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E-beam resist AR-N 7520 in the formation of the photonic structures

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Abstract. The study of plasma resistance of the AR-N 7520 was carried out. The selectivity of the reactive ion etching (RIE) of silicon through the mask of negative electron resist AR-N 7520 also was investigated. The dependence for selectivity was obtained at different fractions of SF6 in the feeding gas and at the different values of bias voltage. A high etching selectivity of 8.0 ± 1.8 was obtained for the etching process. The dependence of the resist line height on the exposure dose is presented. The optimal value for the line exposure dose was found to be 8200 pC/cm.

Keywords: electron-beam lithography; etching kinetic; novolak; reactive-ion etching, waveguide

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Электронный негативный резист AR-N 7520 в процессах формирования фотонных структур

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Аннотация. Проведено исследование селективности плазмохимического травления кремния Si по отношению к маске из негативного электронного резиста AR-N7520 в зависимости от доли SF6 плазмообразующей смеси SF6/C4F8 и напряжения смещения. В оптимизированном процессе была получена высокая селективность травления 8.0 ± 1,8. Получено оптимальное значение дозы экспонирования для резиста AR-N 7520–8200 пКл/см.

Ключевые слова: электронно-лучевая литография, кинетика процессов травления, новолак, плазмохимическое травление, волновод

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Introduction

The study of the e-beam resist properties, optimization of the electron beam lithography (EBL) parameters, and the etching process are important for nanoelectronics and photonics because the resolution of EBL is defined by the properties of e-beam resist and by processes during development and exposure [1–3].

The negative e-beam resist AR-N 7520 belongs to the novolaks and has high contrast and high plasma etching resistance [4, 5]. Novolaks are polymers with a low molecular weight derived from phenols and formaldehyde [6]. In the processes of the reactive ion etching (RIE) selectivity (the ratio of their etching rates) values can be varied.

The study of EBL and RIE processes with AR-N 7520 will enable a technology for forming silicon waveguides and other photonic nanostructures with lower sidewall roughness and different aspect ratios.

Materials and Methods

A p-type silicon (100) wafers were pretreated in n-methylpyrrolidone and acetone. To promote adhesion, the silicon wafer was held in hexamethyldisilazane (HMDS) vapor at 85 °C for 10 minutes. The AR-N7520 with a concentration of 7.3% (PGMEA, 1-methoxy-2-propanol acetate) was spin-coated onto the surface using an SM-180 centrifuge (SAWATEC AG, Switzerland) at a centrifuge speed of 3000 rpm. The thickness of the resist layer was measured using a spectral ellipsometer M-2000X (J.A. Woollam Co., Inc., USA) and amounted to 100 ± 1nm. The exposure was carried out using EBL system Raith-150 (Raith, Inc., USA) with the e-beam energy of 30 keV, the beam current was 150 pA. The pattern of lines of 1 mm in length was formed. The line exposure dose ranged from 4000 to 16000 pC/cm with a step of 200 pC/cm. Development was performed in 25% tetramethylammonium hydroxide (TMAH) solution for 50 s at 21 °C.

RIE was performed on a Dual PlasmaLab 100 (Oxford Instruments Plasma Technology, UK) using an inductively coupled plasma (ICP) of the SF_6/C_4F_8 feeding gas. The wafers were segmented to obtain a set of samples with identical patterns of lines (60 lines per sample). Variation of the SF6 fraction in feeding gas in the range of 15% – 25% was investigated at 125 V DC bias. The effect of DC bias voltage on the etching process was studied in the range of 80 V – 150 V at a constant fraction of SF6 in feeding gas 22%. The etching process time was 30 s.

Images of the pattern of lines after etching and the thickness of the AR-N 7520 resist before and after the etching process, and the depth of silicon etching were obtained using a scanning electron microscope (SEM) Ultra 55 (Carl Zeiss AG, Germany).

The selectivity of the silicon RIE through the AR-N7520 mask was calculated as the ratio of the Si etching depth to the decrease in the height resist line during the etching process:

$$S = \frac{d_{\mathrm{Si}}}{d_0 - d} \tag{1}$$

where d_{Si} is the depth of silicon etching, d_0 is the height of the resist line before etching and d is the height of the resist line after etching. The etching rate was calculated as the ratio of the etching depth to the etching time for each line.

Results and Discussion

The study of the samples after development was carried out to determine the dependence of the line height on the exposure dose. The dependence of the line height on the exposure dose is presented in Figure 1. It can be seen that the optimal value of the line exposure dose is 8200 pC/cm.

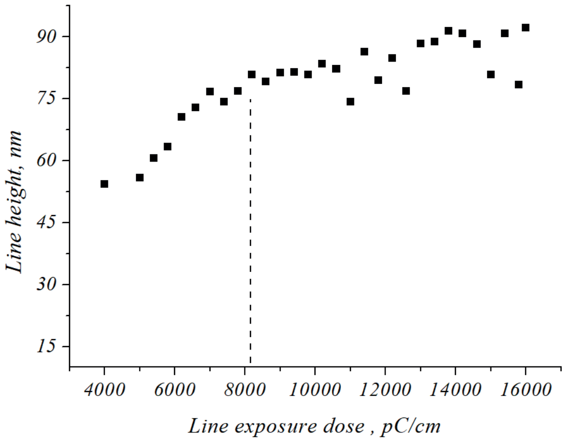

Fig. 1. Dependence of line height after development on the line exposure dose

The selectivity dependences on the fraction of SF6 in the feeding gas and bias voltage were obtained. Figure 2, *a* shows the dependence of the silicon etching rate (R_{Si}), etching rate of AR-N 7520 resist ($R_{AR\text{-}N}$), and selectivity (S) for the RIE at different SF_6 fractions in the feeding gas and constant bias voltage of 125 V. Figure 2, *b* shows the dependence of silicon etching rate (RSi), resist etching rate ($R_{AR\text{-}N}$), and selectivity (S) at the different values of bias voltage (−80 V, −100 V, −150 V) in the process of RIE and with a constant fraction of SF_6 in the feeding gas equal to 22%.

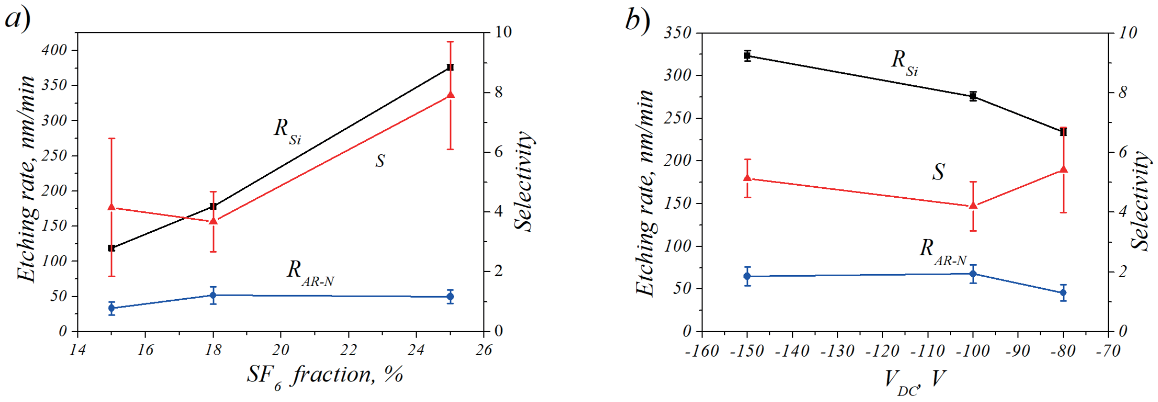

Fig. 2. Dependence of silicon etching rate, etching rate of AR-N 7520 resist, and selectivity on the SF_6 fraction in the feeding gas (*a*); dependence of silicon etching rate, etching rate of AR-N 7520 resist, and selectivity on the bias voltage (*b*)

The resist etching rate remains almost constant with an increasing fraction of SF_6 in the feeding gas, and the etching selectivity of silicon to the AR-N 7520 increases. The RIE process with a fraction of SF_6 in the feeding gas equal to 25% provides an etching selectivity of 8.0 ± 1.8. In the processes with the voltage in range from 100 V to 150 V the resist etching rate grows insignificantly. The process allows to obtain etching selectivity of 5.0 ± 1.4.

Figure 3 shows the dependence of the sidewall angle α on the SF_6 fraction in the feeding gas during RIE.

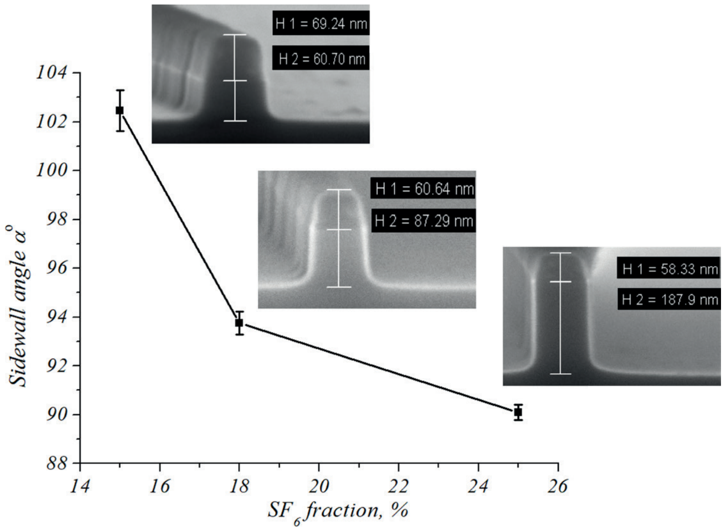

Fig. 3. Dependence of the sidewall angle of structures as a function of the SF_6 fraction in the feeding gas. SEM images of the lines also are shown (line width is about 60 nm)

Changing the ratio of the gas fraction in the feeding gas, it is possible to control the sidewall slope in the structure. Using the 25% fraction of SF_6 in the SF_6/C_4F_8 feeding gas allows us to obtain structures with a sidewall slope angle of 90.1 ± 0.3°

Conclusion

The RIE process with a fraction of SF6 in the feeding gas equal to 25% and a bias voltage of 125 V provides an etching selectivity of 8.0 ± 1.8. The optimum electron beam exposure dose for defining the mask was found to be 8200 pC/m at 30 keV. Selectivity does not depend on the exposure dose, at dose values over 4000 pC/cm.

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