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 ($B=0.17 \, \text{Tl}$) 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
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-anti-cathode).

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.

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 (\( D = 325 \text{ Gr} \)), 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.

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 \( \approx 275 \text{ pF} \).

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 ($B = 0.17 \text{T}$) show the effect on the sensory VFC p-n-transitions which is opposite to the action of X-ray radiation.

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