Evaluation of a Next-Generation Vector Electron Beam Mask Pattern Lithography System

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Abstract:

A new vector electron beam mask pattern generation system has been developed for high throughput 0.25 μm design rule and below reticle production. The UltraBeam V2000 is based on the core technologies introduced in the EBES 4.0 system developed previously by Lepton, Inc., which included a unique vector scan architecture, high brightness Thermal Field Emission (TFE) source, as well as a 500 MHz chip set.[1] The new UltraBeam system features a number of significant hardware and software enhancements which have resulted in increased precision in the multilevel deflection and stage control systems. In addition, a new writing strategy featuring a soft boundaries vector writing technology has been developed, allowing the UltraBeam V2000 to meet the resolution, accuracy, and edge placement precision required for subresolution applications such as optical proximity correction (OPC).

This paper describes the new hardware and software features of the V2000 and summarizes the performance of the new system in the areas of CD uniformity, placement accuracy, overlay, and CD linearity. In addition, a comparison will be made of the writing times achieved for advanced commercial production masks.

Keywords: Maskmaking, UltraBeam, pattern generator, vector

1.0 Introduction

In order to meet the production requirements of reticles for 0.25 µm design rule and below ICs, a new technological approach is needed to significantly improve the accuracy and productivity of advanced e-beam tools used for the most demanding reticle applications.

Rapidly shrinking device geometries and increasing device densities are placing new requirements on leading-edge e-beam systems' ability to write mask features uniformly and place them accurately. In addition, the transition from 5X to 4X lithography systems accelerates the decrease in reticle geometry sizes. Also, as chipmakers continue to push the boundaries of optical lithography and extend the capabilities of their existing technology, they are putting new mask techniques such as phase shift and optical proximity correction (OPC) into production. The addition of these subresolution features further challenges the technical performance of e-beam tools.

Therefore, along with better technical performance, mask makers will also require higher writing rates. This combination will allow them to continue producing masks with increased design complexity, resulting in a much higher data volume, while remaining cost-effective. Furthermore, advanced logic and memory devices require a greater number of masking levels. This creates capacity and return-on-investment concerns for maskmakers due to the elevating cost of their most advanced e-beam tools.

The UltraBeam V2000 addresses these difficult issues with its next-generation vector e-beam system. A comprehensive analysis of the previous system's error budget resulted in a major re-engineering program to improve the accuracy of the multilevel deflection writing system and the stage. In addition, several software enhancements were added including a new compressed format, extended addressing capabilities, and a new soft boundaries writing strategy. The soft boundaries writing strategy was developed in order to give the system more flexibility in writing across cell boundaries. This way, the figures written across the cell boundaries do not have to be cut, resulting in improved CD uniformity by eliminating butting errors in critical dimensions.

The V2000 achieves this improved technical performance while maintaining high throughput by relying on the system's vector writing strategy. This fundamentally efficient writing strategy is bolstered by a 500 MHz chip set that allows the system to write at a high rate. The system's high brightness 20 kV thermal field emission electron gun produces a 250 nA current into a 1/8 micron beam size. This yields a current density of up to 1600 A/cm^2 and, at a writing rate of 500 MHz, results in an exposure dose of 3.2 µC/cm^2. A range of doses from 0.64 C/cm^2 to 32 C/cm^2 can be achieved using the full range of both the chip set and the allowable current.

2.0 Improved System Architecture

The core technologies of the V2000 have been previously described.[2] The basic column design and system architecture are shown in Figures 1A and 1B. They include a multilevel vector architecture which is composed of a 2 µm, 32 µm, and 256 µm deflection system. These three independent deflection systems are used to position and write the reticle features.[3] The independence of the deflection systems allows each of them to be optimized for speed and accuracy based on the requirements of the features being written.

As shown in Figure 2, a detailed error budget was developed which accurately predicted the previous system's performance. Based on this model, several large contributors to system performance were improved, including all three deflection systems and the stage. For example, the 2 µm electrostatic deflection system was redesigned to reduce cross talk and improve impedance matching. In addition, the electrostatic 32 µm system was redesigned in order to provide for a more linear field. More bits were added to all of the systems, including the 256 µm magnetic deflection system, in order to provide for dynamic correction of field non-linearities. Also, dynamic correction of stage yaw was added to the digital signal processor. Figure 1B highlights all the improved modules in the hardware control system.

3.0 New Writing Strategy

In the previous tool's writing strategy, shown in Figure 3, design figures were fractured by data preparation software into cells containing macro figures of rectangles, trapezoids, or triangles with dimensions of up to 32 microns. The macro figures were further decomposed by hardware into micro figures with a maximum size of 2 microns. These micro figures were then written at high speed by the 2 µm electrostatic deflection system by stepping the 125 nm beam in the direction of the long axis (in either X or Y direction) of the micro figure. The origin of each micro figure was placed by the high accuracy, electrostatic 32 µm deflection system and multiple micro figures were combined to form the design figures. The cell had a fixed size of 32 microns. The 256 µm magnetic deflection system stepped out a column of 32 x 32 µm fixed-size cells to form a stripe eight cells high or 256 µm high by the width of the pattern file. The stripe height was fixed at 256 microns.

The V2000 incorporates a new writing strategy referred to as the "soft boundaries" writing strategy, shown in Figure 4. The new writing strategy is embodied in the new compressed format which allows for the expression of repeated data which reduces data transfer time and data storage requirements. With the soft boundaries writing strategy in the new format, the absence of rigid cell boundaries means that figures do not have to be cut on cell boundaries and stripe boundaries as was previously necessary. The elimination of butting errors in critical dimensions results in improved CD uniformity performance. Cell sizes are now variable, can extend over stripes, be of any size up to a maximum of 32 x 32 microns, and overlap in extent. Also, micro figures can extend over the maximum 32 micron cell boundary.

As shown in Figure 5A, the micro figures can be a maximum of up to 2 x 2 microns, composed of multiples of the 1/8 micron beam. However, the origins of these beam spots can be placed on nominal 1/64 micron addresses, causing the edges to be pulled in or pushed out in 1/64 micron units as shown in Figure 5B. Dose is maintained constant by varying the clock frequency on the fly. This allows for continuous addressing from 20 nm up to approximately 130 nm.

4.0 UltraBeam V2000 Performance Results

The significant hardware and software enhancements has resulted in improved system performance, as shown in the product performance specification shown in Figure 6. The V2000 recently completed its phase one factory acceptance testing. A FAC test plate was written once per day over a one-week period. Figure 7 shows that the system readily meets its placement accuracy specification of 35 nm and that the maximum overlay performance was well under its 25 nm specification. Figure 8 shows that both local and global CD uniformity met the 35 nm specification while CD linearity was well under its specification of 20 nm. For the purposes of separating the inherent composite nature of the CD uniformity specification, UltraBeam has defined global CD uniformity as the effects of beam stability, depth of focus, and material effects while local CD uniformity addresses the impact of deflection distortion and stripe butting.[4]

Figure 9 shows the overlay performance achieved by a 2-point overlay of four six inch plates. The maximum overlay error achieved was 10 nm in X and 14 nm in Y. In addition, the maximum error in X was 23 nm and the maximum error in Y was 25 nm.

Figure 10 shows a comparison of write times achieved by different mask writing systems on a variety of production plates. The total write time achieved by the V2000 vector system on an advanced memory metal level was 182 minutes compared to 167 minutes for the laser beam system. On an advanced memory contact level the results were even more impressive, with the V2000 attaining a write time of 68 minutes versus 210 minutes for the laser system. Finally, on an advanced microprocessor metal level, the V2000 achieved a write time of 208 minutes versus 184 minutes for the laser beam system. In general, the write times achieved by the V2000 were either comparable or significantly shorter than those attained by the laser beam system.

5.0 Conclusions

The UltraBeam V2000 represents a significant improvement in technical performance versus the previous vector electron beam system. The increased accuracy of the system is achieved by several hardware and software enhancements, including development of a new soft boundaries writing strategy. In addition, a comparison of writing times for a variety of mask designs shows that the V2000 is capable of maintaining a high writing rate due to a bright electron source which produces high current density and an efficient writing strategy. In general, the write times achieved by the V2000 vector system were comparable to those attained by the laser beam system. This demonstrates that the V2000 is capable of delivering advanced technical performance without compromising throughput.

6.0 Acknowledgments

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7.0 References

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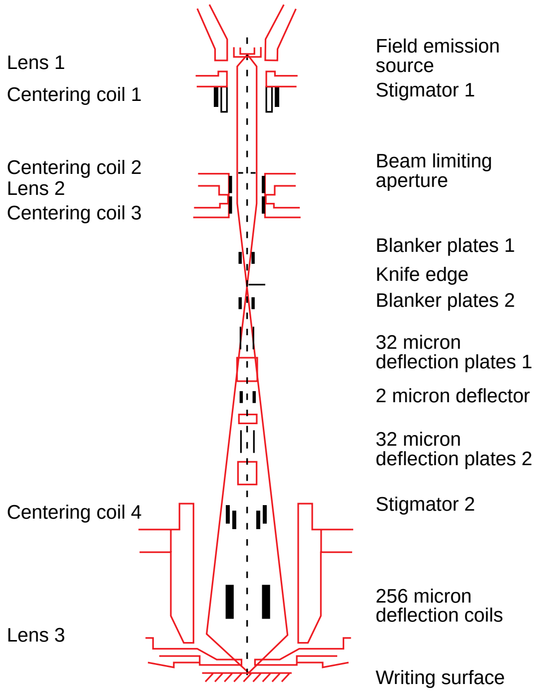


Figure 1A: UltraBeam electron optics

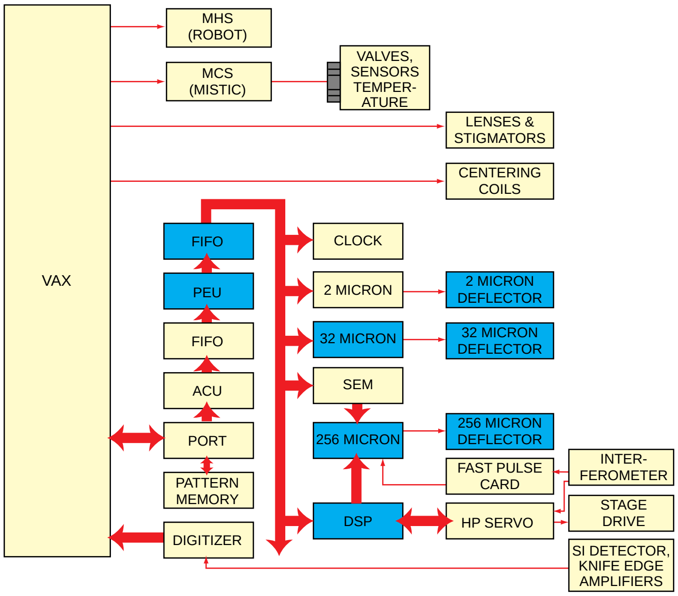


Figure 1B: UltraBeam hardware control

Parameter	EBES4	UltraBeam V2000
Noise	4.2	3.0
32 digitization	1.8	1.0
32 performance	4.5	1.4
256 digitization	2.4	1.1
256 performance	2.0	2.0
Stage digitization	2.0	0.6
Beam distortion	2.0	2.0
32 field distortion	2.0	1.0
256 field distortion	2.0	1.0
32 deflection alignment	2.0	1.8
256 deflection alignment	2.0	1.8
256 setting	1.0	1.0
32 setting	1.5	1.5
256 crosstalk	3.0	3.0
2 crosstalk	1.0	0.8
Drift	5.0	4.0
3 Sigma	**32**	**23**

Figure 2: CD error budget improvement

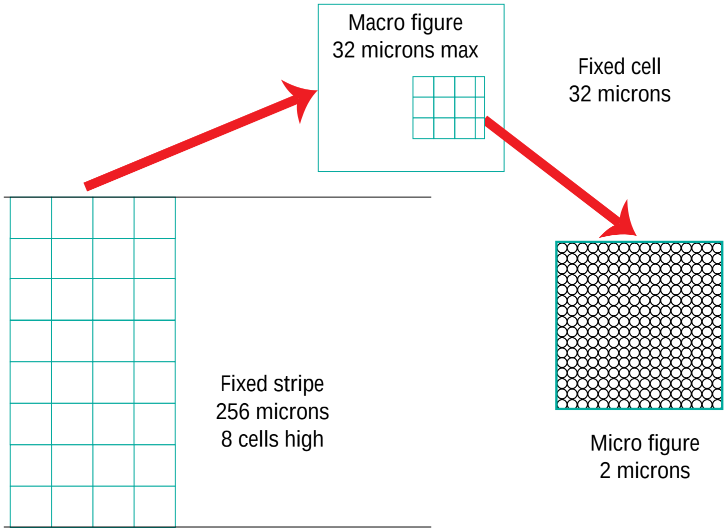


Figure 3: Original writing strategy

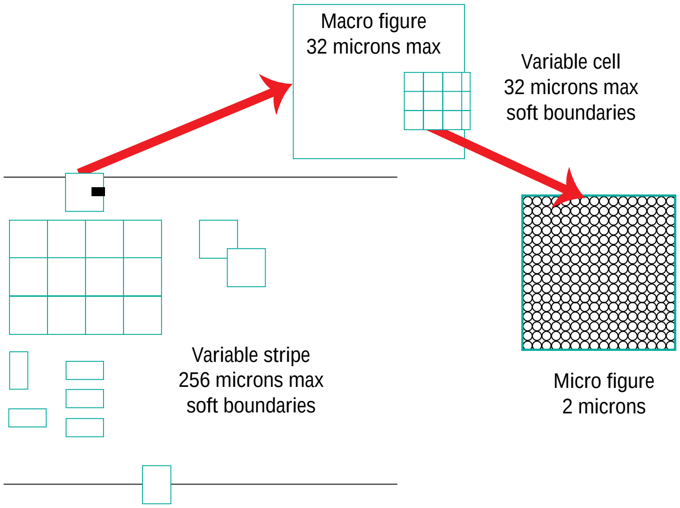


Figure 4: New writing strategy

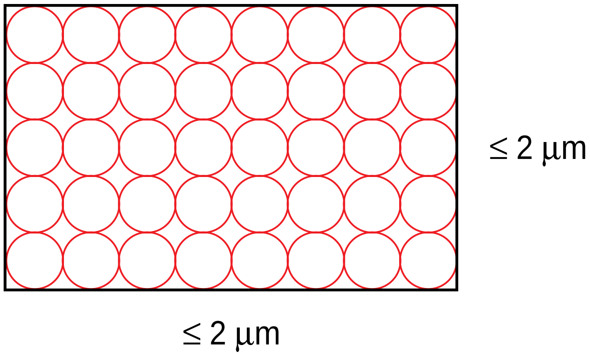


Figure 5A: Normal micro figure

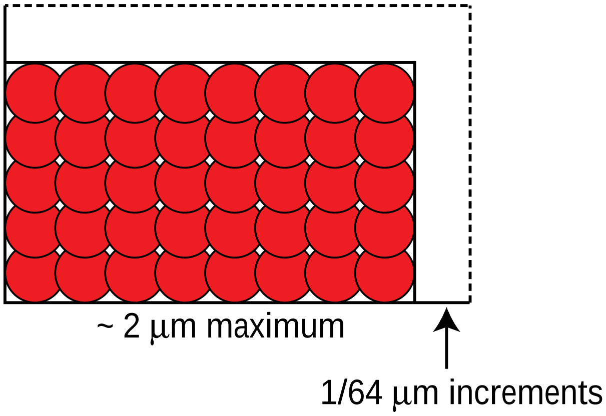


Figure 5B: Micro figure - edges pulled in by 1/64 µm increments

Parameter	Specification
CD uniformity	35 nm
Placement accuracy	35 nm
Overlay accuracy	25 nm
Design grid	20 nm
Mask size	5, 6, 7 inch
Mask minimum feature	250 nm

Figure 6: UltraBeam V2000 specifications

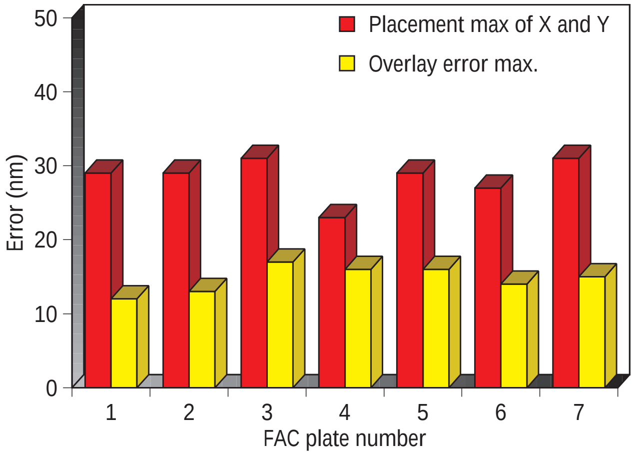


Figure 7: Placement and overlay accuracy

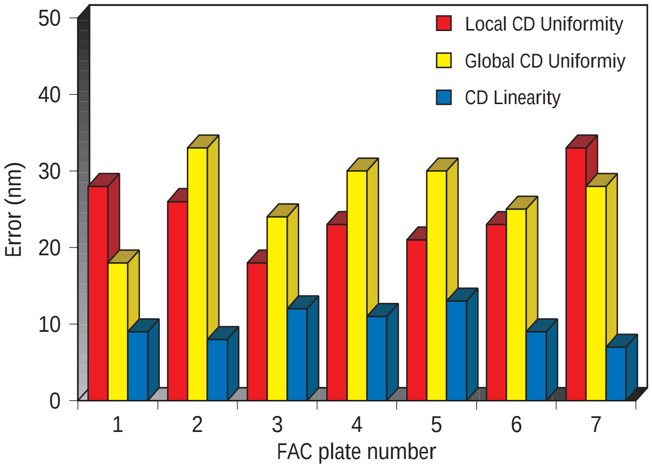
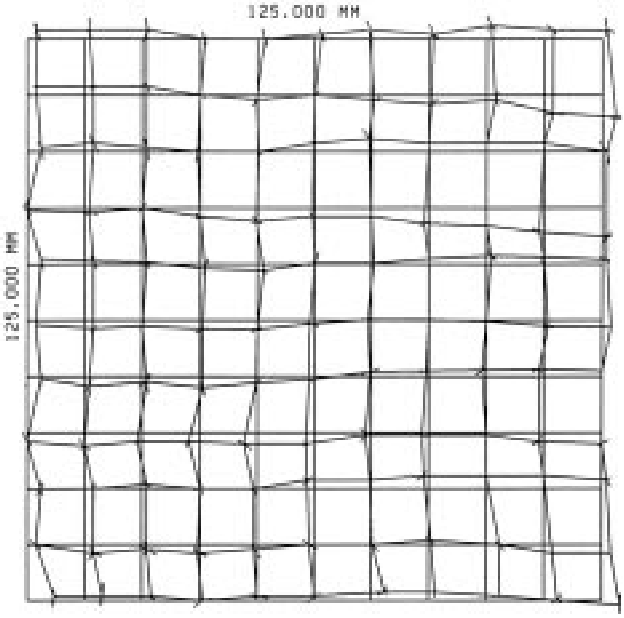


Figure 8: CD uniformity performance



By axis:	X	Y
Max error	23	25
Overlay max	10	14

H scale = 50 nm
V scale = 50 nm

Figure 9: Overlay performance: Two-point overlay of 4 six-inch plates

Device	Layer	Description	Laser Beam	V2000 Vector E-Beam
Advanced Memory	Contacts Metal	 0.12 µm jogs	210 167	68 182
Advanced Micro-processor	Metal	Advanced 5X stepper	184	208

Figure 10: Write time comparison (tool write time in minutes)