MODERNIZED EQUIPMENT FOR PLASMACHEMICAL ETCHING OF INSULATION OF P-N TRANSITION OF PHOTOELECTRIC CONVERTERS

***O.A. Fedorovich*[1]*, M.P. Kruglenko*[1]*, D.V. Lukomskyy*[2]*, A.A. Marinenko*[2]*, B.P. Polozov*[1]**

[1]Institute for Nuclear Researches, NAS of Ukraine, Pr. Nauky 47, 03680 Kyiv, Ukraine;
[2]Joint-Stock Company "Quasar", Kyiv, Ukraine;
e-mail: oafedorovich@kinr.kiev.ua, interdep@kinr.kiev.ua

Basic problems arising at the processing of the insulation of p-n transition of photo converters at the conditions of batch production with the use of the industrial plant "Carter" are determined. The way of elimination of these problems is shown. The modernized plant "Carter" has an advantage over their foreign analogues.

PACS: 52.77.Bn, 81.65.Cf

INTRODUCTION

Increase in the use of reproduced energy sources depends on the development of effective and economically expedient methods of transformation of non-conventional kinds of energy to electric energy [1]. A more plausible way of conversion is the direct transformation of solar energy to electric energy by means of semi-conductor photoelectric converters (PEC).

A technology used to manufacture photoelectric converters requires alloyage of the working surface of silicon plates. After that edges of processed plates become conductive. Therefore, there is a necessity of removal of a conducting layer from edges of plates up to the depths where silicon is non-conducting.

That is why plasmachemical etching (PCE) of edges of silicon plates is one of the most responsible operations in the technological process of manufacturing of PEC. The quality of PCE essentially influences the volt-ampere characteristic and also the efficiency of PEC.

THE BASIC PART

So far the joint-stock company "Quasar" has used the plant "Carter" to process silicon plates. The plant was developed in the beginning of 1980s; it consists of a usual diode system in which in a standard mode of etching silicon plates are installed on an active electrode. In such system at a high-frequency discharge occurring without magnetic field at the frequency of generator 13.56 MHz and the power 2.5 kW the speed of etching of silicon or polysilicon in mixes CF_4 and O_2 does not exceed 0.05 microns per minute. In such a reactor the energy of ions is proportional to the value of digit current and the ratio of areas of active and earthed electrodes [2,3]. In this etching two kinds of mechanisms can be distinguished. The first one is occurred with the use of fluorine containing radicals, atomic and molecular fluorine (chemical component), and the other one is associated with the ion bombardment (physical component).

Ion bombardment stimulates the etching surface and increases the desorption of reaction products affected by the negative potential on an active electrode [2,3]. Mounting of a holder with plates on an active electrode results in alignment of the areas of active and earthed electrodes. The accelerating potential sharply decreases or becomes equal to zero (Fig. 1). In this case the ionic component does not contribute to the etching and ionic stimulation of the surface. Therefore the speed of etching of edges of plates decreases in a few times. The installation of more than four batches of plates increases the area of active electrode, which results in a change of the ratio between areas of active and earthed electrodes.

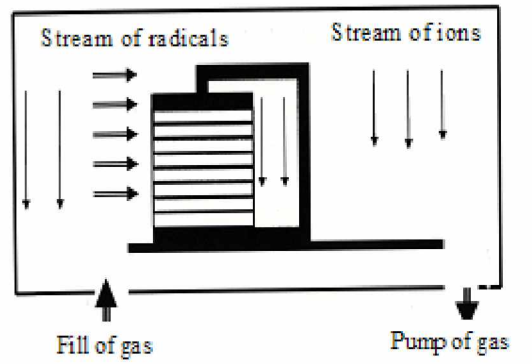

Fig. 1. Scheme of the plant "Carter"(И1М3.152.007)

The potential of the active electrode becomes positive and positive ions get away from the silicon plates located on the electrode. A deposition of products of reaction of silicon with fluorine and polymeric films has been observed, which more strongly inhibits the etching process. The replacement of plasma-forming gases or the ratio of their components in mixtures with oxygen does not improve the situation significantly. The optimal flow of gases in the plasmachemical reactor is violated. As a result three edges of PEC-plate are etched quite well, but the fourth one, which is found in "shadow" (Fig. 1), is etched several times slowly. This requires a longer total time to etch all plates and results in a non-uniform, insufficient and non-reproducible etching of edges at PCE. The efficiency of the plant also drops down. The plant "Carter" has a large working volume of the reactor chamber (58 liters) and the large area of working surface (12×10^3 cm^2). A significant part of the internal surface of the reactor chamber is covered with a polymeric film, which is produced with etching of silicon in a mix of CF_4 and oxygen. The polymeric film absorbs gases and moisture from the hermetic zone's atmosphere. After heating by the discharge the polymeric film liberates the absorbed gases and moisture. Burning of the discharge in the mix of CF_4, oxygen and desorbed gases tends to decrease the rate of etching.

Alloyage of silicon plates in PCl_3 gives rise to the sorption of phosphorus and chlorine at the edges of plates. Chlorine reacts with silicon and forms $SiCl_4$ with the boiling temperature 57.6° C. This chemical should be desorbed from the surface of plates’ edges. Having desorbed $SiCl_4$, the ion stimulation or heating of the edges to the mentioned temperature is necessary. However, the ion stimulation of the surface is not available in the "Carter". That is why the speed of etching of silicon plates by fluorine, especially in the beginning of the process, slows down. Plasma heating of edges of plates effects the evaporations of $SiCl_4$ from the plates’ surface. Only after that the etching of edges of plates in the fluorine containing compounds becomes possible. The product of the reaction of fluorine with silicon is SiF_4. The temperature of its sublimation is -86° C.

A significant part of the mentioned deficiency of PCE in the plant "Carter" is eliminated by the insertion in the reactor in addition with high-frequency fields also a controlled magnetic field. Such kind of a plasmachemical reactor has been developed and made at the Institute for Nuclear Researches of NAS of Ukraine (Fig. 2). It is introduced in the joint-stock company "Quasar" (Kyiv). The appropriate plant using the modernized plasmachemical reactor described above has been called "Carter-M".

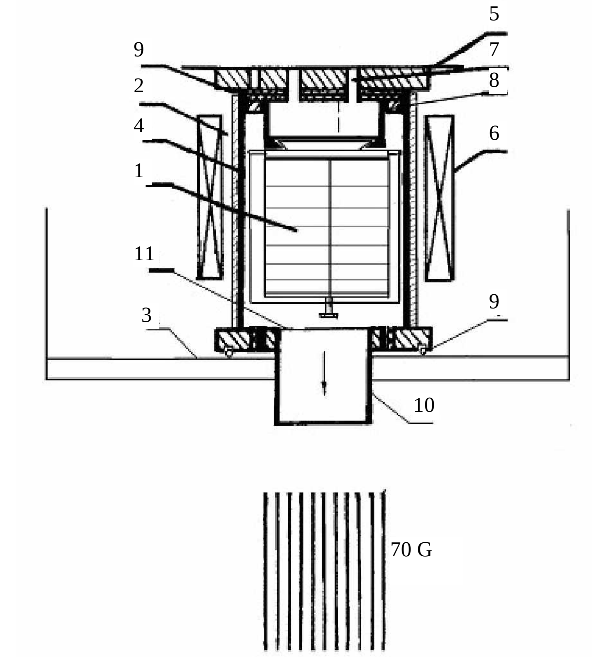

Fig. 2. Scheme of the plasmachemical reactor for etching of silicon plates edges of PEC:
1-active electrode with silicon plates, 2- external earthed electrode, 3- body of plant “Carter”, 4-inner earthed electrode, 5-upper earthed electrode,6- magnetic field coil, 7-water-cooling of active electrode, 8- isolator, 9-sealant, 10-vacuum system, 11-plasma terminator

In a reactor with crossed high-frequency and controlled magnetic fields the concentrations of electrons and ions is more than one order of magnitude larger than in the reactor without magnetic field [4]. The same concerns to the degree of the dissociation of complex molecules of gases from which in a high-frequency discharge chemically active radicals and fluorine are derived.

The volatile products of reaction are formed at the interaction with silicon. Etching of edges of PEC becomes possible if we use the edges as an active working electrode. In this case PEC-plates are packed in a pile since they possess conductivity. High-frequency discharge between the pile of plates and an external earthed electrode in a magnetic field with intensity near 100 Oe steadily burns at $p = 10^{-1}$ to 10^{-2} mm Hg. During a high-frequency discharge a negative potential of about 100 to 200 V is induced on the central electrode and both the chemical and the ionic-stimulating etching of edges of plates takes place. The rate of etching of silicon reaches 0.5 microns per minute at loading in the reactor of 600 plates with the size 150 x 150 mm. Such increase in the etching rate results in growth of the plant efficiency.

The essence of modernization of the plant has consisted in the developing a new design of plasma-chemical reactor. The new reactor allows us to process simultaneously 600 plates instead of 100, magnify the rate of etching from 0.05 up to about 0.7 microns per minute and enhance the uniformity of etching along the surface of edges. It also reduces etching of the right side and the reverse side of plates and removes "shadows".

Ecological compatibility of the process of etching is extended owing to the replacement of CF_4 by SF_6 and the atmospheric emission of halogen compounds is minimized. The expenditure of plasma-forming gases is diminished to 5 liters per hour; the load time and the processing time are reduced by half; control of the energy of chemically active ions by a magnetic field becomes possible.

In the plant "Carter-M" a conventional vacuum system, high-frequency generator and power suppliers are employed.

To estimate the quality of insulation of the emitter transition, one measures reverse current of *p-n* transition and shunt resistance of PEC [5]. In Figs. 3 and 4 the comparative characteristics of PEC after etching of edges of plates in a reactor without magnetic field and in a reactor with an applied magnetic field are shown.

The processing of plates of PEC, which has been carried out by the stock-joint company "Quasar" by using of the plants with the trademark Model 400 Microwave Plasma System of German firm PVA TePla AG has shown, that the qualitative insulation of the emitter transition at a level of the reverse current 5-7 mA is the same, as in the case of the processing with the plant "Carter-M".

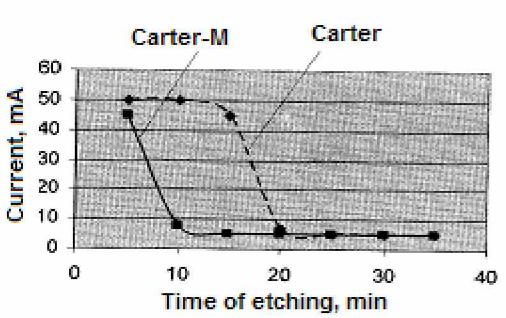

Fig. 3. Dependence of reverse current of PEC on time of etching of plates

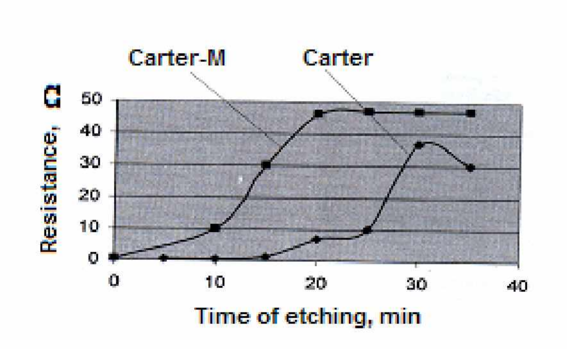

Fig. 4. Dependence of shunt resistance of PEC on time of etching of plates

However, in the first case a significant etching of the phosphorus-silicate glass film on the right side (up to 10 -20 mm from edge of a plate) has occurred. In the case of the plant "Carter-M" such noticeable etching is absent. Besides, the production rate of the plant "Carter-M" is 1200 plates/hour, which three times of the plant Model 400 Microwave Plasma System mentioned above.

CONCLUSIONS

1. The modernization of the plant "Carter" (И1М3.152.007) has allowed us to improve the quality and the productivity of plasmachemical etching of silicon plates used for the manufacture of PEC.

2. The plant "Carter-M" has been applied for the industrial production of PEC at the joint-stock company "Quasar".

3. Technological decisions suggested by the authors can be used for further developments of technological processes exploitable for the manufacture of different types of silicon PECs.

REFERENCES

1. *Clean electricity from photovoltaic* / Ed. M.D. Archer, R. Hill. London: “Imperial College Press”, 2001.
2. *Plasma technology in manufacture SBIS* / Ed. N. Ajnspruka and D. Brown. Moscow: "Mir", 1987.
3. B.S. Danilin, V. J. Kireev. *Application low-temperature plasmas for etching and clearing of materials.* Moscow: “Energoatomizdat”, 1987.
4. V.M. Konoval, V.V. Ustalov, O.A. Fedorovich. Plasmachemical reactor with the closed drift of electrons for manufacture of elements with the submicronic sizes // *Materials of 6th Int. Conf. on The Microwave Technique and Telecommunication Technologies "Crimeco-96"*, Sevastopol, Ukraine, 1996, p. 285-288 (in Russian).
5. S.V. Lenkov and D.V. Lukomskij. Complex parameter of quality and reliability of silicon photoelectric converters // *The Collection of Proceedings ВИТИ NTUU "KPI"*. Kiev, 2005, N1, p. 81-89 (in Russian).

МОДЕРНИЗИРОВАННОЕ ОБОРУДОВАНИЕ ДЛЯ ПЛАЗМОХИМИЧЕСКОГО ТРАВЛЕНИЯ ИЗОЛЯЦИИ P-N ПЕРЕХОДА ФОТОЭЛЕКТРИЧЕСКИХ ПРЕОБРАЗОВАТЕЛЕЙ

О.А. Федорович, М.П. Кругленко, Д.В. Лукомский, А.А. Мариненко, Б.П. Полозов

Определены основные проблемы, возникающие при проведении процесса изоляции эмиттерного *p-n* перехода фотоэлектрических преобразователей в условиях их серийного производства на промышленной установке "Картер". Продемонстрирован путь устранения этих проблем. Приведены преимущества модернизированной установки типа "Картер" перед ее зарубежным аналогом при промышленном производстве кремниевых фотоэлектрических преобразователей.

МОДЕРНІЗОВАНЕ ОБЛАДНАННЯ ДЛЯ ПЛАЗМОХІМІЧНОГО ТРАВЛЕННЯ ІЗОЛЯЦІЇ P-N ПЕРЕХОДУ ФОТОЕЛЕКТРИЧНИХ ПЕРЕТВОРЮВАЧІВ

О.А. Федорович, М.П. Кругленко, Д.В. Лукомський, А.А. Мариненко, Б.П. Полозов

Визначені основні проблеми, які виникають при проведенні процесу ізоляції емітерного *p-n* переходу фотоелектричних перетворювачів в умовах їхнього серійного виробництва на промисловому приладі "Картер". Продемонстровано шлях усунення цих проблем. Наведені переваги модернізованого приладу "Картер" перед його іноземним аналогом при промисловому виробництві кремнієвих фотоелектричних перетворювачів.