TECHNOLOGICAL STUDIES OF THE PLASMACHEMICAL REACTOR WITH CLOSED ELECTRON DRIFT

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The results of recent technological investigations into the plasmachemical reactor (PCR) with closed electron drift, developed at the Institute for Nuclear Research (INR) NAS of Ukraine are presented. The dependence of the monosilicon etching rate on the operating pressure in PCR was investigated. It is shown, that using a constant working gas feed and varying pressure from 10^{-3} to 10^{-1} Torr, the etching rate in the reactor increases from 0.7 up to 2,5 μm/min in the pressure interval (6…8)·10^{-2} Torr. Then the monosilicon etching rate decreases with other discharge parameters unchangeable. The dependence of the etching rate on the working gas (SF_6) flow value at constant pressure is presented. It is shown that this dependence has a nonlinear character with tendency towards saturation under further gas flow increase.

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INTRODUCTION

Plasmachemical reactors (PCR) with controllable energy of chemically active ions find more and more wide application in the industry. The ion energy is controlled by varying magnetic fields. The ion energy in such PCR can be changed in the range 20…1000 eV. Thus, it is possible to carry out both a soft precise plasmachemical etching without radiation damages of a processing surface with high anisotropy and selectivity, and physical sputtering of working layers of materials used in the microelectronics. At low ion energies there is no physical sputtering and redeposition of working layers, protective masks and materials used in PCR. The materials, which do not form volatile substances in reactions with chemically active ions and radicals, can be processed at the same installation by sputtering of materials applied in fabrication of products for microelectronics, computer engineering, optoelectronics, micromechanics, microwave technique, communication devices, photo-electric converters etc. The reactors under consideration permit to obtain micron, sub- and nano-micron size elements or to process epitaxial nanostructures containing new promising semi-conductor materials, such as gallium nitride, silicon carbide etc. [1, 2]. In this connection one shows an increasing interest in the study of technological opportunities of PCR with controllable ion energy.

The paper presents the results of investigations of PCR operation aiming an optimization of technological processes.

MAIN PART

A plasmachemical reactor with closed electron drift was developed in the Institute for Nuclear Research NAS of Ukraine [3, 4]. This reactor was used as a base to develop and fabricate a plasmachemical reactor for creation of insulation (etching of the end faces of photo-electric converters (PEC)). Two such reactors, introduced at the Open Joint-Stock Corporation "Kvazar" in Kiev, have completely satisfied requirements of the enterprise for PEC delivery. Each of these PCRs provides processing per hour of 1200 PEC plates with pseudo-square dimensions of 125x125 mm (plate diameter of 150 mm) and 150x150 mm (plate diameter of 175 mm).

A brief description of PCR designed for etching the PEC end faces and the first technological results of processing the PEC monosilicon plates are presented in [5]. A particular feature of PCR is application of high-frequency discharge in the crossed magnetic and electrical fields that allows one to control the ion energy and to work with chemically active ions having the energy lower than 200 eV. The use of low-energy ions in the plasma allows one to perform the sample etching without radiation damages of the surface and redeposition of PCR material onto the PEC surface. Besides, the presence of magnetic fields enables to obtain a higher degree of working gas molecule dissociation and atomic ionization, and, thus, to realize higher rates of etching of materials used in microelectronics.

The monosilicon etching rate as a function of working gas pressure in PCR, obtained in our experiments, is shown in Fig. 1.

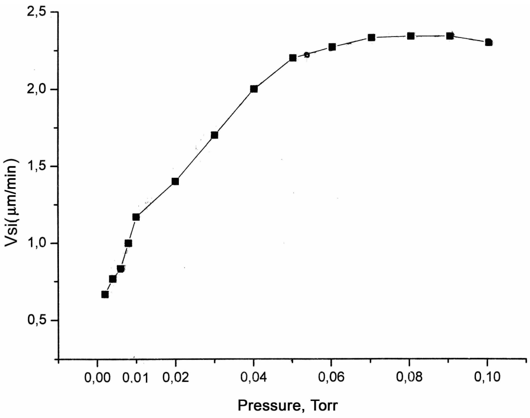

Fig.1. The monosilicon etching rate V_{Si} as a function of the working gas pressure in PCR (SF_6, Q=60 a.u.)

A working gas was SF_6; the magnetic field intensity in PCR – 150Oe; the high-frequency (13.56 MHz) discharge current – 8 A; a 1 kW oscillator with power stabilization was used. The flow (Q) of working gas used for etching was fixed, its pressure was varied mechanically with the help of a valve gate of the diffusion pump N-2T (evacuation rate 2000 l/s). In order to eliminate the loading effect the work areas of silicon plates were chosen to be equal and were S= 2.7 cm^2.

As Fig. 1 demonstrates, when the pressure in PCR changes from 10^{-3} to 10^{-1} Torr the etching rate increases from 0.7 μm/min to 2.5 μm/min. The increase of pressure above 10^{-1} Torr leads to some decrease of the monosilicon etching rate. To prevent the influence of different-type silicon properties on results of these investigations, the samples from one plate of the same PEC batch were used. As follows from these results, for silicon etching the optimum pressure of a working gas in the reactor is 6-8·10^{-2} Torr with above-mentioned other discharge parameters fixed. Apparently, with the further pressure increase in the discharge chamber there is a lack of the high-frequency generator power under indicated conditions, i.e. it is insufficient for dissociation and ionization of working gases in large quantities.

However, it has been found that the monosilicon etching rate depends not only on the working gas pressure in the chamber.

In Fig. 2 the monosilicon etching rate as a function of the working gas flow is presented.

At constant pressure in the chamber closely corresponding to the maximum etching rates ($P=5\cdot10^{-2}$ Torr), and with the same other discharge parameters, the fivefold gas flow increase results in the etching rate increase from 0.6 to 2.2 µm/min. It means that the gas flow rate through PCR should also be chosen properly in order to obtain the maximum etching rates.

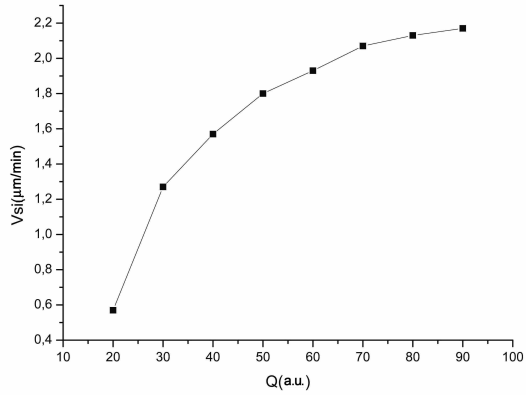

Fig. 2. The monosilicon etching rate V_{Si} as a function of the working gas flow (SF_6, $P=5\cdot10^{-2}$ Torr)

According to results of the carried out researches, it was succeeded to obtain the optimal etching rates of the end faces of monosilicon plates for creation of an isolation layer between working and back sides of PEC. With loading of 600 PEC plates, the etching rate can reach 0.5 µm/min at a discharge current of 16 A, and the etching time can be decreased down to 8 min during the total operation cycle of 30 min.

In the best PEC of the Alcatel Company with loading of 500 plates, the total operation cycle lasts 1 hour, and the etching time exceeds 30 min. As the result of so long etching time, a significant etching of the PEC working surfaces, up to 10 mm from their faces, takes place.

In contrast, at the plasmochemical reactor developed in INR a similar effect is not observed. It is worthy to note that the working gases filled in PCR are used completely, and the exhaust gases contain only the products of SF_6 interaction with silicon.

CONCLUSIONS

The experimental results demonstrate that at a constant flow of the working gas into the reactor and by varying the pressure in PCR from 10^{-3} to 10^{-1} Torr the etching rate increases from 0.7 to 2.5 µm/min. After that pressure value the monosilicon etching rate decreases and other discharge parameters are unchangeable. The nonlinear dependence of etching rate on the working gas flow with a tendency to saturation during the further gas flow increase is shown.

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ТЕХНОЛОГИЧЕСКИЕ ИСПЫТАНИЯ ПЛАЗМОХИМИЧЕСКОГО РЕАКТОРА С ЗАМКНУТЫМ ДРЕЙФОМ ЭЛЕКТРОНОВ

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Приведены результаты технологических исследований плазмохимического реактора (ПХР) с замкнутым дрейфом электронов, разработанного в ИЯИ НАНУ. Исследована зависимость скорости травления монокремния от рабочего давления в ПХР: при неизменном потоке подачи рабочего газа в реактор и изменении давления в ПХР от 10^{-3} до 10^{-1} Торр скорость травления возрастает от 0,7 до 2,5 мкм/мин на участке $(6\ldots8)\cdot10^{-2}$ Торр. Далее происходит уменьшение скорости травления монокремния. Приведена зависимость скорости травления от величины потока SF_6 при фиксированном давлении. Показана нелинейная зависимость скорости травления от расхода рабочего газа с тенденцией насыщения при дальнейшем увеличении газового потока.

ТЕХНОЛОГІЧНІ ВИПРОБУВАННЯ ПЛАЗМОХІМІЧНОГО РЕАКТОРА З ЗАМКНУТИМ ДРЕЙФОМ ЕЛЕКТРОНІВ

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Наведено результати технологічних випробувань плазмохімічного реактора (ПХР) з замкнутим дрейфом електронів, розробленого в ІЯД НАНУ. Досліджена залежність швидкості травлення монокремнію від робочого тиску в ПХР. Знайдено, що при незмінному потоці подачі робочого газу в реактор і зміні тиску в ПХР від 10^{-3} до 10^{-1} Тор швидкість травлення зростає від 0,7 до 2,5 мкм/хв на проміжку $(6\ldots8)\cdot10^{-2}$ Тор. Далі проходить зменшення швидкості травлення монокремнію при інших незмінних параметрах розряду. Показана нелінійна залежність швидкості травлення від розходу робочого газу SF_6 з тенденцією насичення при подальшому його збільшенні.