

Planar betavoltaic converter creation with plasma-immersion ion implantation process^{*}

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Abstract. Some results on planar diode structure creation by the method of a plasma-immersion ion implantation is presented in this paper. Obtained leakage current $\sim 1 \text{ uA/cm}^2$ at reverse voltage -1 V .

Keywords: betavoltaic element, p-i-n diode, plasma-immersion ion implantation.

Introduction

Direct conversion radioisotope micropower sources have drawn significant attention because of their potential of providing a long-term energy solution for low-power consuming microsystems. In recent years, a series of studies have been reported on betavoltaics with planar silicon p-i-n diodes [1-8], irradiated with Ni-63 isotope layer. The efficiency of these p-i-n structures rely on high-quality p-n junctions, in particular low leakage currents.

The similar research in the field of betavoltaics carrying out with efficiency enhancement of solid p-n junction neutron detectors [9, 10]. Common to these applications is the task of effective betaelectrons silicon detector creating, based on p-n junction with extremely small leakage current. In [10-12] shown, that planar epitaxial diode structures with narrow junction field region has leakage at the level $\sim 1 \text{ uA/cm}^2$; same p-i-n diode with wide junction field region has leakage about 20 nA/cm^2 .

In this research, authors research possibilities of application of a plasma-immersion ion implantation process (PIII) of boron into silicon were analyzed, also planar p-n junction was formed and leakage currents were measured to compare with parameters of epitaxial junction formed in [9].

Production and measurement of the planar p-n junctions

Silicon wafers «КЭФ-4,5 (100)» (n-type silicon wafers, doped with Phosphorus, 4,5 Ohm·cm volume resistivity) were used to experiment. Manufacturing mode is selected so that formed with PIII method p-n junctions were similar in concentration to epitaxial structures,

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studied in [9]. The wafers passed preliminary high purity reagents cleaning with next scheme:

1. Isopropyl alcohol about 1 minute.
2. De-ionized water 5 min.
3. H₂O₂(50%):NH₄OH(25%):H₂O (1:2:5) 1 min.
4. De-ionized water 1 min.
5. HF (10%) 1 min.
6. De-ionized water 1 min.
7. Dry nitrogen continuous-flow drying

After preliminary cleaning, then was carried out surface layer doping by BF₂⁺ ions with the PIII method on a laboratory plant. The laboratory plant has low-pressure high frequency plasma ICP-source, in plasma-forming BF₃ gas, where base ion is BF₂⁺. The ion implantation process passed in pulsing periodic mode, with applying rectangular accelerating negative polarity impulse to wafer. Impulse potential ($-V_{acc}$) define energy of the implanted ions; the relation between duration of constant potential to duration edge/drop of impulse define energy dispersion. Impulse duration was 10 us, the form is rectangular, pulse repetition frequency 1 kHz, amplitude 5 kV. Thus, energy of the implanted ions was 5 keV. The process of formation of the implanted structures include the following:

1. Preamorphisation of silicon facial layer by ions He⁺ for channeling effect exceptions of implantable boron into silicon.
2. Large dose implantation of boron ($D = 2 \times 10^{15} \text{ cm}^{-2}$) from gas plasma BF₃ in immersion mode by boron-containing molecular ions BF₂⁺ (dominant), also with a small amount of BF⁺ and B⁺.
3. Exposure surfaces of the implanted layer in hydrogen plasma to eliminating of boron precipitates from a surface, formed by large-dose implantation process of low energy boron ions.
4. The stage of cleaning a surface from boron precipitates is compatible to the PIII process and it carried out in the same technological camera. The surface of the implanted structure is exhibited into hydrogen plasma without giving of electric shift on a plate at temperature of 300°C.
5. After implantation process of annealing and electric activation of boron was carried out by fast photon annealing. The plates were annealed in the atmosphere Ar (99,9%) at temperature of 780 °C. Annealing time of admixture was 10-25 minutes, including a stage of the diffusive acceleration.
6. Laying tungsten on a silicon surface was carried out by the method of magnetron dispersion. Dispersion was carried out in DC mode in argon atmosphere, thickness of tungsten layer is 150 nm. The backward contact was created with analogous method.

Measurements of I-V characteristic in structures formed by PIII method (area about 1 cm²) were carried out at the room temperature with probe station Micromanipulator 7000, which are connected to the system Keithley 4200-SCS.

First of all interest was caused by the reverse bias of the diode characteristic, that determines reverse current, and standard dependence is given in a figure 1.

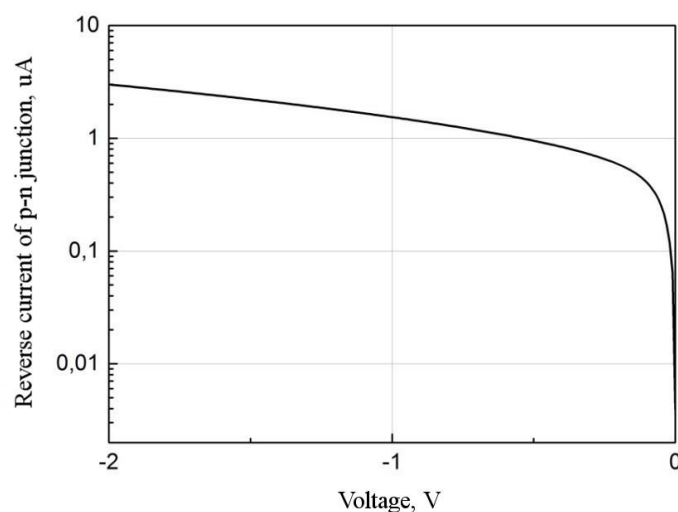


Figure 1. The reverse bias of the diode characteristic formed by the PIII method p-n junction which measures on mesa structure.

Conclusion

Thus, the results obtained in p-n planar diode structure, formed by plasma-immersion ion implantation process, by leakage are at the level of $\sim 1 \text{ uA/cm}^2$ at $U = -1 \text{ V}$, which corresponds to the epitaxial planar junctions obtained by high-temperature CVD-methods. It permits to suggest, that made by PIII method p-n junction with a wide depletion area would be had leakages, acceptable for betavoltaic power source.

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