High Rate Removal of Photoresist Films in the Microwave Discharge Afterglow in Oxygen

Bordusau S.V., Madveika S.I.

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

The results of experimental investigation of the process of removing photoresistive protection layers in oxygen microwave discharge afterglow are presented. The process demonstrated good characteristics and may be successfully used in very-large-scale integration circuits (VLSI) processing in automated manufacture conditions.

Keywords: oxygen microwave discharge, photoresist removal

1 INTRODUCTION

In the production of integrated circuits (IC) the main requirement to the removal of photoresist from semiconductor substartes with plasma ashing is a complete absence of photoresist after processing. Besides, it is necessary to provide the possibility of full process automation with fast individual processing of substrates with a diameter 150, 200 and in perspective 300 mm.

At present, because of the increasing scale of IC integration, it is necessary to exclude ion bombarding of semiconductor substrates with devices structures, which may accelerate the removal of photoresist but also lead to a significant pollution of substrate surfaces and result in undesirable changes of devices characteristics [1]. Hence, with reference to the process of photoresist removal from the surface of semiconductor substrates, it is better to perform the process of treatment outside the microwave discharge zone in order to avoid direct contact of semiconductor structures with plasma.

2 THEORY

The main factors during photoresist removal are three kinetic parameters: 1 – photoresist state; 2 – atomic oxygen concentration; 3 – temperature of the materials. The photoresist state should not be considered as an independent variable parameter as it is determined by the previous operations (baking and etching), and it should be removed irrespective of the state. Thus, only two varying elements remain which should be optimized by the respective choice of equipment construction and processing conditions.

As the atomic oxygen is the main reagent in the process [2], the heart of the installation for individual substrates processing should be an effective source, for example, of electrodischarge type. In this case, to prevent ion bombarding of the substrate it should be placed outside the plasma discharge zone below the gas stream. The discharge in this reactor should create minimum plasma layer potentials.

Temperature dependence of reactions and atomic oxygen concentration on the photoresist surface are important for the process of photoresist removing. The main limit for heterogeneous processes is the decrease of reaction rate because of reagents consumption caused by slow (with respect to the reaction itself) diffusion gas reagent inflow into the close-to-the-surface reaction layer. This, so-called, “loading effect” can be compensated by providing sufficient reagent influx to the substrate surface [3]. As a result, the velocity of heterogeneous reaction becomes the limiting factor. Dry phoresist removal by oxygen processing is very sensitive to the “loading effect” because oxygen molecules dissociate with difficulty. So, as a rule, phoresist removal in heavily loaded reactors in case of significant gas medium depletion by atomic oxygen goes on very ineffectively [4].

To compensate the “loading effect’ it is necessary to increase maximally the partial pressure of atomic oxygen that has not reacted in the working reactor volume with its sufficient influx. Because of this, the reaction process will not affect the concentration of atomic oxygen significantly [2]. In this case, it is important to differentiate active reagent concentration

from its mass flow. High active reagent concentration in the flux provides high initial velocity of the reaction while high mass flux maintains high reaction velocity, preventing medium depletion by atomic oxygen.

3 EXPERIMENT

Fig. 1 shows schematically the construction of a technological microwave gas discharge system in which the investigation of the process of photoresist mask layers removal in plasma afterglow was carried out.

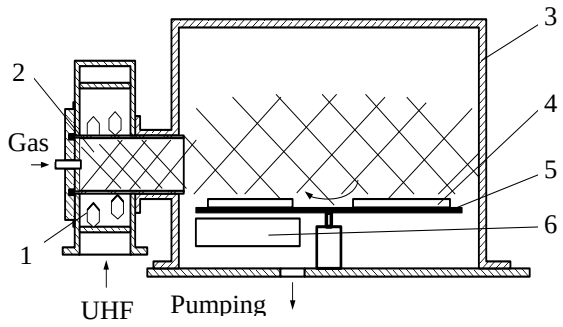

Fig. 1: Diagram of the plasma microwave discharge system: 1 – plasmatron; 2 – microwave discharge zone; 3 – vacuum chamber; 4 – substrates; 5 - substrate-holder; 6 – heater

A resonant type microwave plasmatron 1, constructed on the base of a rectangular waveguide bent into a ring with holes on the internal surface for inletting microwave energy into the resonant zone, was used as a plasma source. Alongside the axis of the wave guide applicator a quartz discharge chamber was placed in which gas discharge 2 was excited in vacuum. The substrates to process 4 were placed in the vacuum chamber 3 on the horizontal substrate-holder 5 below the edge of the discharge chamber. The construction of the substrate-holder supposes rotation around the axis. There was a heater 6 below the substrate-holder near the discharge chamber that provides contact-free heating of substrates to 550 K.

In such system, the substrates are well protected from direct plasma and plasma generated ultraviolet radiation. The construction of the discharge installation is designed for a significant gas flow.

The experiments were performed at films of positive photoresist AZ-1350J on the Si substrates of 150 mm diameter. The thicknesses of the photoresist layers was 1,5 μm. The coating and heat treatment of photoresist films were conducted using standard photolithography stages with usual temperature and time regimes. In all experiments the level of power (at 2,45 GHz frequency) was 600 W. To improve the uniformity of the photoresist removal process wafers were placed on a rotating substrate-holder. The measurement of photoresist film thickness was performed applying the interferometric method with using MII-4 interferometer.

4 RESULTS

The activity of atomic oxygen with respect to photoresist is very high, but for accelerating the process (because of moderate activation energy) substrates should be heated. It has been experimentally proved that heating up substrate to the temperature higher than 450 K significantly accelerates the reaction (note, at a wide interval of other parameters) producing minimum thermal effect on the substrate. Fig. 2 shows the dependence of photoresist removal rate (v_r) on the temperature of the substrate.

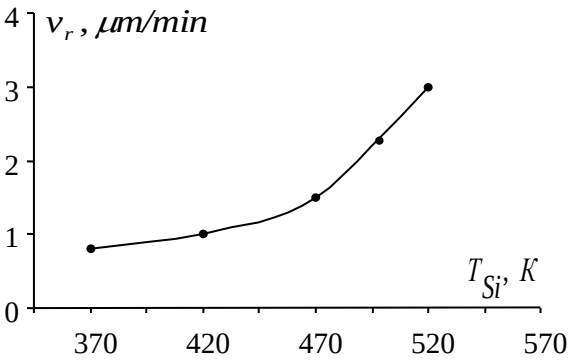

Fig.2: Dependence of photoresist removal rate on the substrate temperature

The dependence of photoresist removal rate on the oxygen pressure has an extreme character and reaches its maximum value at the pressure 260 Pa that can be explained by reaching in this case optimal discharge conditions (Fig. 3). The important factor for this process is that the atomic oxygen do not react with SiO_2 and Si.

The measurements of SiO_2 layer thickness (100 nm) and polysilicon (230 nm) showed no thickness change in the result of 20 min processing. Assuming the reproducibility of layers thickness measurements equal to 1nm, selectivity will exceed $3 \cdot 10^4$ at the rate of photoresist removing 3 μm/min i.e. turns to be infinitely big.

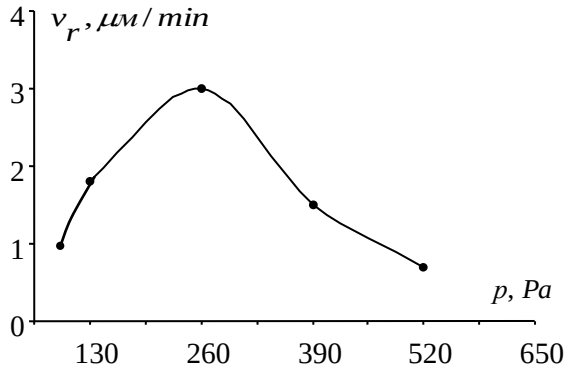

Fig.3: Dependence of photoresist removal rate on the pressure of oxygen in the discharge chamber

The increase of oxygen flow rate leads to a certain maximum rate of photoresist removal process. At oxygen flow rate higher than optimal the speed of photoresist removing slows down.

According to the theory, the efficiency of oxygen dissociation in the discharge and atomic oxygen concentration in the afterglow zone should go down with the flow increase [2]. However, the concentration in this process is not so significant as an integral quantity of atomic oxygen in flow above the substrate. Moreover, high reagent flow weakens the "loading effect".

The most important factor in this process is the losses of active reagent because of homogeneous and heterogeneous recombinations. In the reactor shown in Fig. 1 the time of atomic oxygen outflow from the luminescence zone to the surface of the substrate at optimal conditions equals to ~0,6 ms. It is approximately three value orders less than calculated duration of life of recombinational molecule formation of O_2 and O_3 [3]. Of course, heterogeneous recombination is inevitable, but high oxygen flow reduces its effect.

5 CONCLUSION

The performed experiments showed that the process of photoresist protective coating removal in the zone of plasma microwave discharge afterglow has high quantitative and qualitative characteristics. It makes it very perspective for application in IC and VLSI manufacturing technologies especially in automated production.

REFERENCES

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

[2] Dostanko A, [et al.], Plasma Process in Electronics Production, In 3 Vol, Vol. 1, Minsk: FUAinform, 2000.

[3] Einspruch N, Brown D, Plasma Processing for VLSI, Academic Press, Inc. 1984.

[4] Bordusau S V, Madveika S I, Dostanko A P, Specific characteristics of «loading effect» at microwave plasma chemical processing of silicon wafers, proc of the XXth Int. Symp. Physics of Switching Arc, Brno, Czech Republic, September 2 - 6, 2013, Brno University of Technology – Brno, 2013, P. 96-99