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ENHANCING PARAMETERS OF SILICON VARACTORS USING LASER GETTERING

The authors investigate how and why defects influence the inverse characteristics of varactors. The paper presents experimental results on the effect laser gettering has on the electrical parameters of varactors. The mechanisms of the laser gettering effect on the parameters of varactors are analyzed.

Keywords: varactor, silicon, impurities, gettering, reverse current.

Varactors are widely used in radio electronics as variable capacitor diodes, the capacitance value of which is controlled by voltage [1—3]. The main parameters of the varactor are its Q-factor, nominal capacitance, reverse current and capacitance overlap ratio. The latter determines the frequency range of the varactor [1]. The development of varactors with a reverse gradient of the impurity concentration in the base makes it possible to significantly increase the capacitance overlap ratio. At the same time, another problem arises: such varactors have a low yield due to variance in nominal capacitance in the structures over the area of the plate, and to a high level of reverse currents. As studies have shown, this is mainly caused by structural defects and uncontrolled impurities in the active regions of the diodes [4—6].

Various gettering methods are used to reduce the density of structural defects in silicon [7—10]. Despite the variety of gettering methods of structural-impurity defects, many of them (e.g., mechanical introduction of defects into the back of the plate using abrasive treatment) are not technologically efficient, which makes it difficult to apply them in production. Therefore, a very topical issue is the development of effective technological methods for gettering structural defects and impurities in silicon.

This work is devoted to the study of how structural defects effect the parameters of the silicon varactor with the inverse gradient of impurity concentration in the base, and to the possibility of using laser gettering to improve the parameters and the yield of varactors.

Test samples

The investigated varactors were produced using the standard planar-epitaxial technology [11] and based on n-type silicon epitaxial structures with a specific resistance of 12 Ω·cm and a thickness of 8 μm, grown on silicon substrates oriented along the (111) plane.

Varactor structures were manufactured according to the following main technological operations:

— thermal oxidation of silicon wafers in water vapor at a temperature T = 1050°C for 100 minutes, followed by annealing in argon for 30 minutes at the oxidation temperature;

— 1st photolithography for opening windows in silicon dioxide;

— phosphorus ion implantation at a doping dose of 35 μC/cm^2 and phosphorus diffusion at a temperature of 950°C for 55 minutes to create a reverse concentration gradient;

— 2nd photolithography for opening windows for boron diffusion;

— boron doping in argon and oxygen at T = 980°C for 25 minutes to form a p—n junction;

— 3rd photolithography for opening windows in a borosilicate glass film;

— formation of the ohmic contact on the working side of the plate by depositing an aluminum film in vacuum, and the 4th photolithography on an aluminum film followed by annealing the contact in an inert medium at T = 500°C;

— polishing the back side of the plate and forming an ohmic contact on it by successive deposition of titanium and nickel layers using the vacuum thermal evaporation method, and deposition of gold using galvanic precipitation.

Investigation of structural defects

Tests of the faulty (according to the reverse current parameter) varactor structures showed a high density of oxidative stacking faults (**OSF**) in their active regions. After each high-temperature operation, metallographic tests of the crystal structure were performed. To reveal structural defects, selective etching was carried out using the Sirtl etch during 10 to 180 s. The type of structural

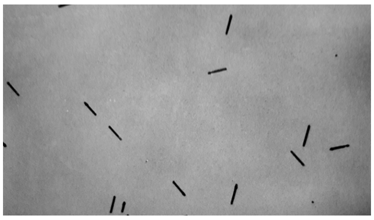

Fig. 1. Surface of the varactor structure with revealed OSFs

defects and their density were determined using an ММУ-3 (MMU-3) optical microscope.

Immediately after thermal oxidation of silicon, OSFs with a density of up to 10^2—10^3 cm^{-2} were found in the varactor structures, and after the last high-temperature operation (boron doping), the density reached 10^5—10^6 cm^{-2}.

Fig. 1 shows a microphotography of the surface of one of the tested structures after selective etching in a Sirtl etch for 20 s.

Gettering technology

To select an effective gettering method, which would seamlessly fit into the manufacturing route for the varactor, several gettering methods were tested. It is worth noting, that gettering should be done at the very beginning of the varactor manufacturing route [9, 12], i.e., before thermal oxidation, during which, as indicated above, OSFs already begin to form. The obtained experimental data have shown that an effective method of suppressing OSFs would be to use laser gettering in order to create a gettering area with an inverse concentration gradient of the impurity in the base on the back of the plate [13].

The getter region was formed by processing the back of the plate with a laser at a radiation density of 12 J/cm^2 followed by annealing in argon (140 L/h) and oxygen (10 L/h) at 1050°C for 40 min. Silicon wafers were processed by an LTN-102 type Nd laser [7, 14] with a radiation wavelength of λ = 1.06 μm. The surface scanning speed of the laser beam was 0.5 m/s. The wafers were processed with continuous laser radiation in the heat flux regime, which ensured the melting of silicon without evaporation.

Laser processing causes tensile stresses to appear in the silicon wafer [7]. Subsequent heat treatment in argon and oxygen leads to recrystallization of the back surface of the plate, where a dislocation network is formed in the region processed by laser radiation. The regions of the crystal lattice disturbance on the non-working side of the plate serve as a drain for point vacancy defects and atoms of rapidly diffusing metal impurities [9, 12]. Since the diffusion coefficients of these defects are several orders of magnitude higher than those of such dopant impurities as boron, phosphorus or antimony, during heat treatment they migrate through the semiconductor wafer and are deposited on structural defects in the layer with a broken crystal lattice.

Testing the effectiveness of the developed technology

To test the approach, four batches of varactors were produced using the basic technology (without gettering) and four more batches were made according to the developed technology (using laser gettering). The efficiency of the technology was evaluated by the varactor structures yield according to two parameters:

— reverse current I_{rev} (validity criterion: I_{rev}= = 0,2 μA at 16 V reverse voltage);

— nominal capacity C_{nom} (validity criterion: C_{nom} = 510—608 pF at 1 V reverse voltage).

It is obvious that the yield percentage is inversely proportional to the variance of the C_{nom} values over the area of the plate.

The analysis of the data from the **table** shows that using the developed varactor manufacturing technology makes it possible to increase the structures yield by an average of 7.5% according to the reverse current parameter, and by 7.3% according to the nominal capacity parameter. At the same time, the level of reverse currents in the structures made by the developed technology is 2—5 times lower than for the ones manufactured using the basic technology. The variance of the C_{nom} values over the area of the plate is also lower.

Dependence of the structures yield on their manufacturing technology according to the reverse current and the nominal capacitance values

Manufacturing technology	Batch number	Yield, %
I_{rev} control		
Basic	1	91
	2	89
Developed	3	97
	4	98
C_{nom} control		
Basic	5	42,1
	6	43,8
Developed	7	48,5
	8	51,9

Metallographic studies performed before the formation of ohmic contacts on the working side of the plates showed that the structures manufactured using the developed technology contain no OSFs .

Fig. 2 shows reverse branches of the current-voltage characteristics of the varactors. It can be seen from the figure, that gettering substantially reduces the level of the reverse currents in the diodes.

The effect of the laser-created getter layer on the parameters of the varactor structure can be

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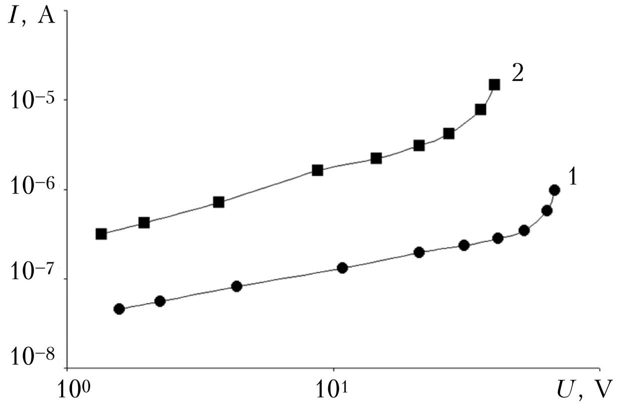

Fig. 2. Current-voltage characteristics of the varicap structures made using laser gettering (*1*) and the basic technology (*2*)

explained as follows. During high-temperature operations (thermal oxidation, phosphorus diffusion, boron diffusion), an effective gettering of metal impurities is carried out by the getter layer created on the back of the plate. The nuclei of structural defects that were formed during ingot growth and during epitaxy are removed, which to a great extent prevents forming new defects and helps removing the OSFs already formed in silicon. The interstitial silicon atoms that form OSFs diffuse to the created getter region and are captured by it.

As a result, the previously formed OSFs decrease in size or disappear completely. Effective gettering of metal impurities and structural defects provides a significant reduction in the variance of the nominal capacitance of varactor structures over the area of the plate (due to a more uniform diffusion of phosphorus over the plate area during the formation of an inverse concentration gradient of the impurity in the base of the varactor structure and a more planar boron diffusion front when creating the $p-n$ junction), as well as a significant decrease in the level of reverse currents in varactors, the increase of which was caused by defects.

Conclusion

Thus, oxidative packing defects formed in the active regions of the structures are the reason for the low yield of varactors with an inverse gradient of the impurity concentration in the base according to the reverse current and the nominal capacity parameters. The use of the developed technology for manufacturing varactor structures with laser gettering allows preventing or significantly decreasing the OSF density in the active regions of the structures. This makes it possible to reduce the level of reverse currents and to decrease the variance of the nominal capacitance of varactors over the area of the plate and, thus, to improve the devices yield.

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ПОЛІПШЕННЯ ПАРАМЕТРІВ КРЕМНІЄВИХ ВАРИКАПІВ ПРИ ВИКОРИСТАННІ ЛАЗЕРНОГО ГЕТЕРУВАННЯ

Варикапи широко використовуються в радіоелектроніці як змінна ємність, величина якої управляється напругою. Основними параметрами варикапа є його добротність, номінальна ємність, зворотний струм і коефіцієнт перекриття по ємності, який визначає частотний діапазон використання варикапа. Розробка варикапів зі зворотним градієнтом концентрації домішки в базі дала можливість значно збільшити коефіцієнт перекриття по ємності. При цьому, однак, виникла проблема, пов'язана з низьким виходом придатних приладів через розкид значень номінальної ємності структур по площі пластини, а також високого рівня їх зворотних струмів.

Робота присвячена дослідженню впливу структурних дефектів на параметри кремнієвого варикапа зі зворотним градієнтом концентрації домішки в базі і можливості застосування лазерного гетерування для поліпшення його параметрів і підвищення виходу придатних приладів.

Встановлено, що головною причиною низького відсотка виходу придатних досліджуваних варикапів є окислювальні дефекти упакування (ОДУ), що утворюються в активних областях структур в процесах проведення високотемпературних операцій. Детально розглянута запропонована технологія виготовлення структур варикапів з лазерним гетеруванням, а також особливості створення області гетера на зворотному боці пластин. Приведено експериментальні результати досліджень впливу лазерного гетерування на електричні параметри варикапів. Показано, що застосування розробленої технології дозволяє запобігти або істотно зменшити щільність ОДУ в активних областях структур, що дає можливість знизити рівень зворотних струмів і зменшити розкид значень номінальної ємності варикапів по площі пластини і, як наслідок, підвищити вихід придатних приладів

Ключові слова: гетерування, зворотний струм, кремній, домішки, варикап.

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УЛУЧШЕНИЕ ПАРАМЕТРОВ КРЕМНИЕВОГО ВАРИКАПА ПРИ ИСПОЛЬЗОВАНИИ ЛАЗЕРНОГО ГЕТТЕРИРОВАНИЯ

Работа посвящена исследованию влияния структурных дефектов на параметры кремниевого варикапа с обратным градиентом концентрации примеси в базе и возможности применения лазерного геттерирования для улучшения его параметров и повышения выхода годных приборов.

Установлено, что главной причиной низкого процента выхода годных исследуемых варикапов являются окислительные дефекты упаковки (ОДУ), образующиеся в активных областях структур в процессах проведения высокотемпературных операций. Подробно рассмотрена предложенная технология изготовления структур варикапов с лазерным геттерированием, а также особенности создания области геттера на обратной стороне пластин. Приведены экспериментальные результаты исследований влияния лазерного геттерирования на электрические параметры варикапов. Показано, что применение разработанной технологии позволяет предотвратить или существенно уменьшить плотность ОДУ в активных областях структур, дает возможность снизить уровень обратных токов и уменьшить разброс значений номинальной емкости варикапов по площади пластины и, как следствие, повысить выход годных приборов

Ключевые слова: геттерирование, обратный ток, кремний, примесь, варикап.

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