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Sub-0. 1-μm Ion Projection Lithography

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Ion Projection Lithography (IPL) uses demagnifying ion-optics for reduction printing of open stencil masks at 5x or 10x scale. A feasibility study with a research type Ion Projection Lithography Machine (IPLM-01) demonstrates sub-0.1-μm resolution combined with a high depth of focus and the possibility of an electronic alignment of the projected ion image in X, Y, rotation and scale. Furthermore, the IPL technique offers the possibility of an electronic adjustment of intrafield distortion.

§1. Introduction

Ion beam lithography[1] is developed in three directions (Fig. 1): Focused (FIBL), Masked (MIBL) and Ion Projection Lithography (IPL).

Focused Ion Beam Lithography is a serial technique, where a beam of ions is focused onto the wafer and is moved in X and Y like in a scanning E-beam system. Even with the high current densities of A/cm² achieved[2] FIBL writing speeds are not sufficient even for low volume production.[3] But this technique is best suited for Focused Ion Repair of masks[4] and for chip repair and adjustment. MIBL is 1:1 shadow printing with ions, either using a channeling "all silicon" mask[5] or an open stencil[6] mask. Mask heating problems[7] restrict this technique to the exposure of sensitive organic resists.

Ion Projection Lithography follows the same principles as an optical wafer stepper but uses ions instead of light to image reticle patterns of open stencil masks to the wafer at 10x (or 5x) reduction. In contrast to focused ion beam scanning Ion Projection Lithography exposes the circuit patterns in one flash which makes the IPL technique from 4 to 6 orders of magnitude faster because with IPL techniques an ion current of several 100 μA may be used whereas only several 100 pA are available for single focused ion beam scanning.

Figure 2 compares the IPL technique with other high volume production techniques for submicron

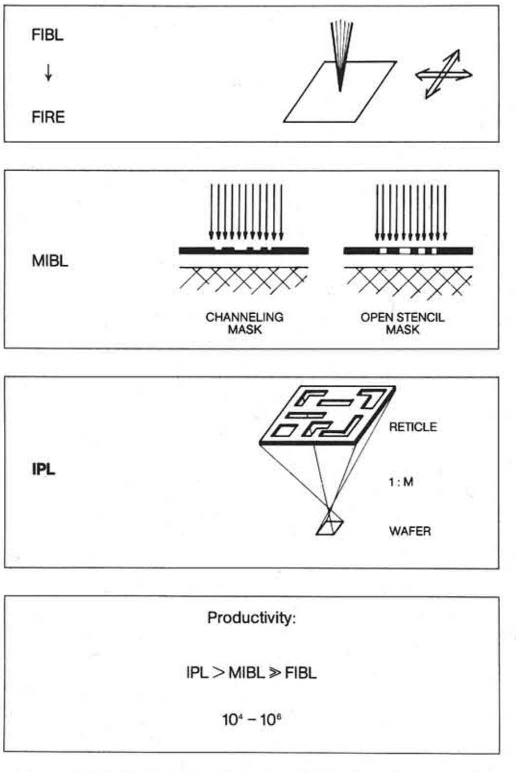


Fig. 1: Ion beam lithography development.

devices. Using reduction lens optics the optical wafer stepper proved to be the most succesful development with about half micron production limits. Further progress in optical lithography may be expected from DUV 1:1 projection[8] and using X-rays with 1:1 shadow printing.[9]

Pushing out the limits of optical methods, resolution is not the main bottle neck but there are severe limitations with respect to alignment and intrafield distortion. Both have to be controlled within at least 20 % of resolution, thus well below 0.1 µm for sub-0.5-µm device fabrication.

Using charged particles in parallel exposure an electronic die-by-die alignment[10] and electronic adjustment of intrafield distortion[11] may be achieved. These improvements in lithographic performance imply the use of open stencil masks.

Thus, using an Ion-Optical Wafer Stepper the IPL technique promises not only the necessary resolution but also precise and rapid alignment and correction of intrafield distortion for high volume sub-0.2-µm device fabrication.

SUB-MICRON
HIGH VOLUME PRODUCTION TECHNIQUES

		RESOLUTION µm			ELECTRONIC ALIGNMENT	ELECTRONIC ADJUSTMENT of INTRAFIELD DISTORTION
		< 0.7	< 0.5	< 0.2		
OPTICAL WAFER STEPPER		•				
DUV 1:1 STEPPER			o			
1:1 SHADOW PRINTING	X-RAY		•			
	E-BEAM		•	o	•	•
	ION-BEAM (MIBL)		•	•	o	o
IPL: ION - OPTICAL WAFER STEPPER				•	•	•
				USE of OPEN STENCIL MASKS		

Fig. 2: Sub-µm High Volume Production Techniques
• demonstrated, o feasible.

§2. Demagnifying Ion Projection

Figure 3 shows the main building blocks of an Ion Projection Lithography Machine (IPLM)[12] using principles of demagnifying ion projection.

The electrostatic lens system is operated in a paraxial condition with very small numerical apertures which results in an extremely large depth of focus in the order of millimeters. (Taking into account the change of scale of the projected ion image with wafer Z-position, the effective depth of focus is in the order of several 10 µm.)

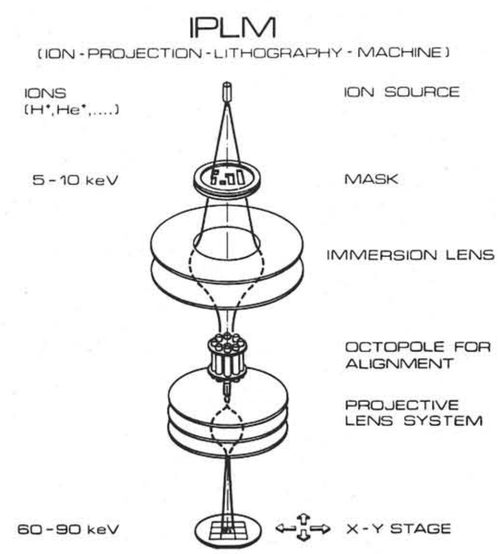


Fig. 3: Demagnifying ion projection.

§3. Ion Projection Lithography Machine

For feasibility studies a research type Ion Projection Lithography Machine (IPLM-01) was developed[12] allowing the 1:10 exposure of test masks[13] with an active area of 30 mm Ø and thus 2 mm x 2 mm chip size on the wafer. Figure 4 shows the experimental set up. System height is 2.5 m.

Conventional organic resists like AZ-materials and PMMA can be used for Ion Projection Lithography. These resists can not only be used as a positive but also as a negative resist implementing image reversal[14] techniques. This fact is evident from Fig. 5 which shows a pattern with 5.000 lines/mm (0.2 µm periodicity). An overexposure leads to negative development so that the resist remains at the sites of IPLM-01 exposure. Figure 6 is an enlarged part of this pattern showing 0.13 µm lines and 0.07 µm spaces.

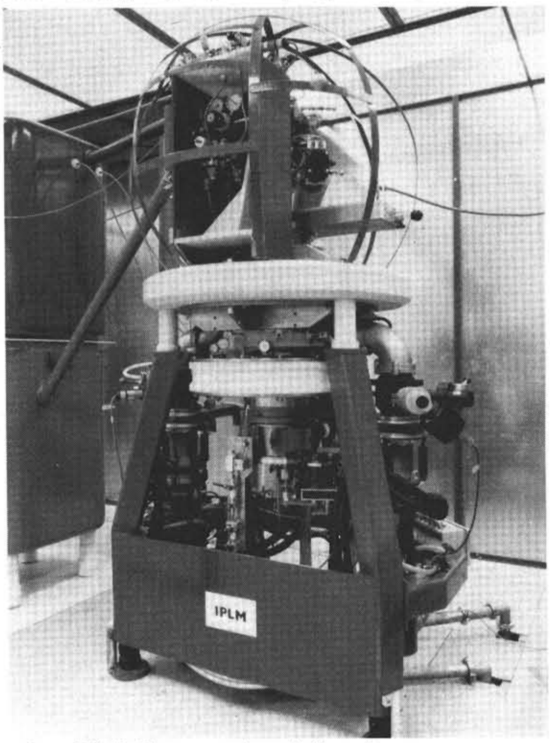
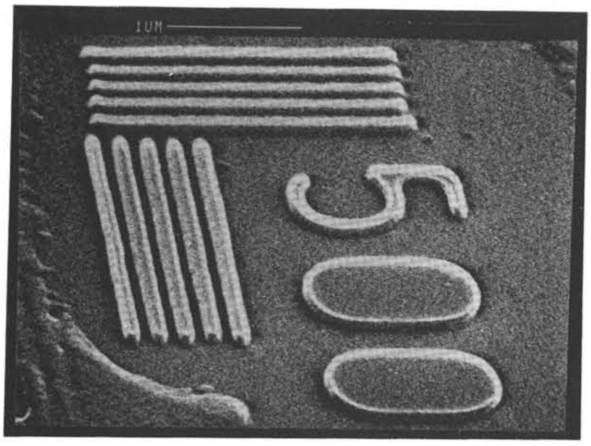
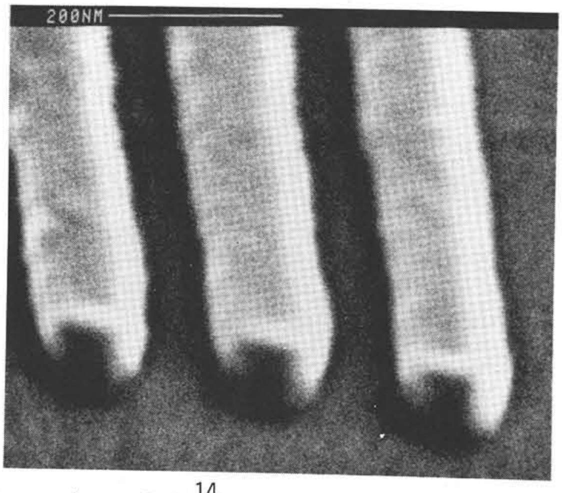


Fig. 4: IPLM-01 experimental set up.

§4. IPL Chip Exposure Times

A significant advantage of demagnifying ion projection is the possibility to expose the mask





Figs. 5 & 6: IPLM-01 exposure of PMMA on Si: 80 keV He^+-ions, dose: $2x10^{14}$ ions/cm², chip exposure time: 0.5 sec, development: MIBK/IPA=1/1, 45 sec, SEM∢=80°, 5.000 lines/mm (0.2 μm periodicity). (PMMA resist surrounding the pattern may be removed by a blanket DUV exposure prior to development /14/.)

foil permanently to the ion beam. An effective stabilization of the mask heated by the ion beam is possible.[15] The reticle can be operated at 100 - 150 °C with ion current densities up to 10 μA/cm² corresponding to a power load of 50 mW/cm². With 10x reduction the ion current density at the wafer is enhanced by two orders of magnitude up to 1 mA/cm². The power load at the wafer target is enhanced with respect to the mask level by three orders of magnitude to values up to 100 W/cm². Thus, lithography can be extended to insensitive organic and inorganic (SiO_2, Si_3N_4, Si, Ge,...)[12] resist layers with subsecond chip exposure times.

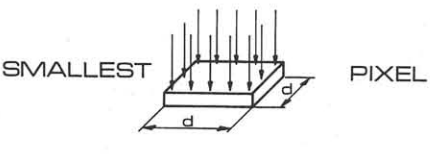
For a statistically reliable pattern transfer process the smalles pixel must be exposed with about 1.000 ions[16] resulting in a minimal dose of 10^{13} ions/cm² for half micron pattern transfer. For 0.1 μm design rules pixel size goes down to 0.02 μm and thus more insensitive resists have to be used. The IPL technique delivers the necessary ion current density and total current to enable sub-second chip exposure times (Fig. 7) and consequently pixel transfer rates exceeding 10 GHz surely not possible with single ion beam scanning.

§5. Electronic Die-By-Die Alignment and Electronic Adjustment of Intrafield Distortion

Fabricating devices with sub-0.2-micron design rules calls for an overlay of different mask layers to better than 0.05 μm (3 σ) precision.

For die-by-die alignment Ion Projection Lithography offers the possibility to perform fine registrations of the projected ion image without

STATISTICAL REQUIREMENT:
EXPOSURE OF 1000 IONS



PIXEL d	0.10	0.05	0.02	μm
LINE WIDTH	0.50	0.25	0.10	μm
DOSE	10^{13}	4×10^{13}	3×10^{14}	ions/cm²

CHIP EXPOSURE TIME: 0.3 sec
DIE SIZE: 5mm × 5mm

PIXEL NUMBER	3×10^{9}	10^{10}	6×10^{10}	pixels/5%o
CURRENT DENSITY	5	21	133	μA/cm²
REQUIRED ION CURRENT	1	5	33	μA
PIXEL TRANSFER RATE	10	33	200	GHz

Fig. 7: IPL sub-0.5-μm pattern transfer.

moving mechanic parts. Applying voltages to the pre-projective lens octopole (Fig. 3) the ion image can be moved in X- or in Y-direction.[12] A fine rotation of the projected ion image is achieved with an axial magnetic field generated with a solenoid at the octopole site. The scale of the projected ion image can be altered adjusting the voltage of the projective lens. So far, alignment tests have been performed in one direction.[12]

Furthermore, the IPL technique offers the unique possibility that a correction of intrafield distortion is also accomplished electronically.

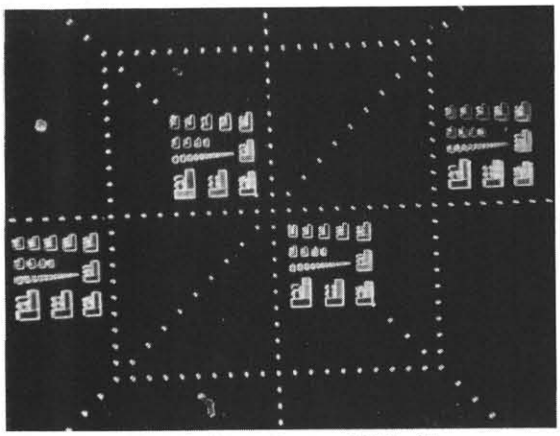


Fig. 8: Superposition of two IPLM-01 exposures in self-developing nitrocellulose on Si with different sets of voltage configurations applied to the pre-projective lens octopole, scale: 50x.

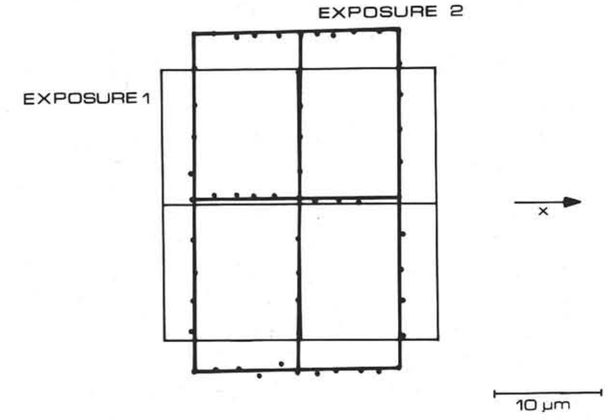


Fig. 9: Evaluation of the two IPLM-01 exposures of Fig. 8 reveals an anmorphistic distortion of the second exposure with respect to the first exposure.

Figure 8 shows two IPLM-01 projected ion images where for the second exposure a voltage configuration was applied to the eight rods of the pre-projective lens octopole. The corresponding evaluation of the difference between these two exposures reveals that for the second exposure an anamorphism is obtained with respect to the first exposure.

Even more effectively an electric and magnetic multipole situated between mask and immersion lens influences the flow of ions through the ion-optical system thus enabling correction or adjustment of a large variety of intrafield distortion patterns (e.g. single corner pin cushion).

§6. Conclusion

Implementing electronic die-by-die alignment and electronic adjustment of intrafield distortion a mix & match technique with optical (or X-ray) steppers can be developed which renders the use of a production-IPLM, the Ion-Optical Wafer Stepper, to the most critical device levels and to new production techniques not accessible to other lithographic tools.

Examples of applications are sub-0.5-µm lithography using H^+ or other gaseous ions, ion beam mixing[17], direct patterned ion implantation using doping ion species, and direct patterned isolation techniques (e.g. using H^+ or O^+ ions for GaAs[18] devices). Furthermore, important applications exist in the exposure of polymers[19] and for the fabrication of integrated optics[20], surface acoustic wave[21], sensoric, magnetic bubble[22] and also for future electronic devices requiring sub-0.1-µm processing such as quantum coupled devices[23, 24].

References:

1) A.J. Muray, J.J. Muray, Vacuum 35(10), 467,85.
2) R.L. Seliger, R.L. Kubena, R.D. Olney, J.W. Ward, V. Wang, J.Vac.Sci.Technol. 16, 1610,79.
3) W.L. Brown, T. Venkatesan, A. Wagner, Solid State Technology 24(8), 60, 1981.
4) A. Wagner, Solid State Technol. 26(5), 97, 83.
5) John L. Bartelt, Solid State Technology 29(5), 215, 1986.
6) J.N. Randall, D.C. Flanders, N.P. Economou, J. P. Donnelly, E.I. Bromley, J.Vac.Sci.Technol. B3(1), 58, 1985.
7) J.N. Randall, R. Sivasankar, 30th Int. Symp. Electron, Ion and Photon Beams, May 27-30, 1986, Boston, t.b.p. in J.Vac.Sci.Technol.
8) David A. Markle, SEMI Technology Symposium 85, Tokyo, Dec. 1985 (SEMI Inc., Mountain View,CA).
9) Anton Heuberger, ibid.
10) J. Frosien, B. Lischke, K. Anger, J. Vac. Sci. Technol. 16(6), 1827, 1979.
11) H. Bohlen, U. Behringer, J. Keyser, P. Nehmiz, W. Zapka, W. Kulcke, Solid State Technology 27(9), 210, 1984.
12) G. Stengl, H. Löschner, J.J. Muray, Techn. Proc. SEMICON/West 1986, p. 42 (SEMI Inc.1986).
13) H. Kraus, company Heidenhain, Traunreut, FRG.
14) G. Stangl, F. Rüdenauer, W. Maurer, W. Fallmann, Microcircuit Engineering 85, p. 167, North Holland 1985.
15) G. Stengl, H. Löschner, J.J. Muray, Solid State Technology 29(2), 119, 1986.
16) A. Macrander, D. Barr, A. Wagner, Proc. SPIE Vol. 333, 142, 1982.
17) J.W. Mayer, M. Nastasi, MRS 1985 fall meeting, Boston, Dec. 2-7, 1985.
18) D.C. D'Avanzo, IEEE-MTT-30(7), 955, 1982.
19) T. Venkatesan, M. Feldman, B.J. Wilkens, W.E. Willenbrock, J. Appl. Phys. 55(4), 1212, 1984.
20) P.D. Townsend, J. Phys. E 10, 197, 1977.
21) K. Yamanouchi, in Nanometer Structure Electronics, Y. Yamamura, T. Fujisawa, S. Namba Eds., Ohmsha Ltd. and North Holland, 1985.
22) T.J. Nelson, D.J. Muehlner, V.V.S. Rana, B.J. Roman, G.P. Vella-Coleiro, AT&T Bell Labs. Techn. J. 63(2), 337, 1984.
23) G.H. Heilmeier, IEDM 1984, Washington DC, Dec. 1984.
24) C.F. Cook, T.R. AuCoin, G.J. Iafrate, Solid State Technology 28(10), 125, 1985.