PLASMA TECHNOLOGIES FOR MANUFACTURING OF MICRO-STRIP METAL DETECTORS OF IONIZING RADIATION

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The manufacturing of elements of micro-strip metal detectors (MSMD) for ionizing radiation applying plasma-chemistry technologies for etching of multilayer structures is described in details. Results obtained by using plasma-chemistry technologies for MSMD production as well as its advantages in comparison with a wet chemical etching, problems arising and possible ways of their elimination are presented.

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Now, for carrying out research with beams of the charged particles or synchrotron radiation micro-strip metal detectors (MSMD) are getting applied [1]. For their production silicon substrates are mainly used as far as microelectronic technologies of silicon processing are well developed currently.

The important MSMD features determining complexity of their manufacturing are micrometer sizes of elements, high accuracy of elements as well as of their relative positioning. Basic elements of MSMD are thin metal films (1 μm thick), from which it is necessary to generate narrow (width up to 35 μm and 5-15 mm long) strips with a pitch of few tens μm on the area up to one hundred mm^2 (Fig. 1).

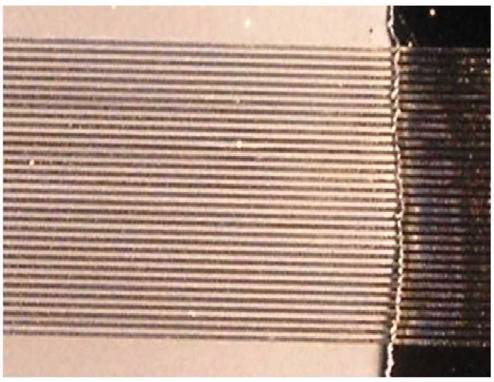

Fig. 1. The micro-strip metal detector

The silicon wafer KDB-100 (thickness 400-480 μm, diameter 100 mm) was used as a substrate. For creation of insulating layer silicon substrate was oxidized in the environment of oxygen from both sides at temperature varying from 800 °C up to 1300°C to obtain optimum thickness of SiO_2 layer ~ 0,1-0,2 μm. Thicker SiO_2 layer (about 1 μm) creates extremely tense film which breaks metal strips when a back side of a substrate is etched. On that layer of isolation (SiO_2) a layer of silicon nitride (Si_3N_4) 0,1-0,2 μm thick was disposed.

Both sides of a subtstrate were covered by a thin layer of the titanium (0,05-0,1 μm) for better adhesion, and a layer of nickel (thickness ~0,5-1,0 μm) was superimposed afterwards. In some cases, a layer of silver (~0,5 μm thick) was added from the front side. A silicon substrate prepared in this way was covered by a photoresistive layers from both sides. By means of a photolithography the required geometry for strips as well as for contact lines between them and pad was provided. Chemical etching of silver, nickel and titanium was processed to obtain the figure set by a lithography (providing exact overlapping of figures from both side). The Si_3N_4 layer serves here in the same manner as in the case of a passivation of microcircuits: to protect metal films of the defined figure. Metal films width after etching is in the range of 10 - 35 μm (depending upon the request).

After that cycle of operations a silicon substrate was cut on few plates, everyone with one detector. Now it was necessary to make metal strips in a working zone of the detector free from a silicon substrate and layers SiO_2 and Si_3N_4 under them.

This could be realized by using either plasma-chemistry or chemical etching or their combination. As numerous studies have shown, to etch silicon from the rare side without damaging thin metal films was not possible by none of the above mentioned processes. Most of all, this happens due to the fact that thermally oxidized silicon SiO_2 is mechanically tense and at etching up to low thickness of silicon it starts crack and results in damage of deposited metal films.

Besides that the silicon substrate, as a rule, is heated up to 300°C at the procedure of covering it by metal films, and then at the cooling phase due to different factors of linear expansion of silicon, nickel, silver and titanium , there is a superficial tension also in metal films. The slightest roughness in a width of a film results in its break. Therefore one of the problem arising at manufacturing strips of film detectors is a development of a technology to superimpose non-tensed films of nickel on silicon with the oxidized surface, with high enough adhesion to surface of SiO_2 or Si_3N_4. An aluminium films frequently used in microelectronics for manufacturing of micro-strip detectors appeared to be unsuitable due to small mechanical durability (the strength limit for aluminium in 7-9 times less than that for nickel).

At chemical etching the direction of axes of a silicon crystal is important, while at plasmachemistry etching such impact is not essential, that, undoubtedly, is in this case an advantage. But there are other, specific problems related, for example, to the energy of ions in plasmachemical reactor (PCR). As it has been shown [2], at ions energy higher than 250 eV the nickel film starts to be sprayed intensively, and for successful etching of a silicon substrate without damaging metal films the energy of ions should be much lower.

The PCR with adjustable energy of ions [3] has been developed. The energy of chemically active ions in this reactor is adjusted by means of controlled magnetic fields in the range of 20 - 700 eV (Fig. 2).

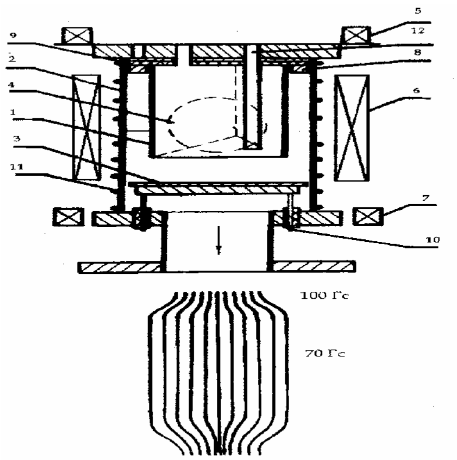

Fig. 2. The scheme of PCR

Use in PCR of the HF-fields crossed with magnetic fields, allows to generate plasma with chemically active ions with high concentration, that, in turn, enables to receive high enough speeds of etching of silicon: from 0,7 μm/min (a pressure of a gas in PCR $7x10^{-3}$ mm Hg, discharge current 6A and energy of ions ~40 eV) up to 2,5 μm/min (a pressure of gas $\sim10^{-1}$ mm Hg, discharge current 10 A, energy of ions ~80 eV).

In our case a plasma was excited by means of the HF-generator operated at the power of 4 kW that allowed to receive discharge currents up to 16 A. Yet, increasing of etching speed appeared to be inexpedient since the big thermal loadings on a substrate resulted in a separation of metal strips from silicon substrates (Fig. 3).

Fig. 3. Separation of metal strips from a silicon substrate

The SF_6 gas and its mixture with oxygen were used as operating reagents in PCR. At the beginning of studies we have tried to remove a silicon substrate from the back side, only. Unfortunately, there were only 2-3 (out of 32) strips survived, while others were broken, apparently, due to the tension in SiO_2 and nickel layers.

For elimination of a tension of a continuous film under silicon a number of experiments has been carried out to etch a SiO_2 layer in gaps between strips of nickel from a front side. For that purpose etching was carried out during 15 minutes in plasma SF_6 at so-called «soft mode»: at pressure $(7\text{-}8)x10^{-3}$ mm Hg, a current in the discharge 6 A and energy of ions 80 eV. After etching of the SiO_2 layer in the SF_6 plasma an oxygen was added in quantity of ~10 % from the general pressure and the energy of ions was reduced down to 40 eV. An addition of oxygen in working gas of plasma allowed to increase a speed of etching of silicon, and on the other hand to receive practically vertical walls of flutes [4].

Low energy of ions and small disharge currents allowed to etch flutes with a depth of 20-80 μm at the etching rate of a silicon of 0,3-0,7 μm/min .without damaging nickel or nickel-silver films. A part of the detector which should not be etched was covered by a thin foil. The width of an etched fragment at the front side was in the range 5-15 mm. After that an etching of the back side of a silicon substrate was processed.

The width of etched window at the back side was ~1 mm higher, than at the front one. A special attention was paid to providing perfect overlapping of windows of etching at both sides. Up to a thickness of ~50-100 μm the etching of silicon substrate was processed with a speed of 1,6-2,5 μm/min, in «a rigid mode». After that to reduce thermal loading and to preserve integrity of nickel strips etching was made in a soft mode. The depth of etching was monitored at the sample made out of the same silicon wafer.

In some experiments at the thickness of nickel of ~0,3 μm and strip width of ~10 μm it was possible to obtain all strips (32 in this case) undamaged. Yet, after a week of storage in the tight container due to the tension remained in the structure only 3-5 strips were left unbroken. The length of strips was in the range of ~5-15 mm. This result indicated a non-sufficient mechanical durability of strips. Therefore a thickness of nickel film has been increased up to ~1 μm, and a width of strips up to 35 μm. With those sizes it is possible to get the detector with all strips (up to 8 mm long) surviving during long term of conservation and operation. Among problems which require further studies are: a reduction of a superficial tension of nickel films, an improvement of a photolithography and chemical etching of nickel layer (or nickel with a silver covering).

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ПЛАЗМЕННЫЕ ТЕХНОЛОГИИ ИЗГОТОВЛЕНИЯ МИКРОСТРИПОВЫХ МЕТАЛЛИЧЕСКИХ ДЕТЕКТОРОВ ИОНИЗИРУЮЩИХ ИЗЛУЧЕНИЙ

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Приводится подробное описание изготовления элементов микростриповых металлических детекторов (МСМД) ионизирующих излучений с использованием плазмохимической технологии травления многослойных структур. Показаны результаты использования плазмохимии в технологии изготовления МСМД, её преимущества в сравнении с применением химического травления, а также возникающие при этом проблемы и возможные пути их устранения.

ПЛАЗМОВІ ТЕХНОЛОГІЇ ВИГОТОВЛЕННЯ МІКРОСТРІПОВИХ МЕТАЛЕВИХ ДЕТЕКТОРІВ ІОНІЗУЮЧОГО ВИПРОМІНЮВАННЯ

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Приведено детальний опис технології виготовлення елементів мікростріпових металевих детекторів іонізуючого випромінювання (МСМД) з застосуванням плазмохімічного травлення багатошарових структур. Представлено результати застосування плазмохімічної технології виготовлення МСМД, її переваги перед хімічним травленням, а також виникаючі при цьому проблеми та можливі шляхи їх усунення.