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ACTION OF MAGNETIC AND X-RAY FIELDS ON ELECTRO-PHYSICAL PROPERTIES OF TEMPERATURE SENSORS

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Abstract. The influence of X-ray and magnetic fields on the formation of radiation defects in silicon temperature sensors is investigated by the method of capacitance spectroscopy. It is shown that the defects which are generated by X-ray radiation are more sensitive to weak magnetic fields in comparison with structural defects. Effects of weak magnetic fields (*B=0.17 Tl*) on the pattern changes VFC of barrier structures are opposite to the action of X-ray radiation.

Keywords: magnetic field, X-ray, temperature sensor, VAC, VFC, barrier structures, defects

ВПЛИВ МАГНІТНОГО ТА РЕНТГЕНІВСЬКОГО ПОЛІВ НА ЕЛЕКТРОФІЗИЧНІ ВЛАСТИВОСТІ СЕНСОРІВ ТЕМПЕРАТУРИ

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Анотація. Методом ємнісної спектроскопії досліджено вплив магнітного та рентгенівського полів на формування радіаційних дефектів в кремнієвих сенсорах температури. Показано, що генеровані рентгенівським випромінюванням радіаційні дефекти є більш чутливі до дії слабких магнітних полів у порівнянні із структурними дефектами. Дія слабких магнітних полів (*B=0,17 Тл*) на закономірності зміни *ВФХ* бар'єрних структур є протилежною до дії рентгенівського випромінювання.

Ключові слова: магнітне поле, рентгенівське опромінення, сенсор температури, ВАХ, ВФХ, бар'єрні структури, дефекти

ДЕЙСТВИЕ МАГНИТНОГО И РЕНТГЕНОВСКОГО ПОЛЕЙ НА ЭЛЕКТРОФИЗИЧЕСКИЕ ОСОБЕНОСТИ СЕНСОРОВ ТЕМПЕРАТУРЫ

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Аннотация. Методом емкостной спектроскопии исследовано влияние магнитного и рентгеновского полей на формирование радиационных дефектов в кремниевых сенсорах температуры. Показано, что генерируемые рентгеновским излучением радиационные дефекты более чувствительны к воздействию слабых магнитных полей в сравнении со структурными дефектами. Действие слабых магнитных полей (*B=0,17 Тл*) на закономерности изменения *ВФХ* барьерных структур является противоположной к действию рентгеновского излучения.

Ключевые слова: магнитное поле, рентгеновское излучение, сенсор температуры, ВАХ, ВФХ, барьерные структуры, дефекты

Introduction

Creating of reliable electronic systems that could operate in extreme conditions represents an actual problem of modern electronics, which is rapidly growing. The conditions mentioned above are wide range of temperatures and action of external magnetic or radiation fields. Since the temperature is one of the most important parameters characterizing the course of various physical processes, it would be important to study electro-physical parameters of the temperature sensors under the influence of magnetic fields and *X*-rays.

It has passed more than *15* years since the first magneto-plastic effect has been detected in dielectric crystals. Studies of action of weak magnetic fields (*MF*) on the properties of semiconductor crystals, in particular Si crystals or the structures on its basis, have involved almost *7–8* years. There have been reports in the scientific literature concerning the effect of MF with the induction of ~ *1 Tl* at the room temperatures (*KT*) on some characteristics of crystals [1, 2], and also the action of irradiation on temperature sensors [3]. It has been shown that the effect of *MF* increases under the action of pulsed or variables *MF*, depending on the temperature and duration of the *MF*. It is also sensitive to the type of impurity in crystals characterized by complex relationships between the volume and surface properties of structures based on semiconductor crystals.

Therefore we believe that studies of mutual action of the *MF* and irradiation on the active elements of temperature sensors (*p-n*-transitions) are relevant because they allow us to consider and predict possible changes of characteristics and parameters of temperature sensors.

Experimental technique

The object of our study was a portable thermometer sensor *TP-2H* based on silicon uncased transistors *KT-354-2* [4]. Since the collector in the transistor has been short-circuited to the base, we used only the emitter-base *p-n*-transition.

This thermometer was designed to measure temperature in different environments from *–20* to *+150°C* (the limits for the allowable errors were from ± *0.1* to ±*0.5*). The stability of the thermometer was not inferior to traditional platinum resistance converters, though it was an order cheaper.

During our studies the sample was put in turn under the action of magnetic field and *X*-rays. Magnetic processing (*MP*) was made by aging the sensor in a constant magnetic field (*MF*) with the induction of $B = 0.17$ *Tl* (to compare with known literature data). The sample was irradiated at the room temperature using the *X*-ray irradiation with the parameters of $V = 4.5$ *kV* and $I = 8$ *mA* (*W*-anticathode).

Experimental results and their analysis

The results of our previous studies have shown [5] that the low-doze ($D < 500$ *Gr*) ionizing electromagnetic radiation with γ- and *X*-quanta leads to stabilization of the sensor's temperature characteristics. In this case the *VAC* and *VFC* of the barrier structures does not practically change and stabilization of the temperature characteristics is explained by partial "healing" of existing structural defects, which is based on increasing of the diffusion coefficient of inter-atomic defects under the action of radiation fields.

From the practical and scientific points of view it would be interesting to study the effect of the combined treatment imposed by the magnetic and radiation fields. Because real sensors work in real terms — the action of magnetic field of Earth, the radiation of electromagnetic irradiation of surrounding devices.

In *Fig. 1* we show the changes in the *VFC* of the sensor stimulated with the *MF* action, with the duration of *24 h* and *144 h*. This action leads to small changes in the capacity of *p-n*-transition in the positive voltage region. In other words, the capacity of dielectric layer of the *p-n*-transition undergoes small changes (*4.3 %*) under the action of MF (see curves *1*, *2* and *3* in *Fig. 1*) and saturates if the magnetic processing lasts for *144 h*. As there is no displacement of the modulation areas along the voltage axis, the density of surface states remains unchangeable on the verge of separation, and the capacity changes may be caused by decreasing charge localized in the space charge region (*SCR*) of the *p-n*-transition.

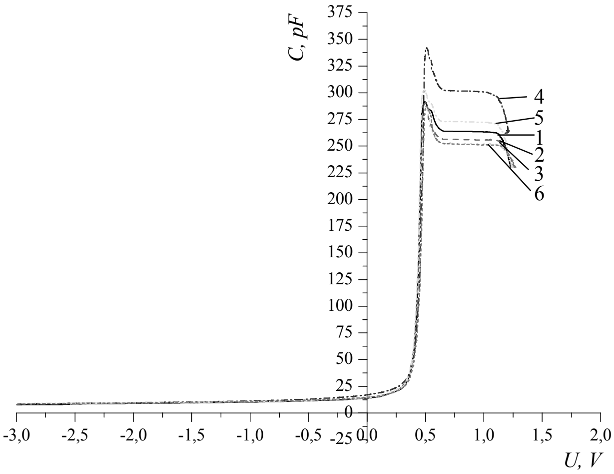

Fig. 1. VFC after the action of magnetic field and X-rays: 1 — initial sample; 2 — after 24h in the magnetic field; 3 — after 144 h in the magnetic field; 4 — irradiated with the dose of 217 Gr; 5 — after 144 h in the magnetic field; 6 — with no action of external factors

If the sensor after the action of *MF* is exposed under the *X*-ray irradiation with the dose of *217 Gr* at *KT*, then the value of *p-n*-transition capacity increases by *50 pF* (*19.3 %*) (see curve *4* in *Fig. 1*). The aging of experimental sample under *X*-ray irradiation during *144 h* at *KT* does not change the capacity, this allowing us to state that there is no relaxation process involving the radiation defects. Repeated action of the *MF* after the *X*-ray irradiation during *144 h* leads to reduction of capacity by *9.4 %* (see *Fig. 1*, curve *5*).

Further annealing of the sample at *KT* during *144 h* after the *MF* action gives rise to further reduction of the capacity down to its minimum value (*250 pF*), which has been peculiar for the first cycle of *MF* action (see *Fig. 1*, curve *6*).

Under repeated action of *X*-rays (*D* = *325 Gr*), the value of the *p-n*-transition capacity increases to *325 pF* (see curve *1* and *2* in *Fig. 2*) and goes then to its saturation.

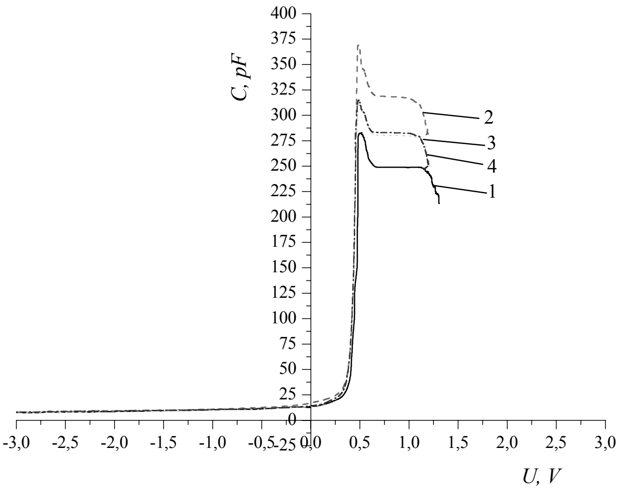

Fig. 2. VFC after the mutual action of magnetic field and X-rays: 1 — initial sample; 2 — that irradiated with the dose of 325 Gr; 3 — after 24 h in the magnetic field; 4 — after 96 h in the magnetic field

Recycling of magnetic processing of the irradiated (*325 Gr*) sensor after the first *24 h* has led to a reduction of capacity of *SCR* by nearly *50 %* (see *Fig. 2*, curves *2* and *3*). Further processing in the *MF* during *96 h* did not lead to any changes in the capacity (curve *4*), which had remained to be ≈ *275 pF*.

While discussing the data obtained above we proceed from the fact that *MF* stimulates some intra-defect reactions that stipulate unitizing processes for some of point charged defects, along with formation of the oxygen-vacancy complexes and decreasing of internal strains in the crystals of *Si* [6]. These effects also induce restructuring of defects and reducing of flaws in the surface layer of *p-n*-transition and, consequently, reducing of the capacity of the *p-n*-transition.

The fact that the capacity of the *p-n*-transition under the influence of *MF* decreases only by *11.7 %* is the evidence of that the structural defects sensitive to *MF* are not peculiar to our initial sample.

The effect of the *X*-ray irradiation leads to destruction of the complexes formed, as well as to generating newly of the ion defects, those of the *A*- and *E*-types, as well as the isolated vacancies and double vacancies (*VV*-centers). That leads to increasing charge localized in the dielectric layer. Some of these defects are meta-stable and relax with time. Significantly larger part of the radiation defects generated by *X*-rays is sensitive to the *MF* and takes part in the evolutionary processes that lead to reduction of the *SCR* capacity.

From the analysis of the results obtained above we can draw the following conclusions:

1. A small part of structural defect in the temperature sensor based on silicon *p-n*-transition is sensitive to the *MF*;

2. Radiation defects generated by the *X*-rays are more sensitive, in comparison with the structural defects responsible to the action of *MF*;

3. Weak magnetic fields ($B = 0.17$ *T*l) show the effect on the sensory *VFC p-n-* transitions which is opposite to the action of *X*-ray radiation.

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