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THE INFLUENCE OF MICROWAVE CF_4 PLASMA ACTIVATION ON THE CHARACTERISTICS OF REACTIVE ION ETCHING OF MONO-SI

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Abstract. The experiments have shown that microwave preliminary ionization of the plasma-forming gas increases the rate of the reactive ion etching of monocrystalline silicon (mono-Si) by four and more times in comparison with the etching process without it. It is established that the mode of plasma activation (the power of microwave discharge) and the value of plasma-forming gas pressure significantly affect the characteristics of mono-Si surface micro-roughness obtained in the result of etching.

Keywords: microwave discharge, activation, etching, roughness, surface.

1. Introduction

One of the main characteristics of material's plasma etching is the processing rate [1]. This parameter becomes of utmost importance during plasma etching of microelectromechanical systems [2], deep etching of integrated circuits elements [3], making sensors using planar technologies methods [4], etc. Note, the necessity of plasma etching process acceleration is connected not only with the requirement to improve the efficiency of technological equipment but with the need to reduce the duration of plasma component influence (primarily of charged particles) on the surface layers of the material and the elements of integrated circuits structures [5]. Direct increase of power applied to the electric discharge plasma is reasonable within certain values. The exceeding of this level can lead to such negative effects as discharge instability, significant heating of technological discharge systems construction elements, uncontrolled heating of treated materials' surface, etc.

Because of this, the investigation and development of such method of non-thermal intensification of the materials' etching process as preliminary etching gas activation in the off-site plasma source becomes interesting. Microwave plasmatron has been chosen as such source. It is determined by the fact that microwave discharge plasma has a number of specific peculiarities that make it rather attractive for the purpose of materials plasma treatment [6],[7].

2. Experimental part

Figure 1 shows schematically the construction of a vacuum gas discharge technological system used for investigation of the reactive ion etching of monocrystalline silicon (mono-Si) wafers.

The preliminary plasma activation of etching gas (CF_4) was performed in a microwave plasmatron 1. It is developed on the base of the rectangular waveguide 6 bent into a ring with holes on the internal surface for microwave energy 7 feed into the internal region 5.

Quartz discharge chamber 2 was placed along the waveguide's axis in which microwave discharge 4 had been excited in vacuum. From one side, the quartz chamber is closed with vacuum-tight cover 3 in the plane of the microwave applicator 5 end face, and from the other side it enters technological chamber 8.

Mono-Si wafer 11 under treatment was placed in vacuum chamber 8 out of the microwave plasma-formation region on the wafer-holder electrode 12. Between grounded electrode 9 and potential electrode 12 of the planar discharge E-type system a glowing low-frequency discharge 10 was excited in which the reactive ion etching process was performed.

The experiments were carried out with the wafers of 76 mm in diameter. The level of microwave power (at 2.45 GHz frequency) was within the range of $P_{MW} = 250$–650 W. CF_4 was used as working gas.

The value of mono-Si etching rate was defined by measuring the depth of the etched hole, dividing it by the time of the wafers' treatment. The local etching of the holes on the surface of wafers was provided with the masking coating which was removed after the treatment. The measuring of the etched holes depth was performed according to the interferometric method by the MII-4 interferometer.

The analysis of mono-Si morphology and surface microrelief after the reactive ion etching was performed by the atomic-force microscopy method. The surface roughness parameter Rz (ten-point mean roughness) was measured using the standard method.

The experimental data were obtained at fixed low frequency generator output power.

The pressure value of CF_4 and output microwave magnetron power served as operation parameters of the treatment process.

3. The results and discussion

It has been experimentally established that microwave plasma activation of the gas used for reactive ion etching allows to accelerate the etching process by

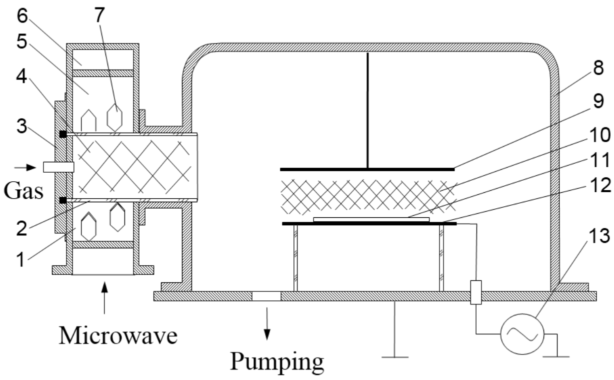

Figure 1. Diagram of the experimental plasma discharge system:
1 — microwave plasmatron; 2 — cylindrical quartz chamber; 3 — vacuum-tight flange cover; 4 — microwave discharge zone; 5 — internal region; 6 — rectangular waveguide bent into a ring; 7 — connection holes; 8 — vacuum chamber; 9 — grounded electrode; 10 — glow discharge region; 11 — wafer; 12 — wafer-holder electrode; 13 — low frequency generator

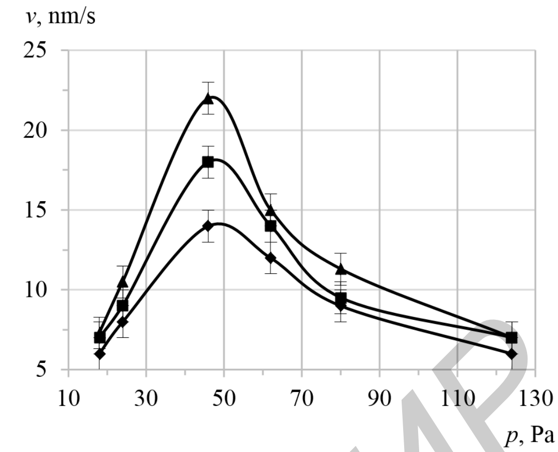

Figure 2. Dependence of the rate values of reactive ion etching of mono-Si in CF_4 *on the values of pressure in the vacuum chamber at various microwave power of etching gas plasma activation:*
♦ — $P_{MW} = 250\,W$; ■ — $P_{MW} = 500\,W$;
▲ — $P_{MW} = 650\,W$

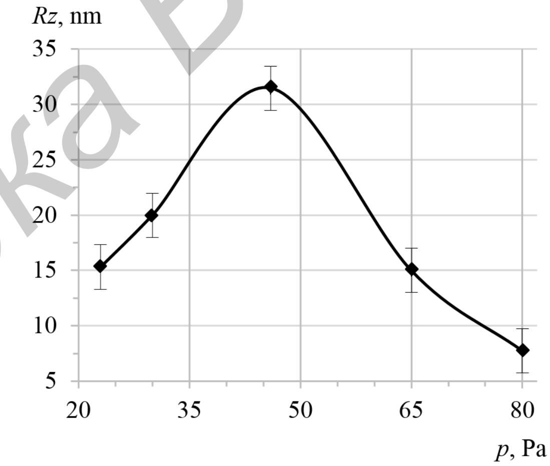

Figure 3. Dependence of hole bottom surface roughness values Rz after reactive ion etching of mono-Si in CF_4 *on the values of pressure in the vacuum chamber at* $P_{MW} = 250\,W$ *microwave discharge power*

four and more times in comparison with the etching process in E-type discharge without activation.

Fig. 2 shows the dependence of reactive ion etching rate of mono-Si in CF_4 on the value of pressure in the vacuum chamber at various microwave power of working gas plasma activation. Within the range of 10–133 Pa pressure these dependencies have extreme character. Maximum rate of mono-Si wafers etching in CF_4 is reached at the pressure of 40–50 Pa in the vacuum chamber.

Fig. 3 shows the dependence of hole bottom surface roughness values *Rz* after reactive ion etching of mono-Si in CF_4 on the value of pressure in the vacuum chamber. It has an extreme form similar to the data of Fig.2.

Fig. 4 shows the dependence of the rate values of reactive ion etching of mono-Si in CF_4 on the value of microwave plasma activation power of the etching gas. The presented data show that the maximum effect of microwave plasma activation is observed at the gas pressure of $p = 46$ Pa, at which the rate of mono-Si reactive ion etching is maximum.

For other pressure values in the chamber (23 and 80 Pa) the influence of gas plasma activation microwave power on the etching rate is lower.

Fig. 5 shows the results of investigation of the hole bottom surface morphology after the process of reactive ion etching of mono-Si in CF_4 in the region of microwave discharge plasma afterglow at various pressure values. The roughness value of the treated samples in the range of the investigated pressure values (20–80 Pa) varies from $Rz = 7.75$ nm to $Rz = 31.5$ nm and correlates with the value of etching rate.

The experiments have shown that in the area of lower pressure values the surface relief uniformity is higher than at 40–50 Pa (Fig. 5) but the rate values of mono-Si etching are lower. In the area of higher pressure values, the wafer surface morphology has a more ordered structure in comparison with the area of lower pressure values (Fig. 5c). The mono-Si wafer surface microrelief at $p = 46$ Pa pressure in the vacuum chamber has a more disordered character (Fig. 5b).

Analysing the character of mono-Si surface microrelief after reactive ion etching in CF_4 at various pressure values it is possible to assume that 40–50 Pa pressure provides better plasma-formation conditions and the silicon wafer surface is bombarded by ions most intensively.

The analysis of experimental data also shows that in case of CF_4 microwave plasma activation presence the etched surface of mono-Si holes bottom has a more

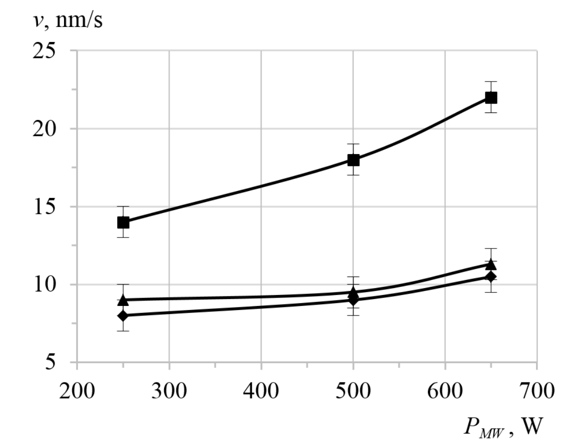

Figure 4. Dependence of the rate values of mono-Si reactive ion etching in CF_4 *on the values of microwave gas plasma activation power:*
♦ — $p = 23\,Pa$; ■ — $p = 46\,Pa$; ▲ — $p = 80\,Pa$

developed periodic structure, the roughness is more even and regular in form than in case of reactive ion etching without it.

4. Conclusions

The results of the performed experiments show the significant effect of preliminary microwave plasma activation of CF_4 on the rate of reactive ion etching process of mono-Si as well as on the character of treated surface microrelief. Choosing the mode of pre-ionisation (the value of microwave discharge power) and the value of plasma-forming gas pressure, it is possible to control the character of surface profile during the process of the reactive ion etching of mono-Si. Note, the character of the surface profile roughness after the reactive ion etching with microwave pre-ionisation may be more ordered and uniform than without it.

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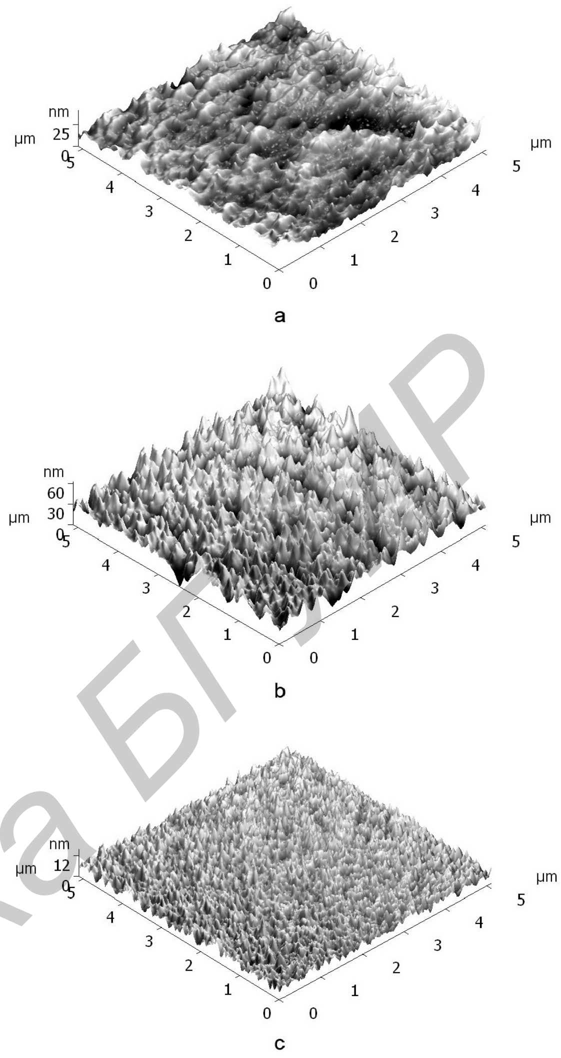

Figure 5. Hole bottom surface microrelief after reactive ion etching of mono-Si in CF_4 *in the conditions of gas microwave plasma activation at various values of pressure in the vacuum chamber:*
a — $p = 23\,Pa$*;* $Rz = 15.32\,nm$*; max height 32.4 nm;*
b — $p = 46\,Pa$*;* $Rz = 31.48\,nm$*; max height 62.8 nm;*
c — $p = 80\,Pa$*;* $Rz = 7.75\,nm$*; max height 15.8 nm;*

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