Advanced End Effector Technology for Reduced Wafer Placement Variability and Tool Throughput Gains

Mike Dailey
Fabworx Solutions

Abstract

In certain semiconductor manufacturing equipment today, wafer placement variability has led to process, equipment and yield issues such as edge film thickness nonuniformity, excessive alarms from wafer position sensors and chamber arcing. In response to these issues, many fabs have reduced their robot speeds, but at the expense of tool throughput. Engineers also realized that, even in tools that did not suffer from these specific issues, if they could effectively hold the wafer in place on the end effector, they could then increase their robot speeds and perhaps gain tool throughput.

This paper will present background data that further defines these issues, will propose a new set of end effector requirements, and will describe a new universal and retrofitable robot end effector technology. Data will be presented showing the technology's contribution to wafer placement repeatability and the resulting improvements in process and equipment performance. Additionally, data on particle performance and tool throughput enhancement will be shown.

Introduction

As semiconductor manufacturing technology has evolved, a significant and continuous challenge has been to optimize robotic wafer handling. Accordingly, semiconductor robot designers have gone to great lengths and expense to develop control systems that maximize robot speed while minimizing the possibility of wafer sliding on the end effector. Today, although the capabilities of most robotic drive mechanisms exceed the market's need for resolution and speed, designers are still limited by the robot's mechanical performance attributes and its inability to hold a wafer in place on the end effector.

Problem Definition

To accurately understand the short-comings of current end effector technology and the impact on fab production, Fabworx Solutions™ conducted a series of tests on various mainstream 200 mm and 300 mm process tools. First, a vibration study was performed on a mainstream 300 mm process tool robot arm. The aim of the experiment was to determine the various acceleration forces present during a standard robot arm extension or retraction, and the effect of those forces on the wafer. It was empirically determined that the force required to break the wafer loose from this end effector is approximately 0.09 g's. Figure 1, excerpted from that study, shows theta-direction acceleration (vibration) during a robot arm retraction. The data identifies several long intervals that were well above this breakaway force, indicating many incidents of wafer sliding during a single arm retraction.

A follow-up laboratory study was performed on a mainstream 200 mm process tool robot to look closely at wafer placement repeatability at various robot speed and acceleration settings. In this study, a microscope with a pixel resolution of 0.25 microns was mounted to a frame, and a wafer with crosshairs was placed on the robot end effector. The robot was repeatedly cycled and brought to a programmed position under the microscope. Final wafer position was measured to examine how much it had moved on the end effector (Table 1, Column 2).

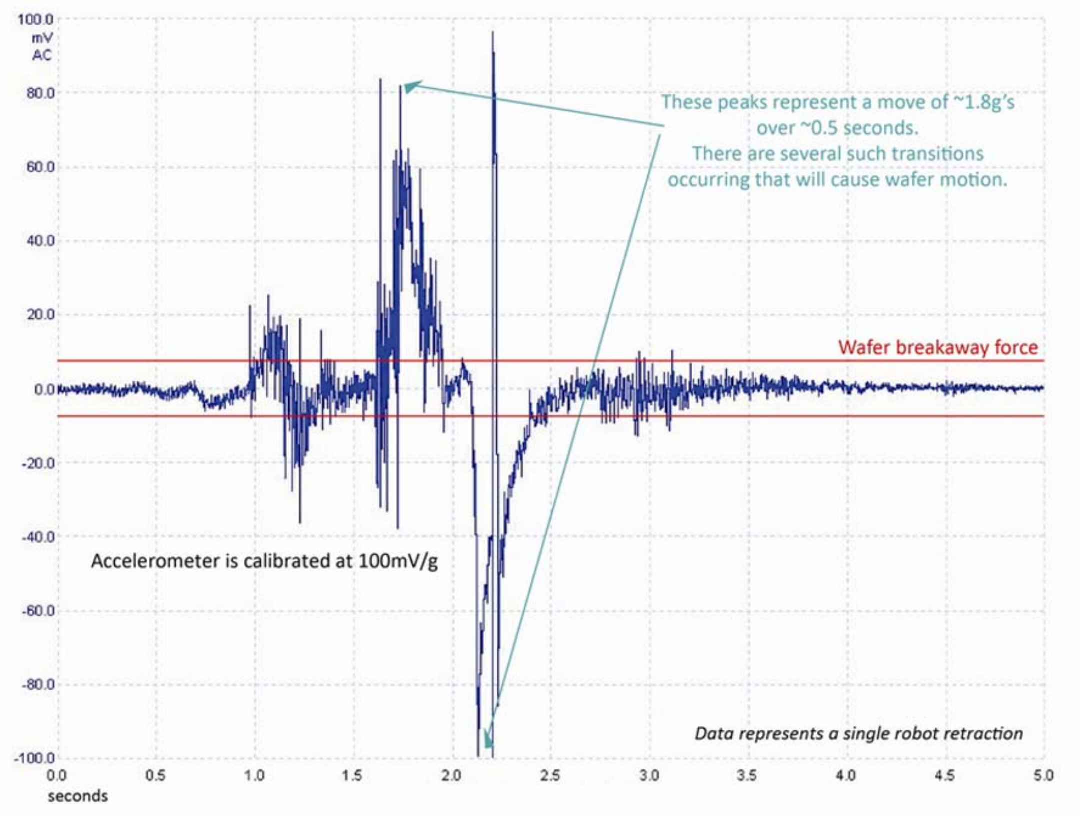

Figure 1. Monitoring Vibration in Theta During a Robot Retraction Move

Repeatedly, the data shows that the acceleration values of the robot vibration far exceed the coefficient of friction between the wafer and the OEM end effector. In other words, the wafer is constantly sliding on the end effector and is often hitting the walls of the pocket. This wafer movement causes particles, creates nonrepeatable wafer placement in the process chamber, and is often a restriction to tool throughput.

Figure 2. Fabworx Gravity Edge Hold End Effector

Gravity Edge Hold Technology

As a result of this study and based on the inputs of several fab engineers, Fabworx defined a list of requirements for a new after-market end effector technology. The new technology must:

- Be compatible with vacuum and atmospheric environments
- Apply to 200 mm and 300 mm wafers
- Have a variety of form factors so that it is retrofitable to a wide array of existing robots on current process tools in fabs
- Require no additional control signal or system software modification
- Meet or exceed performance metrics of existing robotics for particles, metallic contamination and scratches
- Allow the robots to run at their fastest speeds with no trade-off in particles or wafer placement repeatability

As opposed to the harsh edge gripping techniques of many new atmospheric robots, Fabworx sought a gentler approach through the use of a pocket. When a wafer is lowered onto the gravity edge hold (GEH) end effector, the weight of the wafer actuates four small cams located at the wafer perimeter (Figure 2). These cams will realign a wafer that is presented to the robot slightly out of position and will hold it in position during robot movement. When

Robot Acceleration	Aluminum/Nickel End Effector	Gravity Edge Hold
Low *(slope setting of 10,000, robot extend time of ~7.5 seconds)*	+/-0.35 mm	+/-0.01 mm
Moderate *(slope setting of 20,000, robot extend time of ~3.5 seconds)*	+/-0.45 mm	+/-0.01 mm
Very High *(slope setting of 150,000, robot extend time of ~0.7 seconds)*	wafer would not remain on end effector	+/-0.01 mm

Table 1. Wafer Placement Repeatability

Processes tested were BLOk (Barrier Low k) and HARP

- GEH blades installed on 12-9-09
- Scratch test completed (wafers are run upside down to look for scratching across wafers and near cam mechanism). No issues seen.
- Metal contamination test completed. All within spec.
- PARTICLE MONITOR testing complete.
- Cycled 100 wafers before releasing to production. No issues.
- Changed Local Center Find (LCF) warning and fault limits from the OEM-recommended 5 and 10 to 1 and 2. No subsequent warnings or faults seen.
- Run blades in production environment. To date, have cycled over 400,000 wafers with no problems.

BLOk and HARP are registered trademarks of Applied Materials, Inc.

Figure 3. Customer Beta Test Results

lift pins are raised to remove the wafer, the cams simply fall away to their open position.

The primary capture area (cams) is ±0.25 mm. If the wafer arrives out of position, the GEH employs a secondary capture area (sloped walls) of ±1.8 mm. In this case, a wafer will still drop into the pocket and be engaged by the cams. Using the same microscope test fixture described above, wafer placement repeatability using the GEH technology is measured to be ±0.01 mm, regardless of robot speed (Table 1, Column 3).

The first implementation of this technology was for the Applied Materials Producer SE. Based on in-fab testing, all above metrics were met. Previously, the tool's Laser Center Find (LCF) alarm levels were set to 5/10, the loosest available, and alarms regularly occurred. After installation of the

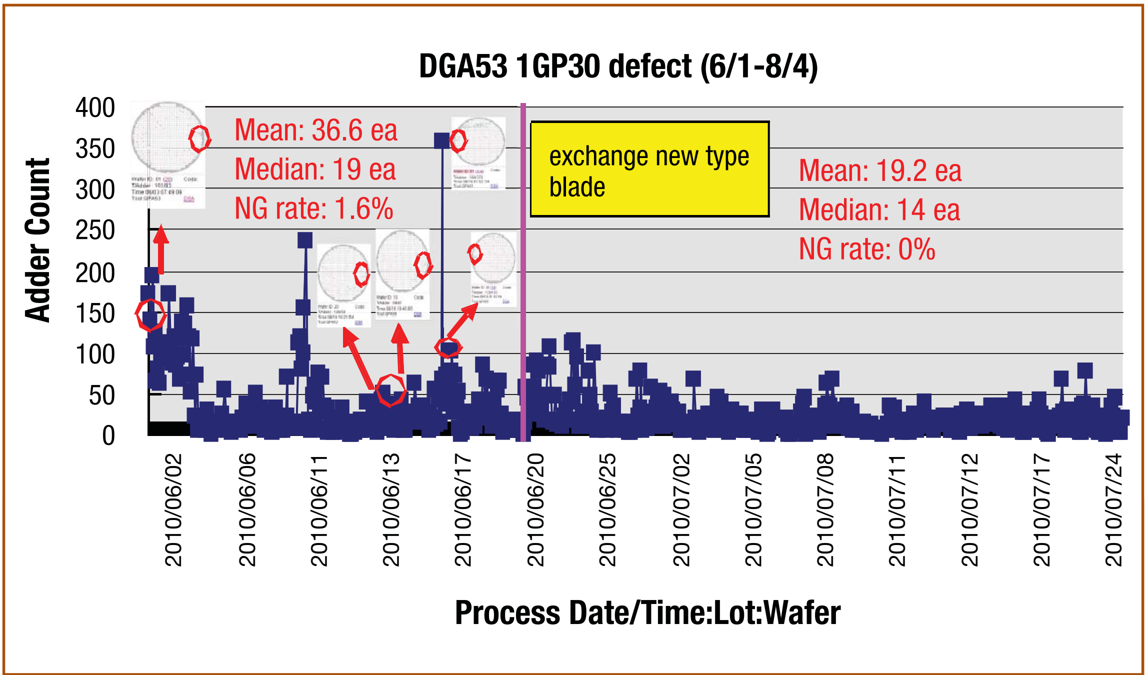

Figure 4. In-line Particle Performance

replacement GEH end effector, LCF alarm levels were set to 1/2, the tightest available. No alarms have occurred since. Chamber arcing has been greatly reduced and film thickness uniformity has improved near wafer edges. Testing was also performed to understand the throughput benefit of higher robot speeds for two particular processes. In one case, a wafer-per-hour increase of 5 percent was observed, and for another, the gain was 15 percent.

The GEH particle performance has been demonstrated to meet or exceed that of the standard OEM end effector. It is well understood that wafer sliding on end effectors generates particles.[1] As indicated in Figure 4, in some cases, particle counts may actually be reduced due to the elimination of this wafer sliding.

Summary

A new end effector technology has been developed to greatly reduce wafer placement variation and eliminate the associated quality problems. Fabworx Solutions' Gravity Edge Hold end effector positions a wafer precisely and repeatedly in a process module, reducing wafer-out-of-position alarms and potentially improving associated process parameters. Further, it captures and re-centers an out-of-position wafer, reducing tool assists and downtime. Particles that are caused by wafer sliding on the end effector are reduced. And existing robots are enabled to run at their highest speeds, both with and without a wafer present, providing wafer-per-hour throughput increases in many process tools.

Reference

1. Angelo, D., Suh, S.M., Khurana, N., & Sankaranarayanan, K. (2004). "Improving Defect Performance through Better System Design." Nanochip Technology Journal. Issue 2, 65-68.

About the Author

Mike Dailey

Mike Dailey received his B.S. in electrical and computer engineering from the University of Wisconsin at Madison. He has held various sales management and technical marketing positions at HP, Novellus and Yarbrough Southwest, and is currently president and CEO of Fabworx Solutions in Austin, Texas. ■