Nikon Electron Projection Lithography System: Mechanical and Metrology Issues

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Electron Projection Lithography (EPL) is one of the leading candidates to replace optical lithography for the patterning of the fine integrated circuit (IC) patterns that will be produced in the near future. This technology is expected to be used in production at the so-called "70 nm Node," where the patterns on the IC's can be as small as 70 nm lines and 70 nm spaces. This technology is expected to be in production beginning in the year 2005.

Nikon has been working in collaboration with IBM on this technology for several years, beginning prior to 1995. Now, several key technology areas have been developed and the design of a prototype system is in process.

In the EPL system the exposure process is accomplished by directing a beam of electrons through a reticle or mask, and imaging the reticle pattern onto a silicon wafer at a demagnification of 0.25 X. The electron optics between the reticle and wafer precisely deflect the electron beam to sequential positions on the reticle and wafer, and make corrections to the beam positioning to correct for stage location errors. The beam is electronically deflected mainly in the X direction while the stages are scanned in the Y direction, simultaneously correcting for the relative stage motion and any known position errors. See Figure 1.

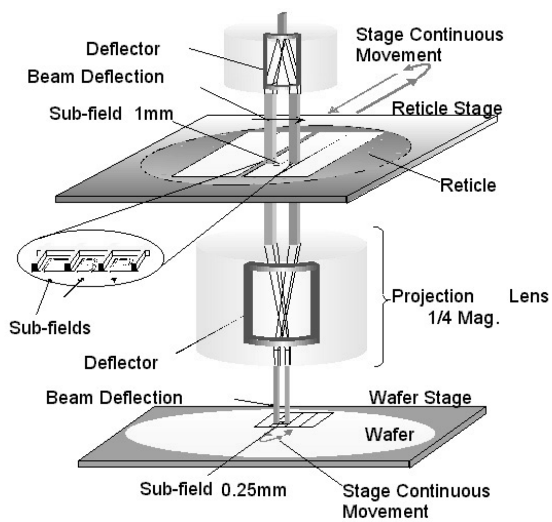

Figure 1. EB stepper exposure process

The reticle itself is made from a 200 mm diameter silicon wafer. The reticle pattern is a 2 dimensional grid of 1x1 mm patterns, subsequently reduced to 1/4 mm x 1/4 mm patterns on the wafer. These reticle patterns consist of a thin membrane supported on a grill structure etched into the silicon (Figure 2).

Electron beam columns have been built at Nikon and IBM to obtain test data and to demonstrate the viability of the electron optics system concept. These columns have been used to demonstrate the excellent resolving ability, shown in the Figure 3, as well as many other basic performance characteristics needed for the next generation of IC's.

In addition to resolution, one of the essential requirements of IC lithographic patterns is the ability to align a pattern being exposed to other patterns on the wafer. As a general rule, the total alignment tolerance is about 1/3 of the linewidth being patterned. For 100 nm lines, this amounts to about 35 nm total from all error sources. Making a system error budget by dividing this error into allowable errors from various sources results in an allowable positioning error from any given source which is very small, typically around 1 to 10 nm. This places a severe challenge for the machine design. In addition, the stages must move at high velocities and be capable of high acceleration in order for the system throughput to be high enough for the machine to be marketable.

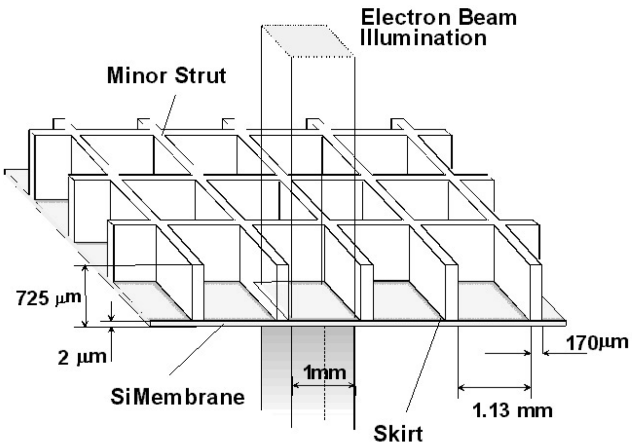

Figure 2. Local structure of Silicon stencil reticle

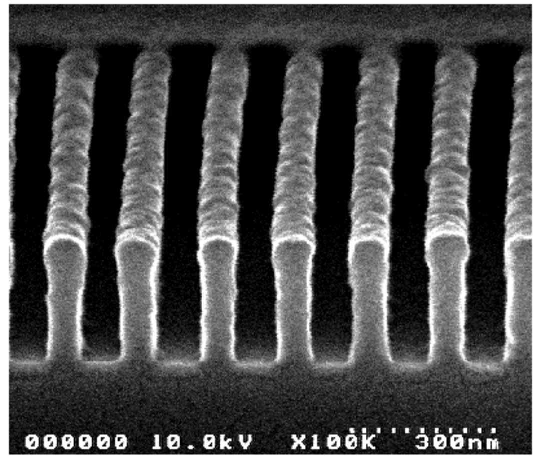

Figure 3. SEM of 80 nm lines and spaces

Nikon has a long history of over 22 years of precision stage development for their lithography systems. Recently, the stages have been based on air bearings and linear motor technology. It is desirable for Nikon to utilize this technology for the EB systems, but the requirements for the EB stages are much different than their optical counterparts.

The stages must operate in a vacuum and cannot cause deterioration to this environment because of gas leakage or outgassing. Air bearings cannot be used without elaborate methods to remove the air escaping from the bearings and effectively prevent air release into the vacuum chamber.

Another major consideration is that the electron beam is extremely sensitive to magnetic fields. Any motors or actuators must be designed properly and be well-shielded to prevent stray magnetic fields, which will shift the X-Y placement of the beam.

Additional considerations make the EB stages more difficult to design and manufacture compared to the optical counterparts. However, a key mitigating factor makes the system design reasonable. The ability to deflect the electron beam acts as a high bandwidth fine stage to make corrections to the stages' position. Thus the stages can have micron level positioning ability compared to the optical system stages' nanometer positioning ability. Figure 4 shows a computer rendering of the electron optics column and the reticle and wafer stages.

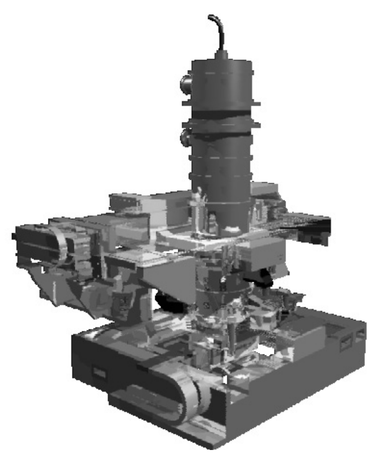

Figure 4. EB column with stages

In order for the electron optics to correct for the stages' positioning errors, the system metrology must still have nanometer level accuracy. The system must be able to determine these errors precisely. This requires considerable attention in the design of the metrology subsystems. Error sources can include component thermal expansion, component and body distortion due to moving stages, vibration, electronic noise, and electronic drift. The laser interferometer system must be extremely stable, and the data timing must be stable and known precisely. If the wafer stage is moving at 200 mm/second, a 5 nsec timing error can cause 1 nm position error, which is considered significant.

Our goal is to maintain a system vacuum level of 10^{-6} Torr. Nikon built a chamber to test and evaluate vacuum compatible air bearing designs. One test fixture is shown in Figure 5. Using this test fixture, data were obtained and the results compared to analytical models. From this, vacuum compatible designs have been made which we think will have acceptable performance in the Nikon EPL system. The bearings perform like a conventional air bearing with typical flows, gaps, and stiffness. In addition a series of pump out grooves are used to scavenge the air escaping from the bearing before it leaks into the main vacuum chamber.

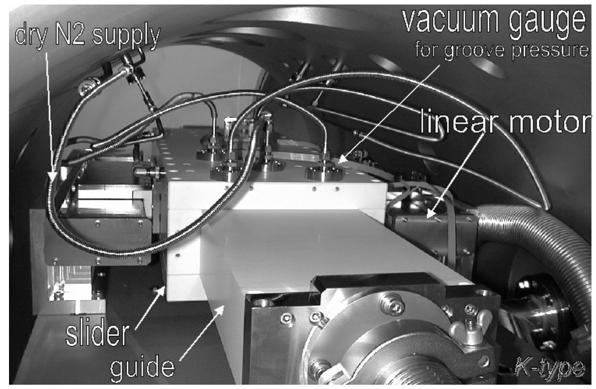

Figure 5. Vacuum air guide test fixture

The management of the magnetic fields near the electron beam is another key design consideration. Electron beams are very sensitive to magnetic fields: AC fields perturb the e-beam while DC fields can, in principle, be calibrated out. However, DC fields can perturb the e-beam if any magnetically permeable materials near the column move. When these materials change position, the DC fields change in position and magnitude, thereby causing the beam to be deflected some amount. If this change is not measured or calibrated out, the result is a beam positioning error. The exposed image is then incorrectly aligned on the wafer. The fields can be external to the system or can come from actuators within the system (eq. Stage motors, loaders, vibration/isolation actuators). For moving magnetic material, even the DC lens fields are a potential problem. Positioning accuracy puts severe limits on beam motion, while throughput almost certainly require stage motors much closer to the column than in previous e–beam systems. These conditions require a system level approach to magnetic shielding.

Both AC and DC magnetic fields from linear motors have been measured by performing experimental studies and have been modeled with computer modeling software (FEA). These magnetic characteristics have been incorporated into the magnetic shielding design. One mitigating factor is that during scanning, the stage moves at constant velocity with low currents to the motor windings. Therefore AC fields from the motors during scan are expected to be much less than during stage acceleration.

The EPL System main body structure has been designed to minimize overall distortion under vacuum loading and stage movement, and particularly the distortion of the stage and metrology components. The vacuum chambers containing the stages are accessible for maintenance via large panels and smaller windows. A version of the main body design is shown in Figure 6.

In order to reduce body vibration and distortion, the reaction forces from the wafer and reticle stages are isolated, and brought out to a reaction frame. This reaction frame is independent from the main body, and is attached to ground. As the stages accelerate and decelerate, these forces are not applied to the body structure containing the metrology and the electron optical components.

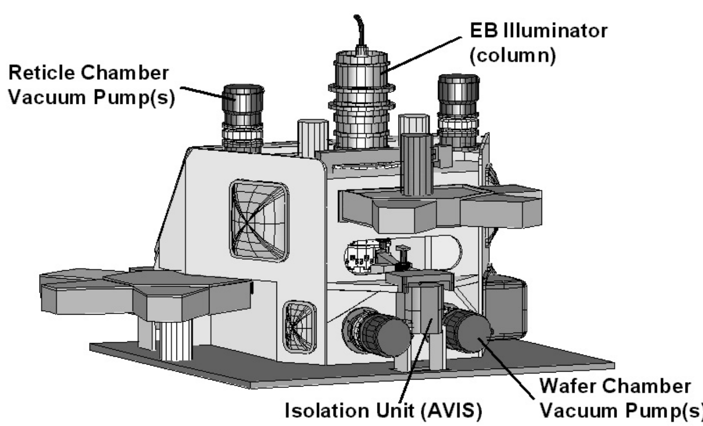

Figure 6. EB body with main components

Figure 7 shows a simplified block diagram of Nikon's EB system mechanics. As can be seen from this diagram, there are many subsystems that are inter-related and must perform in synchrony to achieve acceptable final results. In addition to the electron optics and the stages, there are substrate handling subsystems and vacuum pumps and components. Additional key elements that relate to substrate positioning are optical alignment microscopes, autofocus and autoleveling sensors (AF/AL) and a backscattered electron detector. This last unit can be used to determine the position of the electron beam relative to alignment targets on the silicon wafer substrate or wafer stage.

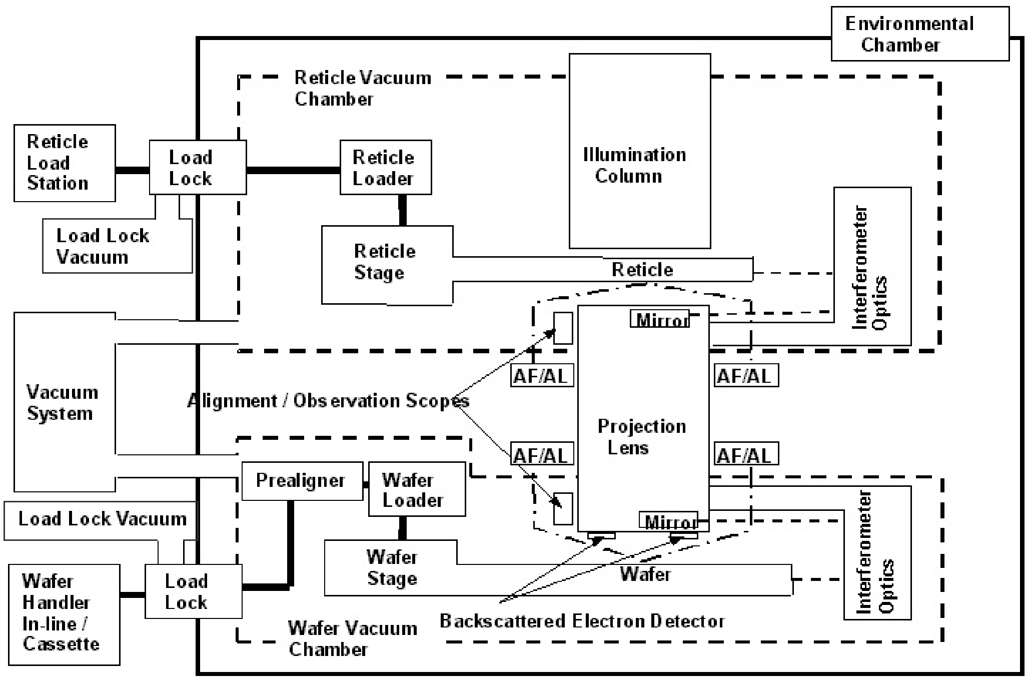

Figure 7. System block diagram of Nikon's EB system mechanics

Many man-years of engineering effort have been spent by Nikon together with IBM developing this next generation lithography tool. The concept and design model for the EB structure and configuration have been developed. FEA modeling of various parts of the structure has been done to optimize vibration modes, structural rigidity and distortion under loads. Thermal analysis has been done to understand and improve the design of the stages, actuators, and electron optics components. Experimental tests, theoretical analysis, and FEA models have been used to study and optimize the magnetic components of the system and the air bearings used in the stages. Further development and modification of the entire concept is being done to address cost reliability, throughput, and production issues. This effort together with IBM's electron optics expertise and Nikon's system and precision stage experience will ensure the achievement of a high throughput and high performance EPL system.

ACKNOWLEDGEMENT

The authors wish to thank M. Sogard and A. Hazelton of Nikon Research Corporation (NRCA); T. Miura, K. Suzuki, T. Yamaguchi, K. Okamoto and Y. Okubo of Nikon Corporation; and H. Pfeiffer, R. Dhaliwal, M. Gordon, R. Kendall, W. Stickel, and J. Rockrohr of IBM Corporation for their contributions both directly and indirectly to this paper.

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