Newly Developed Novolak-Based Resist Materials for Ion Projection Lithography (IPL) with Structure Dimensions of 200-100 Nanometers

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The application of IPL for the fabrication of nanometerstructures requires the development of special resist materials, or, at least, of novel resist development procedures. Not long ago, resist producers held the opinion that novolak-based materials are not useful for structuring in dimensions smaller than 0.3 µm. In cooperation with a well known resist company we succeeded in developing new organic novolak-based resists, which can be structured in lines and spaces smaller than 150 nm by exposure with light ions. IPL experiments were performed with the "Alpha Ion Projector" built by the Viennese company Ion Microfabrication Systems (IMS).

1. Ion Lithographic Process

The ion projection machine is now equipped with a 5x demagnifying ion optical system. An open stencil mask, a two micron thin nickel foil, fabricated by electroplating, is exposed by light ions, H^+, He^+, or clusters like H_3^+ with an energy of 7.5 keV. The ions which pass through the mask are accelerated by the field lens to an energy of typically 50 to 60 keV which is required for a proper exposure of the resist.

1.1. Main Principles of Electronic Alignment:

The demagnified ion image of the stencil mask pattern consists of the "dye beam" and 8 "ion alignment beamlets". The dye beam passes a round center opening in the "scanner block" which is situated between the ion-optical column and the X–Y-stage. The ion alignment beamlets enter corresponding slots in the scanner block. With the help of deflection plates each ion alignment beamlet may be scanned over registration sites (e.g. grooves) which are simulated in this case by a reference plate, attached to the scanner block. Secondary electrons, generated by the ion alignment beamlets, may be collected by 8 channeltron detectors. With the signals of these 8 channeltron detectors the status of the projected ion image may be characterized with respect to X– and Y–position, rotation, scale, anamorphism (X-Y-scale) and trapezoid intrafield distortion. In servo loops this information is transferred to an electrostatic multipole (situated between ion-optical column and scanner block) and to lens voltage power supplies. Inducing electrostatic dipole fields and correcting lens voltages the projected ion image may be stabilized in X , Y and scale, on-line during chip exposure. This feedback control may be enhanced to the control of rotation, anamorphism and trapezoid distortion [1].

1.2. Principles of "Electrostatic Step Exposure"

The projected ion image of the stencil mask pattern is exposed repeatedly with precise displacements. These displacements are induced by proper dipole fields in an electrostatic multipole which is situated between the ion optical column and the wafer plane (Figs. 1, 2) [1].

Fig. 1: Multiple exposures with defined displacement.

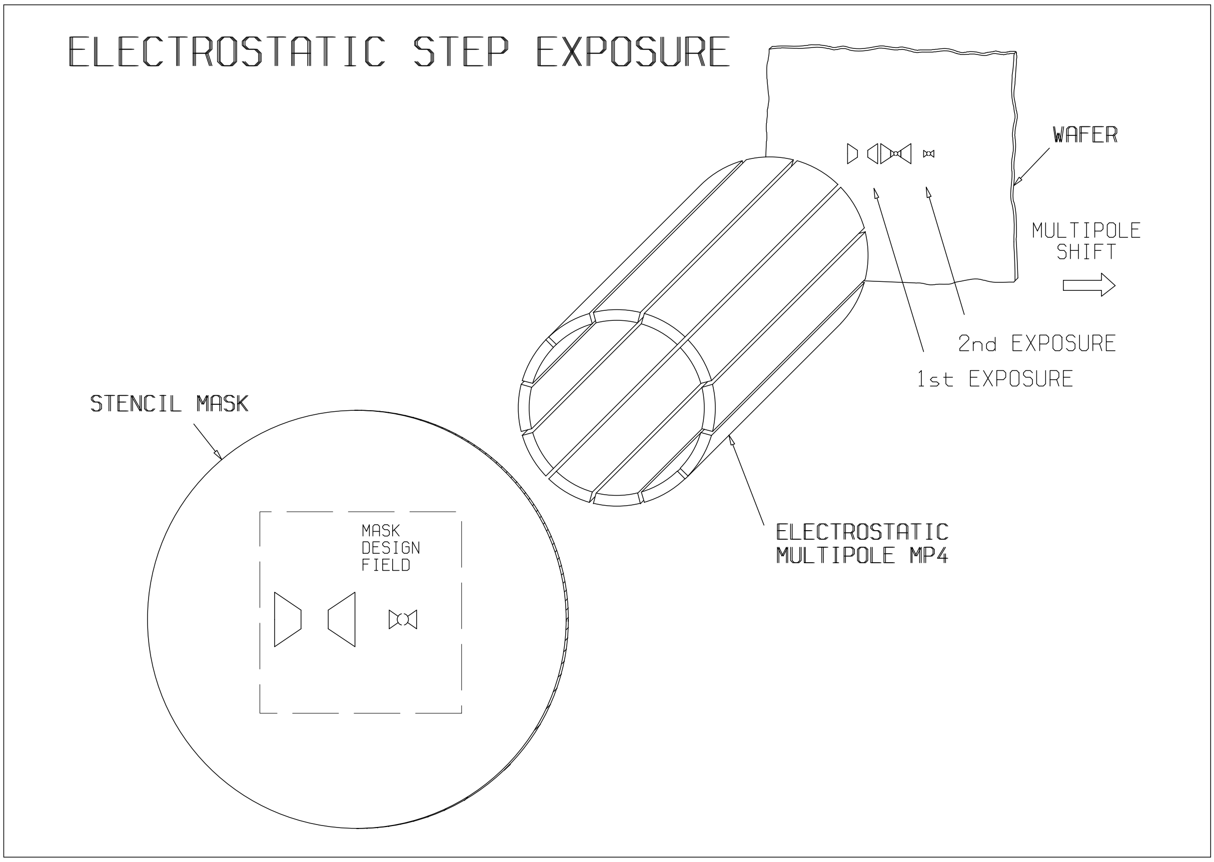

Fig. 2: Electrostatic Step Exposure.

2. Results in Resist Materials

The minimum linewidth which could typically be achieved is less than 200 nm in the positive working research resist (RAY-PF-E) which permits an exposure time of about 400 ms. Best results achieved so far with the second newly developed AZ-Type (RAY-1005), which is negative toned, were structures in the dimension smaller 150 nm with an aspect ratio of about 1:2,5. Conventional wet-chemical spray development with a buffered solution of tetramethylammonium-hydroxide was applied. (Figs. 5, 6)

The bonding connections were realized by means of electrostatic step exposure. Two different projected ion images of the stencil mask structures are exposed twice with a precise displacement induced by proper dipole fields of the electrostatic multipole, placed in between the ion optical column and the wafer substrate. (Fig. 3)

Our best results until now were structures of about 50 nm in width, but unfortunately only in PMMA, a resist material which can not withstand the subsequent reactive plasma etching processes. Therefore, it is of major importance to find novolak resist materials for the nanometer technology whose stability against reactive plasma exeeds that of PMMA by a factor of 100.

The newly developed resist allowed realization of operating quantum wires and rings in GaAs. (Structure dimensions of about 200-100 nm). (Figs. 4, 7)

Fig. 3: Quantum-ring, with bonding connections; IPL 5x exposure in RAY-1005, anisotropic etching in GaAs (Fig. 3)

Fig. 4: Smallest structure (70nm), IPL 10x exposure and anisotropically plasma etched in silicon.

Fig. 5: Quantum wire, IPL5x exposure in RAY-1005, wire dimension 100nm.

Fig. 6a: Test-structures — RAY - PN.

Fig. 6b: Test-structures — RAY - 1005.

Fig. 6c: Test-structures — RAY - PF-E.

Fig. 6d: Test-structures for quantum-devices — RAY - PN.

Fig. 6e: Test-structures for quantum-devices — RAY - 1005.

Fig. 6f: Test-structures for quantum-devices — RAY - PF-E.

Fig. 7a: Test-structures for quantum-devices, anisotropic plasma etching in GaAs — RAY - PN.

Fig. 7b: Test-structures for quantum-devices, anisotropic plasma etching in GaAs — RAY - 1005.

Fig. 7c: Test-structures for quantum-devices, anisotropic plasma etching in GaAs — RAY - PF-E.

Fig. 7d: Test-structures for quantum-devices, anisotropic plasma etching in Si — RAY - PN.

Fig. 7e: Test-structures for quantum-devices, anisotropic plasma etching in GaAs — RAY - 1005.

Fig. 7f: Test-structures for quantum-devices, anisotropic plasma etching in GaAs — RAY - PF-E.

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References

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