MULTICUSP ION SOURCE FOR ION PROJECTION LITHOGRAPHY*

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Abstract

The need to extend to smaller and smaller features (sub-100 nm) in integrated circuits has created the necessity to investigate new technologies beyond optical lithography. Ion Projection Lithography (IPL) is an advance lithographic concept that can provide the solution for the high volume fabrication of sub-100 nm integrated circuits. The IPL system requires low axial energy spread ions in order to minimise the chromatic aberration of the projected image on the wafer. Ion energy spread for the multicusp source has been reduced from 6 eV to below 2 eV by the use of a planar magnetic filter. And most recently, LBNL successfully reduced the energy spread to below 1 eV by employing a co-axial filter configuration. A similar source is being fabricated to be used for a novel IPL machine to be built by IMS in 1999 as part of the European MEDEA project headed by Siemens. This paper describes the multicusp ion source for lithography and shows some exposure results using this source.

1 INTRODUCTION

The enabling technology for integrated circuits is lithography: the repeated printing of fine line features in resist to define the various layers of circuit elements, precisely aligned from layer to layer. There are many lithographic techniques: optical, extreme UV (EUV), ion projection lithography (IPL), SCALPEL and 1:1 X-ray. Although optical lithography has been extended to far smaller dimensions than was predicted 15 years ago, there are definite physical barriers to extending it to the minimum dimensions of well below 100-nm.[1] Ion beam lithography could provide both small minimum dimensions and high throughput. Ions are well suited for lithography because they suffer little or no scattering in the resist unlike electrons.[2-7] IPL may turn out as the sub-100 nm lithography technique with lowest cost of ownership.

In IPL a uniform, collimated beam of light ions (H^+, H_2^+, H_3^+, or He^+) back illuminates a stencil mask. The image of this stencil mask is projected through a series of electrostatic lenses and demagnified onto the substrate (Fig. 1, [2]). IPL operates under vacuum and uses ions instead of photons to expose the mask features onto a resist coated wafer. IMS in Vienna, Austria has built two generations of ion projection lithography systems that have demonstrated many of the features needed for high throughput lithography.

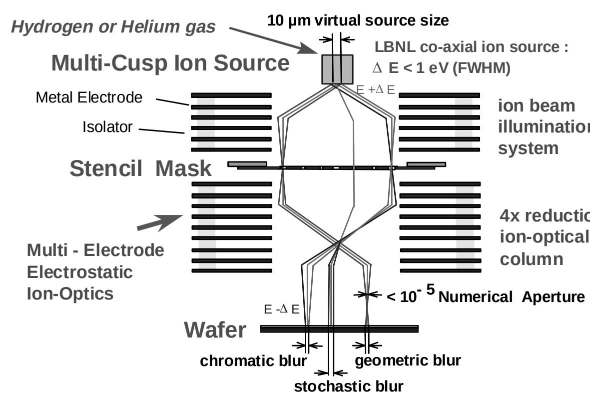

Figure 1: Schematic diagram of ion projection Lithography (IPL).

The ion source is an important component of IPL. Its performance determines many of the parameters of the beam downstream. The axial energy spread of the ion beam couples to chromatic aberrations in the ion optical column, and leads to blur in the printed pattern on the wafer. For a given design rule, the IPL system must achieve a compatible total error budget. For chromatic aberration to contribute a small fraction of this budget, the axial energy spread of the ion beam should be less than about 2 eV (full width at half maximum, FWHM). This paper will describe the source of choice for IPL.

2 MULTICUSP ION SOURCE

The multicusp source is capable of producing large volumes of uniform, quiescent and high-density plasmas with high gas and electrical efficiencies. Recently, it was found that the source can be used to produce low axial energy spread ions for lithography. Columns of

*This work is supported in part by the Defense Advanced Research Project Agency (DARPA), Intl. SEMATECH, Siemens Corporation and the U.S. Department of Energy under contract No. DE-AC03-76F00098

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samarium-cobalt permanent magnets with alternating polarities surround the cylindrically shaped source. These magnets generate longitudinal line-cusp magnetic fields that can confine the primary ionizing electrons efficiently. One end of the chamber is terminated by an end flange, which is covered with rows of permanent magnets. The open end of the chamber is where the low axial energy ions are extracted. The schematic diagram of the source is shown in Fig. 2.

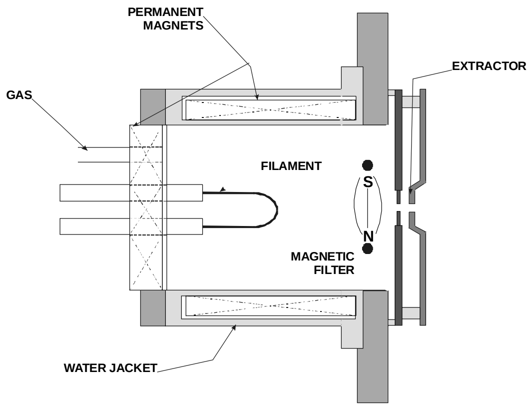

Figure 2: Schematic diagram of the multicusp ion source with the planar magnetic filter.

2.1 Without a magnetic filter

The axial plasma potential distribution inside the source has been studied in previous works by Ehlers, et.al.,[9] and its influence on the axial energy spread has been reported.[10] The plasma potential decreases monotonically towards the plasma electrode. Ions are formed with different energies if they are produced at different axial positions, thus the energy spread is large. The ion energy spread has been measured using a retarding field energy analyser (provided by IMS) and been reported to be approximately 6 eV for a 10-cm-diameter by 10-cm-long filament discharge source.

The importance of ions with low energy spread is clearly shown on the printed features. Although the multicusp ion source with this arrangement has not been tested in an actual IPL machine, exposure tests have been performed with the IPLM-02 research type ion projector at the Fraunhofer Institute for Silicon Technology using a duoplasmatron source. This source is known to have an energy spread of ≈12 eV. Figure 3 shows an exposure result in 390 nm thick DUV resist (Shipley UVIIHS): At 8.4 ion-optical reduction 74 keV hydrogen ions were used with an exposure time of 300 ms; exposure dose was 0.3 μC/cm^2. The line spaces are 80 nm wide (> 4:1 aspect ratio).

2.2 With a planar magnetic filter

The multicusp ion source is provided with a removable magnetic filter system. The magnetic filter design is used to provide a limited region of transverse magnetic field, which prevents the energetic electrons in the discharge chamber from crossing over into the extraction region. The plasma potential distribution in this case is more uniform in the ion production region, resulting in a narrowed potential range where ions are actually formed. The axial energy spread has been reported to be approximately 2 eV for a 10-cm-diameter by 10-cm-long filament discharge source. The exposure result with this source presented a great improvement on the resolution [11]. Figure 4 shows 50-nm line spaces (> 6:1 aspect ratio) exposed with 75 keV helium ions in UVIIHS resist; exposure time 800 ms; exposure dose 0.3 μC/cm^2.

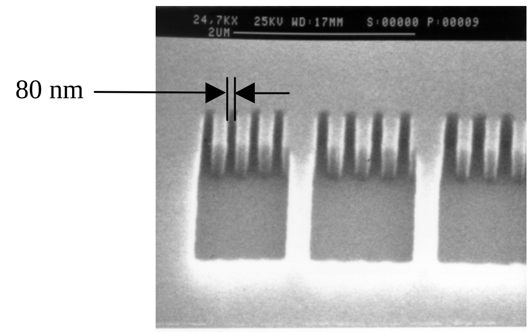

Figure 3: Exposure result using an ion source with a 12eV axial energy spread.

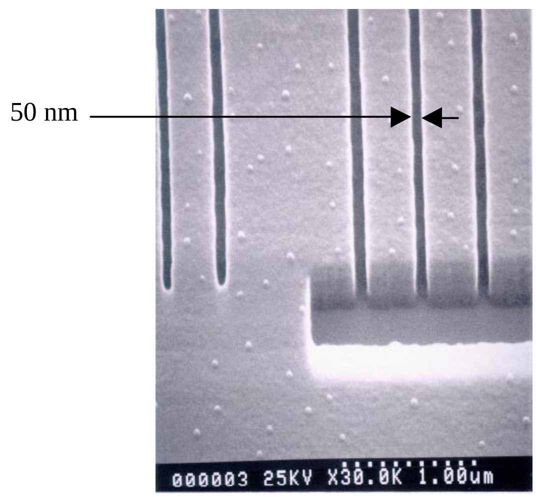

Figure 4: Exposure result using an ion source with a 2eV axial energy spread.

2.3 Co-Axial Source

The axial energy spread of the multicusp ion source can be further reduced by optimising the filter design. In this arrangement, both ends of the chamber are terminated by a flange, which is covered with rows of permanent magnets. One end of the chamber has an opening diameter of 5 cm where the extraction system will be placed. The filter has a co-axial cage configuration, 6-cm ID and 7.8-cm OD, and has 6 water-cooled rods of permanent magnets, shown in Fig. 5. Each rod is 0.8 cm in diameter. Plasma is generated between the source chamber and the filter cage and diffuses into the center. This filter cage controls the plasma potential distribution more efficiently than the planar magnetic filter arrangement.

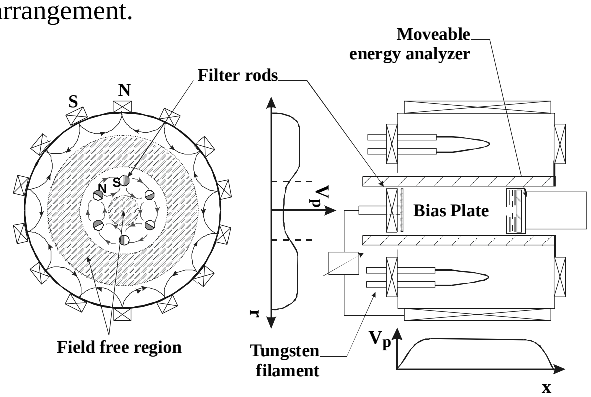

Figure 5: Schematic diagram of the co-axial ion source.

The plasma potential of the co-axial source has also been measured by using Langmuir probes placed in the central region as well as in the annular region of the source. In addition, a biasing plate can be installed in the central region for the purpose of modifying the radial plasma potential distribution, and therefore, the beam emittance.[12]

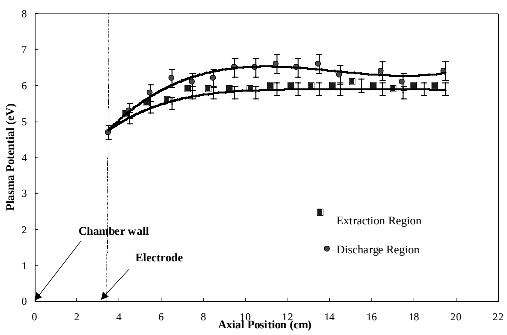

Figure 6: Axial plasma potential distribution for the co-axial source.

Axial plasma potential distribution has been measured in both the central and the outer annular regions. The plasma potential at the center is lower than that of the discharge region (by approximately 0.5 V) as it has been expected (Fig. 6). However, uniformity of the radial plasma potential distribution is not critical in reducing the axial energy spread. Nevertheless, the axial plasma potential distributions are quite uniform in both regions, as illustrated by the plots in Fig. 6. The axial energy spread for the co-axial source was found to be as low as 0.6 eV (FWHM). The resolution testing for this type of source is yet to be performed. This ion source is expected to yield sharp features.

Furthermore, in the co-axial source, the electron temperature (T_e) in the extraction region is lower than that in the discharge region. Electron temperature as low as 0.1 eV has been recorded at the extraction region, which is about an order of magnitude lower than that of the discharge region. Such low electron temperature will enable the source usage in other lithographic technologies.

3 SUMMARY

A co-axial source is being designed and tested at the Lawrence Berkeley National Laboratory, and it will be used for the novel IPL machine to be built by IMS in 1999 as part of the European MEDEA project headed by Siemens Corporation [8]. Fig. 7 shows a drawing of the source to be used for the MEDEA project.

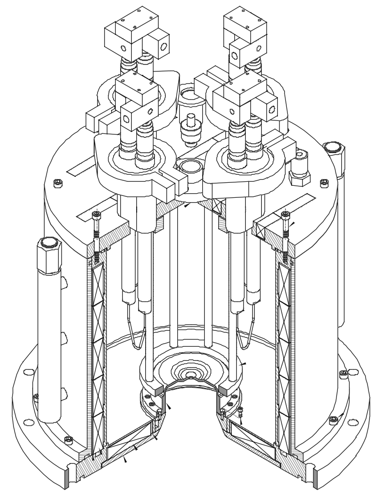

Figure 7: Schematic drawing of the co-axial ion source developed at LBNL for the MEDEA project.

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