MACHINE FOR PRECISION HIGH-SPEED CUTTING OF SEMICONDUCTOR WAFERS

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Emerging applications in the microelectronics industry impose special manufacturing requirements that are not well addressed by conventional manufacturing techniques. Advances in laser technology, optics and beam steering combined with a better understanding of laser/material interaction make laser micromachining a viable, attractive, cost-effective and in some cases enabling technology to support these applications. Key applications include the following [1]:

- *Scribing low-κ dielectric materials*
  The use of new low-κ dielectrics needed for performance enhancement brings numerous concerns, including thermally or mechanically-induced cracking or adhesion loss, poor mechanical strength, and moisture absorption. With dicing saws, large tensile and shear stresses are imparted at the cut zone, producing significant cracking and adhesion loss, leading to delamination of the metal and low-κ layers. The use of coolant during the sawing process leads to moisture absorption and material behavior which changes over time.
- *Dicing thin silicon wafers*
  As the thickness of the silicon decreases, there is an increase in the vibration of the wafer during conventional sawing. This leads to problems with chipping and breaking of the dice. The increasing presence of metal for test structures on the wafer streets also impedes conventional sawing.
- *Dicing III-V semiconductors*
  Compound semiconductors are starting to find increased application in RF and optical devices. The biggest application is in the light emitting diode market, where the substrates used are gallium arsenide, sapphire, gallium phosphide, and silicon carbide. In these applications, the cost of the substrate is high and the value of the wafers following epitaxy is even higher. However, due to the hexagonal symmetry, mechanical scribe and break leads to poor yield. Sawing uses up too much valuable real estate that could otherwise be used to make real devices.

The ESI Model 2700 Micromachining System uses a laser to cut semiconductor wafers. By focusing the laser beam to a small spot size, the machine is able to cut features of any shape with a cut width as small as 10 μm while maintaining a cutting speed that rivals that of saws for many applications and keeping beam positioning errors under 10 μm over the entire area of a 300 mm wafer. Two different mechanisms are used to steer the laser beam over the surface of a wafer. Large motions of up to several hundred millimeters are made using translation stages mounted on recirculating bearings and powered by linear motors. One stage carries the wafer, while a perpendicular stage carries optical elements to position the laser beam. Small beam positioning motions are performed by a pair of galvanometric scanners mounted on the optics stage, which deflect the beam through a telecentric scan lens and onto the wafer, in a 2 mm square field. A drawing of the laser beam positioning system is shown in Figure 1.

Most traditional laser machining systems use step-and-repeat positioning. They use stages to statically position the wafer, while the scanners direct the beam to any point inside a step-and-repeat field. This can lead to two problems. First, it requires large step-and-repeat fields to minimize the number of slow stage moves between fields. This has the effect of increasing both the cost of the scan lens and the nonlinear positioning errors at the edges of the scan field. Second, it could lead to abutment errors of features crossing the edges of step-and-repeat fields.

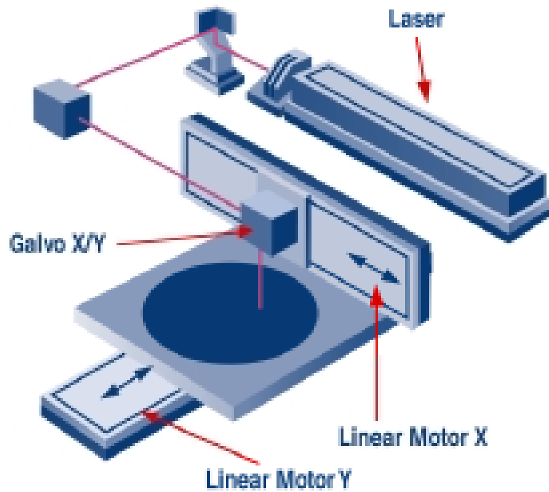

Figure 1. The laser beam positioning system used on the ESI Model 2700 Micromachining System . The beam exits the laser, is deflected by several stationary turn mirrors, is deflected downward by a mirror which moves on the X stage, is directed in X and Y by the galvanometric scanners, then hits the wafer being carried on the Y stage.

The ESI machine avoids the problems inherent in step-and-repeat beam positioning mechanisms by using a patented compound beam positioner [2,3]. The large stages move continuously, tracing the bulk of the beam's desired motion across the wafer, while the scanners steer the beam to generate the fine details of the cut and compensate for any large-stage positioning error. Cuts are made continuously, avoiding abutment errors, while motion between cuts is almost always made by the fast scanners, rather than the slower large stages. The compound beam steering mechanism can thus cut profiles faster and more accurately than a traditional machine. The size of the scan field can be optimized based on speed, accuracy and cost requirements.

A diagram showing the method used to synchronize and control the motions of the stages and scanners and the pulsing of the laser is shown in Figure 2. The laser beam motions required to process a given wafer are calculated before processing begins. All moves are profiled with sinusoidal acceleration, subject to a preset minimum period for the acceleration/deceleration segments of moves and maximum acceleration and velocity limits. The calculated position and acceleration profiles are passed to a fourth-order low-pass filter and then on to the stage controller, where the acceleration is used for feedforward and the position is used for feedback control.

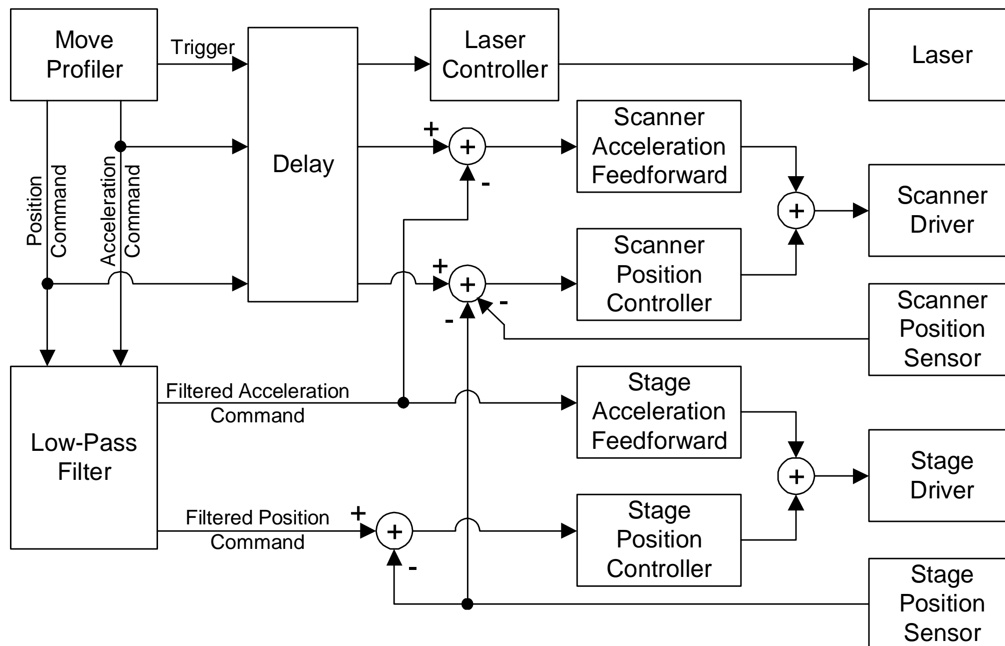

Figure 2. Diagram of method used to control the coordinated motions of the stages and scanners.

The low-pass filter produces phase lag in the stage control signal. If the delay was allowed to remain in the control loop, the scanners would constantly be moving toward their ends of travel as they move the laser beam toward the next hole. To keep the laser beam toward the center of the scan field, a delay is added to the calculated position and acceleration profiles, and these delayed commands are fed to the scanner controller. The scanner controller subtracts the low-pass-filtered stage commands, so the resulting command contains just the higher-frequency components of the total positioning command. As mentioned above, the stage position error (from the filtered stage command) is also fed back into the scanner position command, so the scanners can quickly compensate for whatever stage errors are present, while the stage's controller corrects the errors more slowly.

The ESI Model 2700 also uses special calibration methods to reduce beam positioning errors even further. Using a small amount of scanner angular travel eliminates the need for non-linear calibration of the scan field, minimizing barrel and pincushion optical distortions. Linear stage static errors are then corrected by mapping the workspace with a high-accuracy calibration grid using a machine vision system mounted parallel to the scan lens. Typical uncorrected and corrected errors of the linear stages are illustrated in Figure 3. Application of software correction reduces the static error across the part from 17 µm down to 2 µm. Next, the laser to camera offset, measured as a function of stage travel to account for varying Abbé errors, is corrected by cutting a sequence of features on a wafer and measuring them with the vision system.

Following calibration, during run time, when the wafer is loaded on the machine, the machine vision system looks at alignment features on the wafer and applies coordinate transformations to the toolpath on top of the pre-calculated error corrections. Finally, while the wafer is being cut, the high-bandwidth scanner controller monitors linear stage dynamic position error and moves the scanning beam to compensate. Thus the machine achieves total beam positioning error of less than 8 µm over the entire area of a 300 mm wafer with continuous motion and without stitching step-and-repeat fields. To illustrate this, holes were drilled on a silicon wafer and referred back to the alignment grid using a Nikon

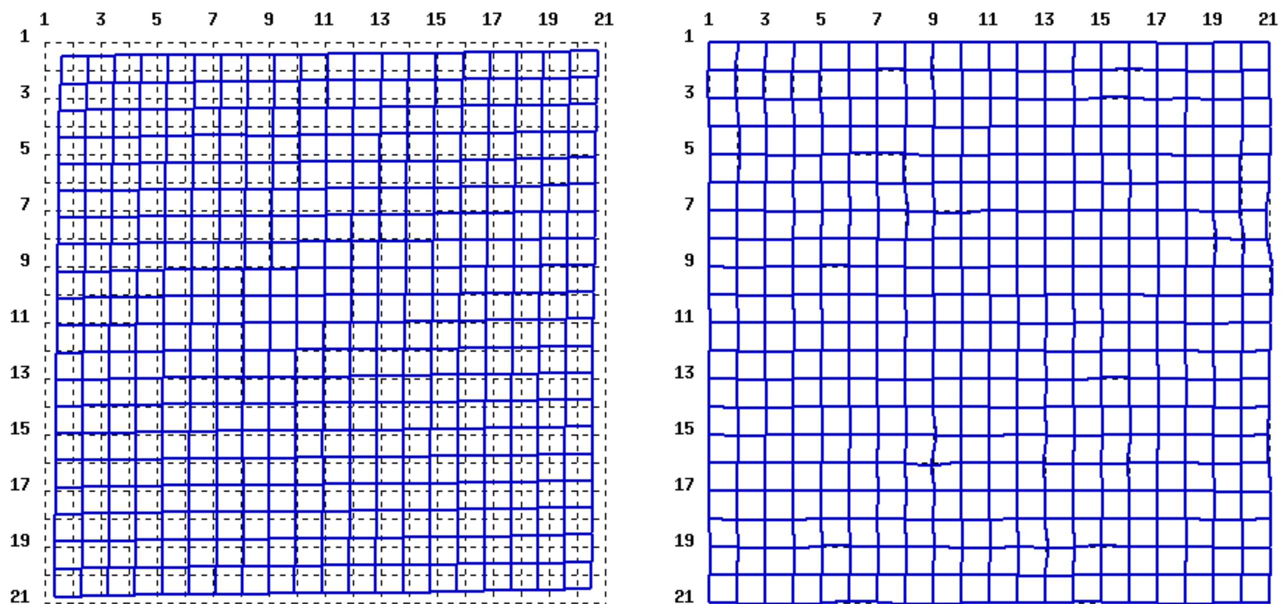

Figure 3: Uncorrected and corrected error plots over a calibration grid. The plot on the left shows uncorrected position, with a maximum error of 17 µm, while the plot on the right shows corrected position with a maximum error of 2 µm.

coordinate measuring machine. A plot of the registration errors of the holes is illustrated in Figure 4. The graphs show that the corrected errors are kept to ±2.5 µm in this test. The normality of the error histogram further illustrates that almost all repeatable geometric errors have been removed using software correction.

The novel beam positioning method of the ESI Model 2700, combined with its thorough error compensation and high-power laser, enable semiconductor manufacturers to maximize their usage of the available space on a wafer and achieve significant quality and throughput gains over traditional dicing machines.

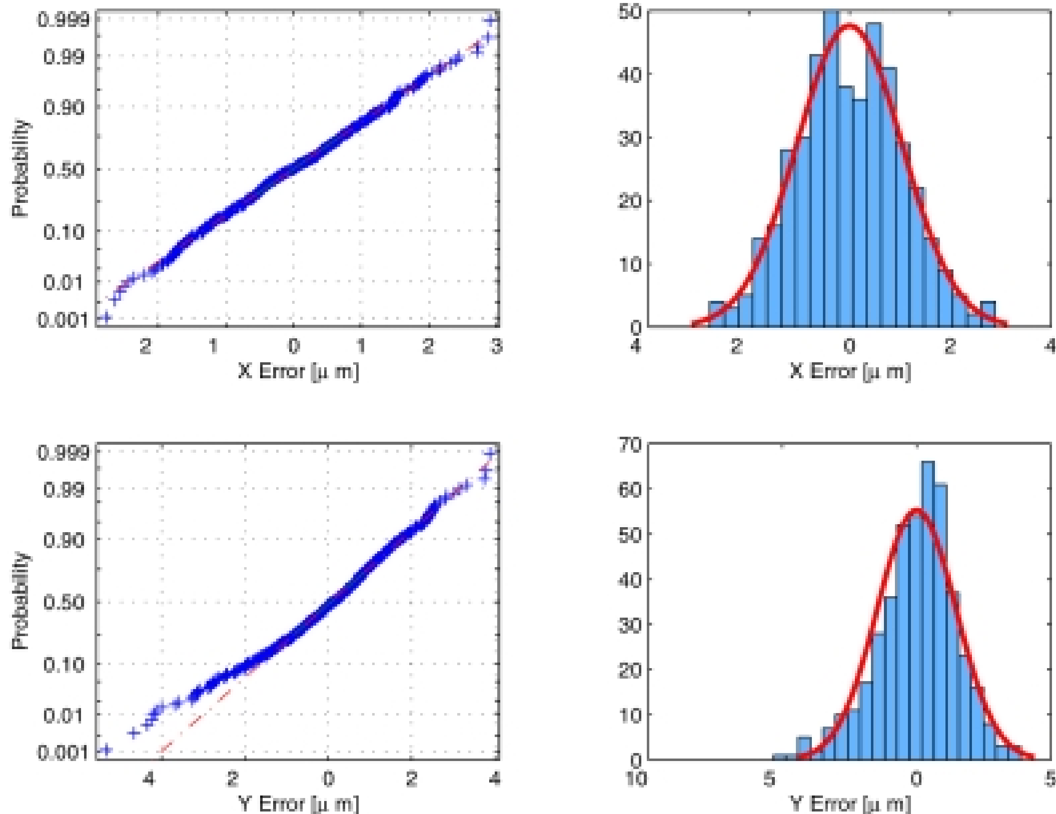

Figure 4: Registration errors, illustrating complete removal of repeatable geometric errors. The lower pair of graphs shows uncorrected error, while the upper pair of graphs shows the error after correction.

[1] Subrahmanyan PK. Laser Micromachining in the Microelectronics Industry: Emerging Applications. In Piqué A, et al., editors: Photon Processing in Microelectronics and Photonics II, Proceedings of SPIE, San Jose, CA 2003; vol 4977, no 26; pp188-197.
[2] Cutler DR, Pailthorp RM, Unrath MA. High Speed, High Accuracy Multi-Stage Tool Positioning System. U.S. Patent 5751585. May 12, 1998.
[3] Cutler DR, Pailthorp RM. Apparatus and Method for Coordinating the Movements of Stages in a Multi-Stage Multi-Rate Positioner System. U.S. Patent 5798927. August 25, 1998.