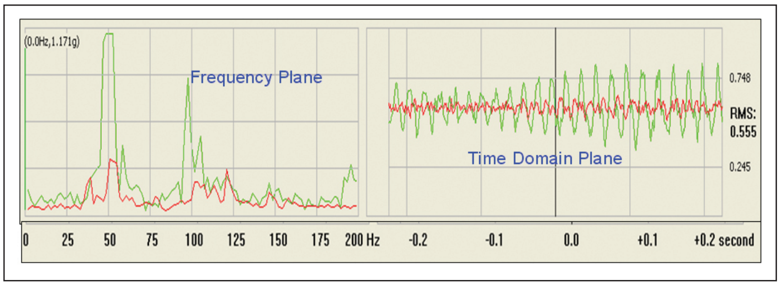

Figure 3

the low frequency spike around 15.6Hz. That is a common indicator of a slower motion source most likely requiring lubrication (failing higher speed components typically have higher frequency spikes).

Problem 2: Miscellaneous vibration sources such as passing carts, the carts themselves and the position of storage cassettes in relation to fans, expose wafers to varying degrees of vibration.

Action: Identify cause of vibration and take corrective action where necessary. For example, tools located close to busy aisles may require extra vibration damping or some tools fans may need to be retrofit with quieter fans.

Example 2 – Red trace tool fans in OFF position; green trace tool fans in ON position:
The effects of systems or events such as fans should not be overlooked when evaluating the total tool for defect causes.

In figure 2 the test signature in red shows Z axis wafer vibration when fans in storage areas fans are OFF. The green trace is the same storage cassette with the fans ON. When the cassettes are not leveled in a tilted back position, as shown in figure 1 above, the risk of "wafer walking" increased (wafers that move can be broken or scratched when the robot retrieves them).

Note that the Time Domain signatures look similar to those in figure 1. However, the Frequency signatures show spikes in the higher frequency range, indicating that the vibration sources originate from faster motions like failing ball-bearings.

Results show that the stage move on the test tool clearly failed, indicating possible defect sources and required maintenance

Example 3 - Red trace tool not by busy aisle, green trace tool by busy aisle:
Some tools, due to their physical location such as next to a busy aisle with carts continually passing, will be exposed to more vibration than tools further away from busy aisles. In figure 3, the green trace shows a tool next to a high-traffic fab intersection and the red trace is of a tool away from the busy intersection. In this case, the tool next to the intersection was identified as needing additional vibration damping systems.

Example 4a: Do the carts transporting wafers to and from the tool need vibration damping? Smooth cart transport to and from tools should not be over looked.

In figure 4a, the X, Y and Z axis as well as the RMS of the three are all displayed. Although the RED vibration-suppressed cart seems to show less vibration than the standard cart, especially in the Y axis, it is good practice to run statistical reports from the raw CSV file data of the vibration wafer outputs at 1000 times per second to quantify the vibration energy exposure.

Example 4b: Quantifying vibration "Test" and "Reference" vibration signatures:

In figure 4b, test and reference signatures shown in example 4a are compared for standard deviation using SPC reports provided with the vibration wafers software application. Although figure 4a visually depicts a general tendency for the enhanced cart (red trace) to be smoother than the standard cart (green trace), by applying statistical reporting to the raw CSV file format output, the actual difference is quantified.

This figure clearly quantifies that the standard deviation of the enhanced cart is measurably less in all three axis than that of the standard cart, thus proving that the vibration-suppressing retrofitted carts do offer greater vibration damping. (The vibration wafer software application comes with many SPC reports for advanced vibration analysis through multiple tests and reference signatures at one time.)

Problem 3: Stocker cassettes were not all leveled when tilted back, resulting in incidents of "wafer walking" caused by tool vibrations.

Action: Level all stocker cassettes tilting back 1mm

Example 5: For a comprehensive program in addressing wafer handling issues associated with excessive vibration, leveling wafer cassettes to established standards should be completed prior to conducting vibration analysis.

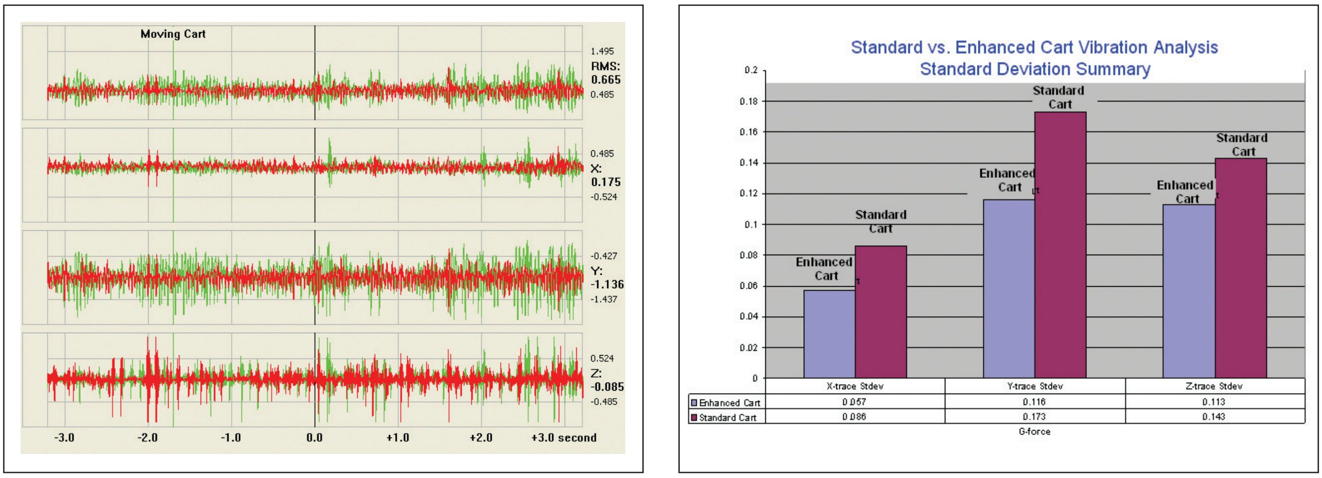

Figure 4a & 4b

Since it is impossible to completely eliminate all vibration in the storage cassettes, optimum inclination is tilted back 1mm to reduce "wafer walking". As the position of storage cassettes is often not an upright position when retrieved by the robot, it is important that levels are accurate. In this scenario, an auto leveling sensor, similar to the auto vibration sensor, was implemented to monitor level of storage cassettes against a set norm.

Leveling was also performed inside the difficult-to-access vertical furnace to assure that when wafers are being processed at 1000c+ degrees, they are at the proper inclination. Figure 5 shows that optimally levelled stockers, levelled with an automatice levelling system tilt back 1 degree to prevent 'wafer walking'.

Auto vibration sensor set new standards for vibration detection

Whenever a wafer is moved or something within the vicinity of the wafer moves, resulting vibrations can be a potential cause of defects. Typically only a few of the common sources of wafer vibrations such as robot arm bearings or lead-screw lubrication are investigated.

When comparing tools that should have identical yields, but one or more tools have abnormally high defects, investigation of the entire wafer path is key to quantify the full range of conditions to which the wafer is exposed.

The diffusion team did just that using the auto vibration sensor (AVS). Once the AVS identified multiple wafer defect causes that were previously overlooked or undetected, engineers at the 200 mm fab conducted a number of corrective actions that included:

- Routine maintenance such as lubrication, which was previously overlooked
- Replacement of failing or substandard parts before yield impact
- Service sub-par sub-systems such as noisy fans
- Where necessary, implement vibration damping systems such as on push-carts or tools near busy traffic areas
- Optimally level storage cassettes to reduce "wafer walking" and mishandling.
- Revise standard procedures to reduce wafer vibration where excessive vibration was identified
- Document new vibration and levelling wafer procedures for implementation into all future routine diffusion tool PMs

The AVS' data logging capabilities also allowed the fab to establish new preventative maintenance requirements and process control standards for both the tools and engineers that are now a part of Best Know Methods in preventive maintenance of tools. As a result, all 13 tools are providing yield at acceptable levels, including the four that were at sub-par levels.

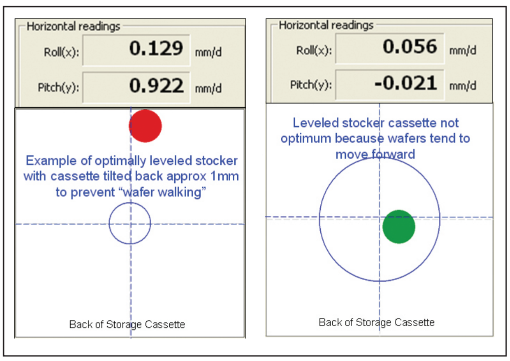

Figure 5