NANOMETER AND HIGH ASPECT RATIO PATTERNING BY ELECTRON BEAM LITHOGRAPHY USING A SIMPLE DUV NEGATIVE TONE RESIST

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The *micro resist technology´*s ma-N 2400 series DUV negative tone resist is evaluated for electron beam lithography using the Gaussian beam machine LION LV1.We could demonstrate the high resolution capability of this resist and the possibility to delineate dense patterns with high aspect ratios. Lines and spaces with dimensions down to 150 nm in an 800 nm resist layer and down to 50 nm in a 180 nm resist layer can be resolved. The patterns show steep sidewalls and demonstrate the possibility to generate resist features with high aspect ratios using a simple one layer resist technology. The aspect ratio has at least a value of about 5. The exposure doses for the resist layers in these experiments range from 120 µC/cm² to 200 µC/cm² using 20 keV electrons.

Exposures with electron energies less than 20 keV show that the resist sensitivity increases with decreasing electron energy. For 2.5 keV electron energy a dose of only 10 µC/cm² is sufficient. Due to the small penetration depth of low energy electrons only resist layers of less than 100 nm thickness can be used in the low energy range.

1. INTRODUCTION

Some DUV resists can be used successfully in electron beam lithography. In this paper the *micro resist technology´*s ma-N 2400 series DUV negative tone resist is evaluated for the electron beam exposure. This resist is composed of a novolak and an aromatic bisazide and has no chemical amplification. Therefore it shows a wide process latitude and a good etch stability. Recently first results of the electron beam exposure of this resist were presented [1,2]. A variable shaped beam machine was used with minimum feature size of 100 nm.

In the new experiments the LION LV1 from *Leica Microsystems Lithography* Jena, Germany - a Gaussian beam machine - was used as electron beam exposure tool. Now we could test the resolution capability of the ma-N 2400 series DUV negative tone resist by exposing patterns in the nanometer region. Secondly the utmost aspect ratios of dense patterns in the deep submicrometer range were determined. At last electron beam exposures with lower accelerating voltages as usual were carried out (< 20kV) to characterise the properties of the resist for such applications.

2. EXPERIMENTS

The used exposure tool LION LV1 is an e-beam lithography system for nanometer patterning with accelerating voltage from 1kV to 20 kV. The electron source is a thermal field emitter yielding a high current density and a small energy spread. Therefore the Gaussian beam has a minimum spot size of only 2 nm at 20 kV.

Various viscosities of the ma-N 2400 resist were used resulting in film thicknesses of 70 nm, 180 nm and 800 nm, respectively. With the resist film thickness of 800 nm we produced high aspect ratio patterns whereas the film thickness of 180 nm was used to find out the resolution capability of the resist. The substrates with resist layers of 70 nm thickness were applied for experiments with low energy electrons .

For better adhesion of the resist film on the substrate 20 nm chromium was sputtered on the wafers. The resist ma-N 2400 was spincoated onto these wafers and baked at 90 °C for 3 minutes on a hotplate.

The resist coated wafers (800 nm, 180 nm) were exposed with a pattern of dense lines and spaces with dimensions from 1 µm down to the nanometer region by 20 keV electrons . The electron dose was varied in the range of 100 µC/cm² to 200 µC/cm². The exposed wafers were developed in the metal ion free developer AZ 726 MIF for 30 s, 60 s or 120 s, respectively.

The low energy exposures (less than 20 keV) were carried out on wafers with a thin resist film (only 70 nm thickness). These experiments were made to explore the influence of the electron energy on the resist sensitivity. Energies of 10 keV, 5 keV and 2.5 keV were used. The exposure doses for the resist layers in these experiments ranges from 1 µC/cm² to 100 µC/cm². The developing time was 20 s.

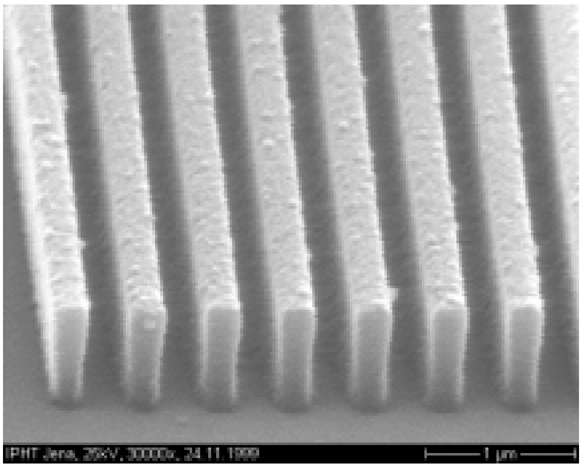

Fig.1: Resist thickness: 800 nm
Lines and spaces: 250 nm
Dose: 160 µC/cm² at 20 keV
Developing time: 2 min.

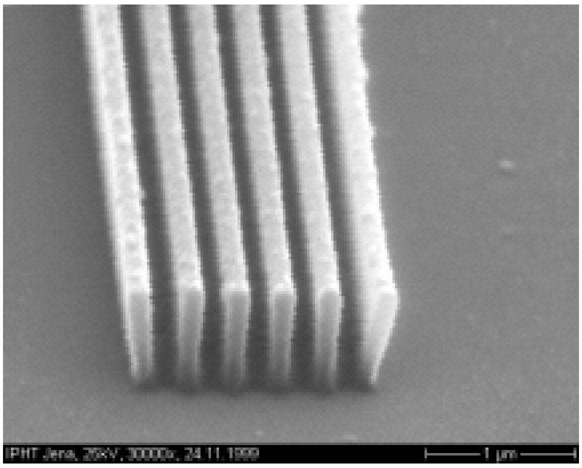

Fig.2: Resist thickness: 800 nm
Lines and spaces: 150 nm
Dose: 200 µC/cm² at 20 keV
Developing time: 2 min.

3. RESULTS AND DISCUSSION

To control the patterning results SEM pictures were taken from the developed resist patterns after applying a thin conducting gold layer by sputtering. We found that for the 800 nm resist layer the developing time must be at least 120 s. So lines and spaces with dimensions down to 150 nm can be resolved. Fig.1 shows lines and spaces with dimension of 250 nm exposed with an electron dose of 160 µC/cm² and Fig.2 such of 150 nm and a dose of 200 C/cm². The patterns show steep sidewalls and demonstrate the possibility to generate resist features with high aspect ratios with a simple one layer resist technology. The aspect ratio has at least a value of about 5. The outer lines in Fig.2 show a weak distortion resulting from forces during the developing process. The inner stability of narrow lines is in general better than the adhesion power on the surface of the wafer, so that high aspect ratio lines can tilt or can be transported completely to another place. These phenomena and especially the collapse of the finest pattern during the developing process restrict the resolution at high resist thicknesses.

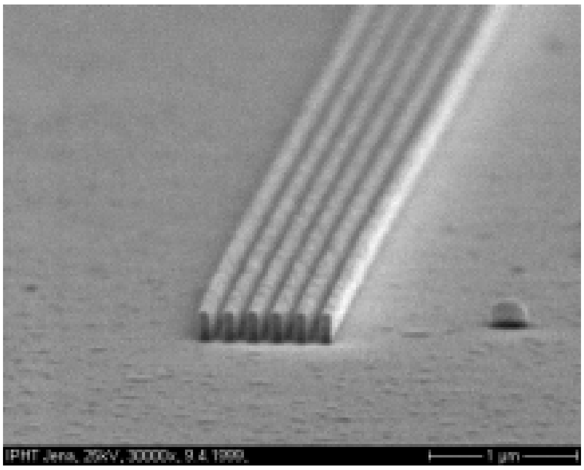

Fig.3: Resist thickness: 180 nm
Lines and spaces: 80 nm
Dose: 120 µC/cm² at 20 keV
Developing time: 30 s

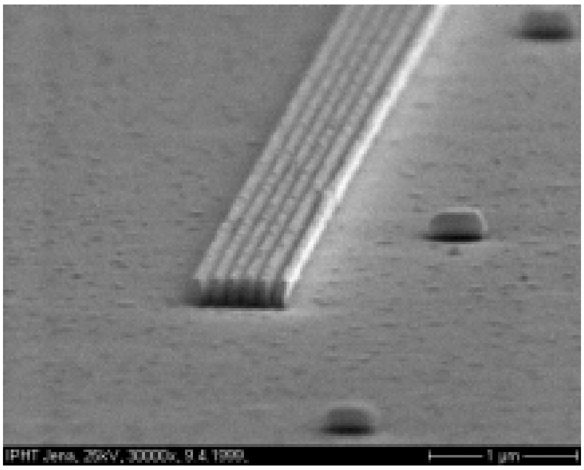

Fig.4: Resist thickness: 180 nm
Lines and spaces: 50 nm
Dose: 140 µC/cm² at 20 keV
Developing time: 30 s

The exposure of resist layers with a thickness of only 180 nm results in a higher resolution. The developing time for this resist thickness can be chosen shorter. Fig.3 shows dense lines and spaces of 80 nm width exposed with a dose of 120 µC/cm². The developing time was 30 s. The patterns are without any distortions. Up to now the finest resolved resist features have 50 nm width (Fig.4). These patterns show again weak distortions at the outer lines. The exposure dose was chosen to 140 µC/cm² at the same developing time.

In the exposure experiments with various electron energies less than 20 keV resist layers of 70 nm thickness were used. Thicker layers cannot be exposed due to the small penetration depth of the low energy electrons. Analysing the exposures with 10 keV, 5 keV and 2.5 keV electrons we found that the resist sensitivity is drastically increased with decreasing electron energy (Fig.5). It seems to be a linear function. For 2.5 keV electron energy a dose of only 10 µC/cm² is sufficient. The sufficient doses

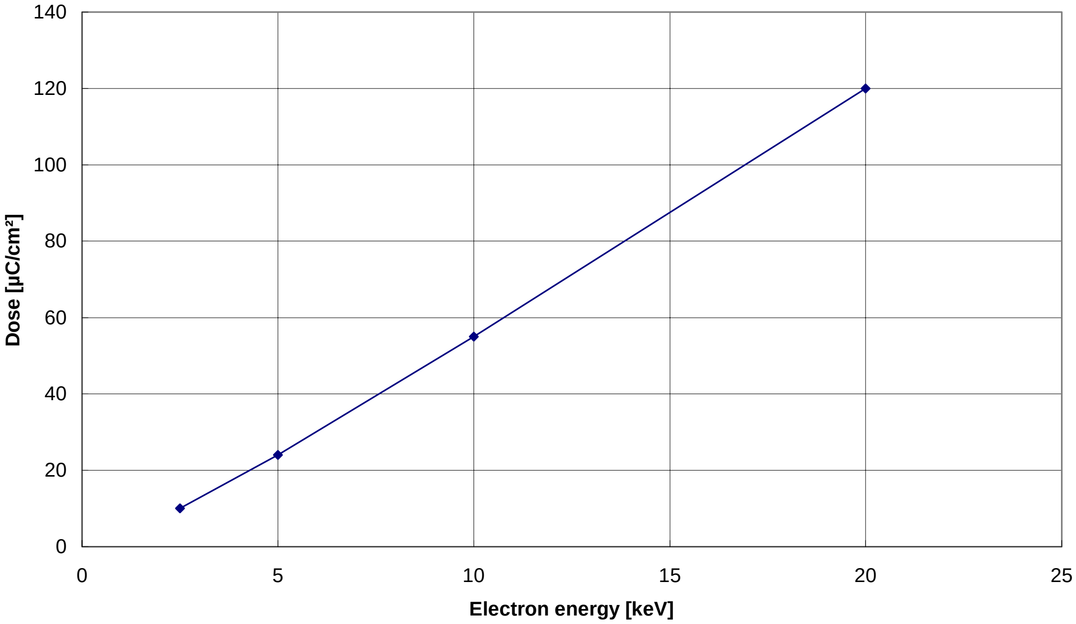

Fig.5: Exposure dose for ma-N 2400 resist vs. electron energy.

were estimated from the SEM pictures of a line and space group exposed with various dose values. As an example in Fig.6 features with 80 nm width exposed with 2.5 keV electrons and a dose of 10 µC/cm² in a resist layer of 70 nm thickness are shown. The developing time for this features was 20 s.

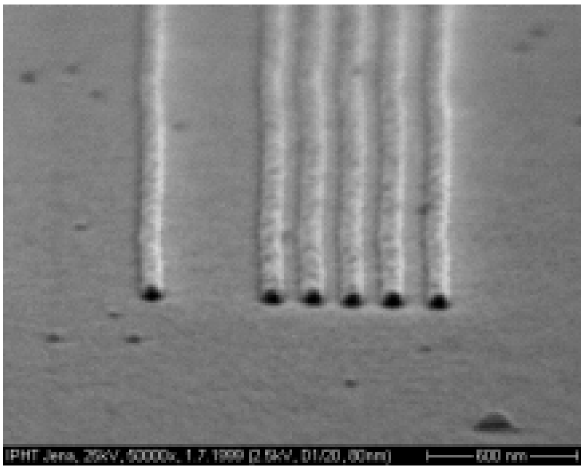

Fig.6: Resist thickness: 70 nm
Lines and spaces: 80 nm
Dose: 10 µC/cm² at 2.5 keV
Developing time: 20 s

4. CONCLUSIONS

Using a simple DUV negative tone photoresist and electron beam lithography we can generate high aspect ratio patterns with an aspect ratio of about 5 in resist layers of 800 nm thickness. In thinner resist layers we can produce dense lines and spaces in the sub-100 nm region. We got a minimal feature size of 50 nm . Probably the resolution limit of the resist is at much finer structures but obtaining the right working point is more critical, especially the developing process must be done with care.

The resist technology is very simple because in the resist no chemical amplification takes place.

Therefore no post exposure bake is necessary and we got a wide process latitude. Further the resist samples have a longer shelf life in comparison with resists with chemical amplification and no susceptibility to poisoning is observed.

For the low voltage electron beam lithography this resist has a good sensitivity and for all energies a high resolution capability.

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REFERENCES

[1] "Evaluation of the ma-N 2400 Series DUV Photoresist for the Electron Beam Exposure", H. Elsner and H.-G. Meyer, A. Voigt and G. Gruetzner, MNE ´98, Leuven, Belgium. 22-24 Sept. 1998. Microelectronic Engineering 46 (1999) 389-392.

[2] "Nanometer Patterning Using ma-N 2400 Series DUV Negative Photoresist and Electron Beam Lithography",
A. Voigt, H. Elsner, H.-G. Meyer, G. Gruetzner, Proceedings of SPIE Vol. 3676, 485-491.