CONF-961111--1

SAN096-0662C
SAND--96-0662C

POSITIONING PERFORMANCE OF A MAGLEV FINE POSITIONING SYSTEM

John B. Wronosky, Tony G. Smith, Jay D. Jordan, Joel R. Darnold
Sandia National Laboratories, Albuquerque, NM 87185-0501

ABSTRACT

A wafer positioning system was recently developed by Sandia National Laboratories for an Extreme Ultraviolet Lithography (EUVL) research tool[1]. The system, which utilizes a magnetically levitated fine stage to provide ultra-precise positioning in all six degrees of freedom, incorporates technological improvements resulting from four years of prototype development experience. System enhancements, implemented on a second generation design for an ARPA National Center for Advanced Information Component Manufacturing (NCAICM) project, introduced active structural control for the levitated structure of the system.

Magnetic levitation (maglev) is emerging as an important technology for wafer positioning systems in advanced lithography applications. The advantages of maglev stem from the absence of physical contact. The resulting lack of friction enables accurate, fast positioning. Maglev systems are mechanically simple, accomplishing full six degree-of-freedom suspension and control with a minimum of moving parts. Power-efficient designs, which reduce the possibility of thermal distortion of the platen, are achievable. Manufacturing throughput will be improved in future systems with the addition of active structural control of the positioning stages.

The demand for smaller critical dimensions in integrated circuits has driven projection lithography to shorter wavelengths. Research and development to extend this trend to extreme ultraviolet (EUV) wavelengths, in the range of 11 nm to 14 nm, is underway at Sandia National Laboratories in Livermore, California. An EUVL laboratory tool using a 10x reduction Schwarzchild camera and magnetically levitated wafer stage driven by a digital feedback controller facilitate this research. Position stability and accuracy must be precisely controlled to achieve circuit overlay of 100 nm features.

The great expense of the fabs required for integrated circuit manufacturing motivates the emphasis on positioning speed. Increasing fab throughput by increasing the speed of the processing equipment is an economic necessity. For lithography exposure tools, this means minimizing the time spent positioning the wafers between exposures. Unfortunately, regardless of the positioning mechanism, there is a positioning speed limit where further increase in speed results in excitation of structural resonances that degrade accuracy to below acceptable levels. The NCAICM Lithography Structural Control Testbed project develops an active method of structural resonance cancellation. Active structural control is expected to facilitate positioning bandwidth improvement of five to ten times that of the present maglev system.

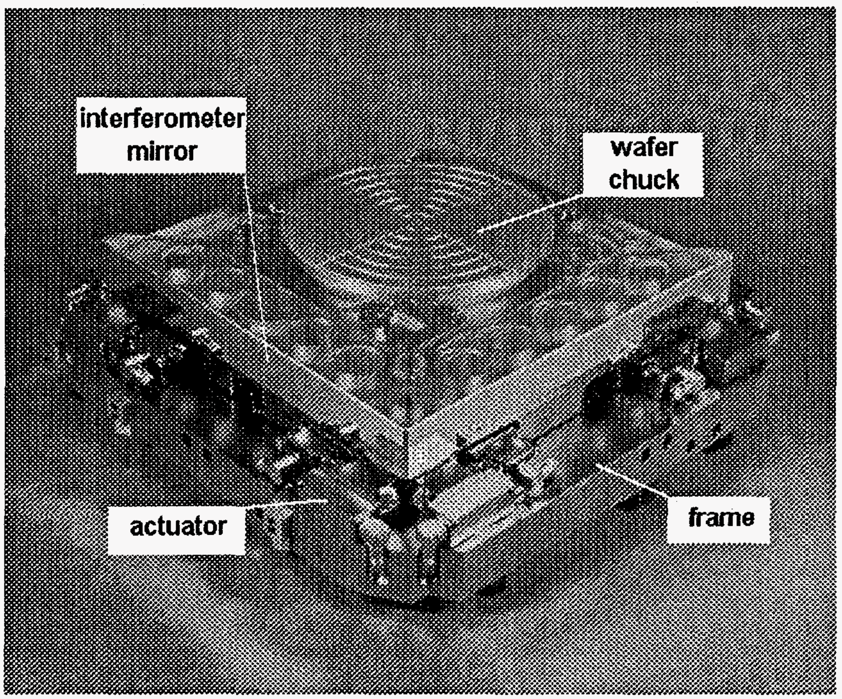
This paper describes the design, implementation, and functional capability of the maglev fine positioning system. Specifics regarding performance design goals and test results are presented.

---

*[1]The EUVL and NCAICM programs, including the subject positioning systems, being performed at Sandia National Laboratories, is supported by ARPA DALP and by the US Department of Energy under contract DE-AC04-94AL85000.

The Maglev Stage

In the late 1980s, a concept for a magnetically levitated fine positioning technique was developed at MIT by Dr. David Trumper. Refinements of the technique, and the design of a control system for its implementation, have resulted in the fine positioning stage shown in the figure below.



The stage consists of the levitated fine stage platen containing sixteen ferrous targets and the interferometer mirror, the frame holding the sixteen E-core electromagnets and six capacitive position sensors. A Hewlett Packard laser interferometry system consisting of five interferometers, two laser sources, beam benders, optical receivers, and high resolution laser axis boards provide position information in all six degrees of freedom. The interferometry can resolve to 0.618 nm in X and Y and 1.236 nm in Z (used only on the EUVL system). The Z axis requires that a wafer be in place to provide a reflecting surface for the light beam. The maglev fine stage utilizes six capacitive sensors for determination of the "gap" between the movable platen and stationary frame. This information is used to linearize the maglev actuator force characteristics for control purposes. The fine stage can be controlled and positioned using only these sensors for feedback, but with less accuracy than that obtainable with the interferometers.

Control System Electronics

Two computers are used in the implementation of the wafer positioning system. An embedded VME-based 486 PC provides the user interface, and a four-processor TMS320C40 board furnishes the control computations. The electronics include a total of seven TMS320C40 DSPs for data acquisition, manipulation, and control. Analog-to-digital I/O is used to gather gap information from the capacitive sensors as well as other miscellaneous system data. Sixteen channels of digital-to-analog I/O control the current amplifiers which drive the electromagnetic actuators.

Custom current amplifiers are used to supply drive current to the sixteen electromagnetic actuators. They are l amp limited, but capable of up to 100 volts output. This provides the inductive magnetic actuator with a fast force response thereby allowing high bandwidth positioning.

System Performance

Measures of system performance are accuracy, repeatability, stability, time required to move to a requested position, and power consumption. For this system, accuracy and repeatability are determined by the performance of the laser interferometry system and the interferometer mirror. The specifications given by Hewlett Packard for the interferometer depend on the application, but both accuracy and long-term repeatability can both be a small fraction of a μm when atmospheric disturbances are not present (as in the vacuum environment seen on EUVL). Errors introduced by mirror distortions are minimized by virtue of the mirror's kinematic mounting scheme, the good thermal properties of the Zerodur mirror material, and the low level of heat dissipated in the maglev actuators.

Elements necessary for achieving very stable positioning are quiet sensors and actuators and a relatively vibration-free environment. The interferometers satisfy the requirement for low noise, as they have less than one least-significant bit of short-term noise. The electromagnetic actuators are also very quiet, due in part to the fact that the force provided is a function of the current in the actuator and the actuator inductance is large. The vibration-free environment for these systems is generally provided by setting the system on a table that is isolated by pneumatics or elastomers from the floor vibrations. This attenuates high-frequency motion, but amplifies motion at the resonant frequency of the isolation system, which the maglev control system must reject. In order for the maglev system to be able to compensate for this motion, the bandwidth of the control system must be higher than the resonant frequency of the isolation system. Another source of vibrations that can cause significant difficulty at this level of accuracy is sound waves. The amplification and transmission of ambient acoustics by the isolated table can easily dominate the system error. Degradation of stability by a factor of four has been observed when the system is exposed to the noise in a clean room without an acoustic enclosure around the isolated table. In quiet surroundings, positioning stability of 1.5 nm RMS (one axis) has been achieved. For two axes, the actual position of the platen is within 5 nm of the desired position 99.3% of the time.

The time required to complete a move is a function of many variables, including the force available from the actuators, the dispatch with which the force can be produced, the bandwidth of the control system, the maximum velocity capability of the interferometers, and the rigidity of the supporting structure. The actuators are capable of producing force sufficient to generate accelerations of over 1g. The rapid generation of the required force is hindered by the large inductance of the actuators, so 100V amplifiers are used to effect the desired actuator currents in a timely manner. High controller bandwidth is crucial to quick step and settle times, but can be quite difficult to achieve due to system structural resonances. These resonances cause the control system to become unstable as the bandwidth is increased. To overcome this problem, piezoelectric actuators are embedded in the levitated platen and are used to suppress the resonances induced by the maglev controller. A bandwidth of 150 Hz was attained in this manner. The laser interferometer system is capable of a peak velocity of 400 mm/sec. This is not a limiting factor on short moves, as that velocity may only be required for a brief duration or not at all. The primary problem that must be overcome to enable rapid step-and-settle times is the lack of rigidity in the supporting structure. This includes the table the system is mounted to, the structure holding the interferometry components, and the isolation system. Most of these items are not difficult to address, but their importance must be understood by the equipment designers - these are not generally elements that can be fixed with a band-aid late in the development cycle. The biggest challenge is the isolation system, because of conflicting requirements placed upon it. The isolation system must be compliant to provide the desired isolation from floor vibrations, but when a large move is undertaken this compliance allows the impulse seen by the isolation system to set the assembly into motion at its resonant frequency. There are several potential fixes, including the use of an active isolation system, shaping the move profile to minimize residual motion, and modifying the isolation system to pass the reaction forces directly to a mechanical ground. An active isolation system has been tried, but with limited success. The other approaches have not been tried, and would be appropriate avenues for future work.

To illustrate the capabilities of the system as it now exists, a move of 20 mm (a reasonable step size for semiconductor photolithography) is executed in a time-optimal fashion with peak available acceleration of 10 m/sec^2 and peak attainable velocity of 400 mm/sec. The move is completed in under 90 msec, with the deviation from the desired trajectory never exceeding 15μm. Due to the residual vibrations, however, it takes the system another 70 msec for the error to drop below 1μm, and another 100 msec beyond that to reach steady state. Again, this situation could be greatly improved by the application of the techniques noted above.

The last measure of performance mentioned above is the power dissipated in the actuators. This is important to minimize any thermal distortions that could degrade the positioning accuracy. By using permanent magnets to offset gravity, the power dissipation is made very low. Power consumption is on the order of 0.1W while stationary, and only a few watts are dissipated during a move, depending on the size of the move, the bandwidth of the controller, and the maximum acceleration requested.

REFERENCES

1. Tichenor, G. D. Kubiak, S. J. Haney, R. P. Nissen, K. W. Berger, R. W. Arling, A. K. Ray-Chaudhuri, K. B. Nguyen, R. H. Stulen, J. B. Wronosky, J. D. Jordan, T. G. Smith, J. R. Darnold, P. M. Kahle, A. A. Jojola, S. M. Kohler, R. S. Urenda, D. R. Wheeler, J. E. Bjorkholm, O. R. Wood, II, G. N. Taylor, and R. S. Hutton, "**Recent results in the development of an integrated EUVL laboratory tool,**" Proc. of the SPIE Symp. on Electron-Beam, X-Ray, and Ion-Beam Submicrometer Lithographies for Manufacturing V, vol. 2437, 292 (1995).

2. R. W. Arling, S. M. Kohler: "**Six Degree of Freedom Fine Motion Positioning Stage Based on Magnetic Levitation**", Second Annual Symposium on Magnetic Suspension Technology, Seattle, WA., August 11-13, 1993.

3. J. B. Wronosky, T. G. Smith, J. R. Darnold: "**Development of a Wafer Positioning System for the Sandia Extreme Ultraviolet Lithography Tool**", Third Annual Symposium on Magnetic Suspension Technology, Tallahassee, Florida, December 13-15, 1995.

4. J. B. Wronosky, T. G. Smith, J. R. Darnold, J. D. Jordan,: **"Maglev six degree-of-freedom fine position stage control system",** The Signal Processing Applications Conference & Exhibition at DSPX 1996.