Investigation of the Process of Microwave Plasma Ashing of Photoresist Films from Semiconductor Wafers Using the Method of Optical Emission Spectroscopy

Bordusau S.V.[1], Madveika S.I.[1], Lushakova M.S.[1]

[1] *Belarusian State University of Informatics and Radioelectronics,*
P.Brovki, 6, 220013, Minsk, Belarus, e-mail: bordusov@bsuir.by

The results of the analysis of photoresist protection coating removal dynamics in oxygen microwave plasma as well as the character of light emission intensity change of spectral line O1 (λ=844,6 nm), used to control the removal of photoresist in case of processing a big number of silicon wafers, are presented. The obtained results enable supplementing phenomenological model of plasmachemical destruction of photoresist films in the volume of oxygen microwave plasma.

Keywords: plasma, microwave discharge, photoresist, films, ashing

1 INTRODUCTION

Microwave (MW) plasma treatment of materials and electronic devices is becoming more and more popular. It is explained by the fact that in electrodeless discharge conditions MW plasma sources provide much higher concentration of active particles and higher density of high energy electrons in comparison with lower frequency discharges. Besides, MW discharge has a significant advantage of giving the opportunity to maintain them stably in a large pressure range [1].

The most perspective process for MW plasma treatment in low vacuum is photoresist protective films ashing from the surface of integrated circuits (IC) wafers which in most cases are silicon plates.

This is the most frequent operation in IC production, so the reduction of treating duration of already formed IC's with MW plasma, thanks to the higher process rate, contributes to improving the functional characteristics of the completed devices.

The present work is concerned with the investigation of photoresist films ashing process peculiarities in the volume of oxygen MW plasma in plasmatron on the base of waveguide slotted applicator.

2 EXPERIMENTAL PART

The investigation was carried out with the use of MW resonator type plasmatron on the base of a rectangular waveguide bent into a ring with holes on the internal surface for inletting MW energy into the resonant zone. Along the axis a quartz reaction-discharge chamber (reactor) was placed where gas discharge was excited in vacuum conditions and the plasma treatment was performed. Plasma-forming gas was fed and the wafers were loaded through the removable vacuum tight lid covering one end of the reactor. Vacuuming and pumping out of plasma reaction products was performed through the lid covering the opposite end of the reactor.

The effective process was controlled with the help of spectrometer SL 40-2-2048 ISA using an optical emission spectroscopy method.

The presence and the area of photoresist film remnants on the surface of a wafer was evaluated visually in a diffused light.

The weight of the photoresist films and its changes in the result of treatment were estimated by weighing on analytical scales WA - 21 with measuring accuracy ±0,0001g.

Technical pure oxygen was used as a plasma-forming gas.

The investigation was carried out with silicon wafers Ø100 mm coated with photoresist AZ-13501, S1813G2SP15, SPR700 that have been treated at standard for photolithographic processes temperatures.

The studies of kinetics of photoresist films removal from silicon wafers surfaces were performed by the registration of temporary oxygen intensity line OI (λ=844,6 nm) changes.

3 THE RESULTS AND DISCUSSION

Fig. 1, *a* shows a typical form of light emission intensity I line OI (λ=844,6 nm) change during the process of photoresist ashing.

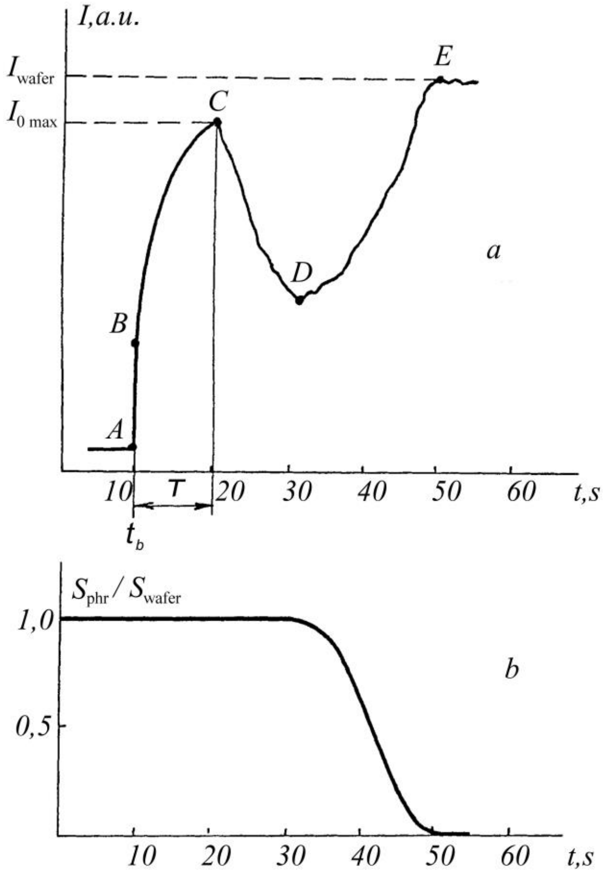

Fig. 1: Intensity I of line luminescence OI (λ=844,6 nm) (a) and photoresist film area change (b) during the process of treating a silicon wafer in the oxygen discharge

We can single out the following phases in the signal change:

point A – switching on the discharge;

section AB – the initial level of the signal, determined by the MW power applied to the discharge and the discharge conditions (pressure, gas consumption etc.);

section BC – corresponds to the stabilization of discharge conditions and the process of setting the energy balance in the discharge volume and in the “discharge-external medium’’ system;

point C – the beginning of the intensive photoresist film ashing accompanied by an active consumption of oxygen;

section CD – photoresist ashing in thickness with the preservation of the surface area covered by it and the increase in the weight of the ashed material;

section DE – photoresist ashing with the decrease of its area on the surface of the wafer;

point E – complete ashing of the photoresist from the surface of the wafer. The intensity of line luminescence OI (λ = 844,6 nm) at that point I_{wafer} corresponds to the luminescence in the presence of clean (without organic matter) wafers.

Fig. 1. *b* shows the obtained experimental changes in the photoresist film area S_{phr} with respect to the area of the semiconductor wafer S_{wafer} compared to the luminescence intensity line OI (λ = 844,6 nm) in the process of treatment.

The comparative experiments to study the behavior of luminescence intensity line OI (λ=844,6 nm) in the process of photoresist ashing in high frequency (HF) discharge (f = 13,56 MHz, a reactor with a voluminous wafer position) and in the oxygen MW discharge showed the following: the duration of time period T, corresponding to the stabilization of discharge conditions and the beginning of establishing the energy (heat) balance in the discharge cavity, with the increase of the number of silicon wafers treated in HF discharge increases, while no such increase is observed for MW discharge (Fig.2).

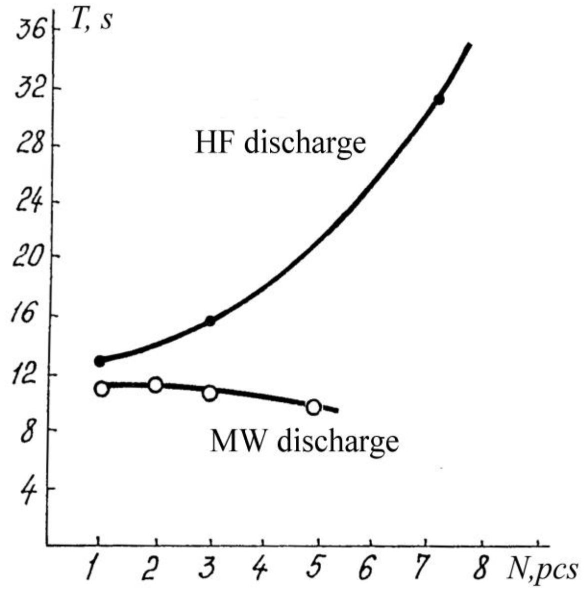

Fig. 2: Time period T of reaching maximum luminescence intensity OI (λ=844,6 nm) in the process of photoresist ashing in HF and MW discharges depending on the number of silicon wafers N

These dependencies can be explained by the fact that according to the technological experiments the speed of photoresist film ashing in oxygen plasma of HF discharge to a great extent depends on the temperature, namely, on the wafers preheating [2]. The increase of time T with the increase of the number of wafers simultaneously treated in HF discharge is connected with the increase of period for achieving heat balance in the system “ionized gas – samples” and the increase of the time for warming up the wafers to a certain temperature from which the process of intensive photoresist ashing starts [3]. For MW discharge the evident tendency to the reduction of time T at the increase of silicon wafers may be explained by increasing influence of such energy factor as the MW field energy absorbing [4].

Fig. 3 shows the dependence of ratio $K=I_{\text{o max}}/I_{\text{wafer}}$ on the number of simultaneously treated wafers in oxygen HF and MW discharges.

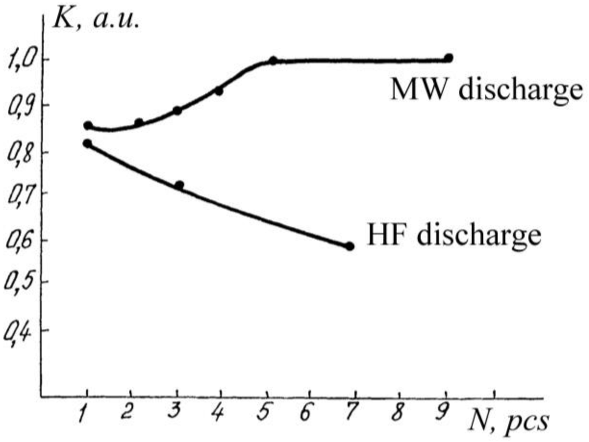

Fig.3: Ratio of $I_{\text{o max}}/I_{\text{wafer}}$ in the process of photoresist ashing in oxygen MW and HF discharges depending on the number of silicon wafers

One can see that with the increase of the number of wafers treated in HF discharge K decreases and it can be explained by deteriorated conditions for discharge stabilization, increase of time for achieving energy balance because of the necessity to warm up a great number of wafers, difficulties in maintaining the discharge because of the elimination of plasma particles on the wafers’ surface and so on. Hence, the intensity of discharge luminescence during establishing the energy balance in gas discharge system decreases, the value I_{wafer} practically being constant. In MW discharge the total oxygen luminescence intensity both for $I_{\text{o max}}$ and I_{wafer} decreases and starting from a certain number of wafers becomes constant. It may happen so because of the process inertness with the increase of wafers number the beginning of intensive photoresist ashing is delayed and $I_{\text{o max}}$ is determined not only by the process of photoresist ashing during which the atomic oxygen should become exhausted and, consequently, decrease the luminescence intensity line of OI (λ=844,6 nm), but also by the decrease of MW energy consumed for maintaining the discharge in the result of its partial absorption by the silicon wafers as well [5]. The performed experiments give the ground to make a conclusion that the process of photoresist ashing in oxygen plasma of MW discharge begins even without substantial warming up of wafers because of high chemical activity of the discharge.

The character of photoresist ashing is influenced by the position of the wafers with respect to the gas flow.

In case of longitudinal position the photoresist on the wafers placed closer to the wall of the plasma chamber is ashed quicker than from those placed in the center. Fig. 4 shows the distribution of photoresist film remnants Q in relative weigh measurement on the wafers placed in line at a slotted antenna in different moments of treatment t (the weight of the photoresist on the wafer before treatment is considered as 1).

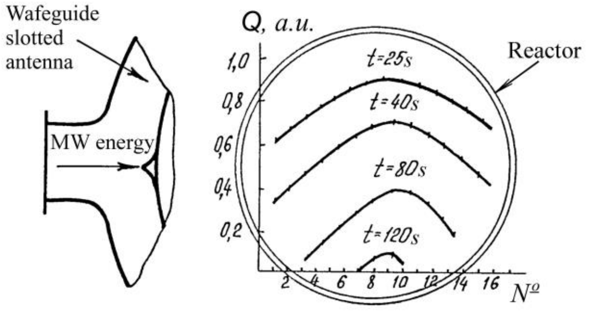

Fig.4: The character of photoresist ashing from the group of silicon wafers placed in line at the antenna

These dependencies show that the photoresist is ashed more intensively from the outer wafers.

The rate of destruction and photoresist ashing are influenced by conditions of applying MW energy as well. It may be seen on Fig. 4 that the process of treatment goes on more intensively from the side of the maximum MW energy entering. The obtained results may be explained by lower oxygen molecules dissociation in the center of the discharge chamber in the result of high MW energy absorption in the surface layer of plasma, impeding the transportation of dissociated chemically active particles to the center of the discharge that is caused by gas dynamic conditions and higher plasma density near the lead-in of the MW energy from the waveguide slotted antenna.

4 CONCLUSION

In the result of the investigation correlation ratio between the character of luminescence intensity line change of atomic oxygen in MW discharge and the process dynamics of photoresist films ashing from the surface of the silicon wafers were defined.

The obtained results enable supplementing the phenomenological process model of plasmachemical destruction of protective photoresist films in the volume of oxygen MW plasma.

The data provided in the work may be useful for developing technological processes of MW plasmachemical ashing of organic films from the surfaces of electronic devices.

Acknowledgements

This research has been supported by the State Program of scientific researches “Functional and composite materials, nanomaterials”, assignment № 4.5.02.

REFERENCES

[1] Bordusov S V, Microwave plasma technologies in the production of electronic devices, Minsk: Bestprint, 2002. – 452 p.

[2] Spencer J E, Borel R A, Hoff A, J.Electrochem. Soc. 133 (1986) 1923.

[3] Esin V I, Electrotechnical industry. Series 3: Conversion devices (1983) 16.

[4] Bordusau S V, Madveika S I, Acta Technica 56 (2011) 284–290.

[5] Bordusau S V, Madveika S I, Dostanko A P, Acta Polytechnica 53 (2013) 113 – 116.