TEMPERATURE EFFECT ON THE CHARACTERISTICS AND LIFE-TIME OF SEMICONDUCTOR DETECTORS

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The paper reports the results from studies into the effect of temperature on the performance characteristics of planar silicon detectors designed and manufactured at the NSC KIPT. A variety of techniques are demonstrated for measuring the temperature effect on various static and spectral characteristics of single-channel planar detectors. The relationship between the static characteristics of detectors and their long-term stability and lifetime is considered.

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1. INTRODUCTION

An important factor in the operation of silicon detectors that influences their performance characteristics is the temperature. It may exert an effect on many vital operation parameters of silicon detectors, such as dark leakage currents and energy resolution. It is known [1] that the studies of the behavior of detector characteristics at different temperature conditions may provide prediction of the nonfailure operation time of the detector. With a more detailed investigation into the behavior of both static and spectral characteristics of silicon detectors versus temperature it appears possible to determine the physical processes of parameter destabilization with time, this being of primary importance at long-term usage of the detectors.

2. TEMPERATURE-LIFETIME INTER-RELATION OF SI PHOTODIODE

Specialists concerned with the reliability of products often describe the lifetime of a product population with the use of a graphic representation called the U-curve [2].

Fig.1 shows the U-like curve that consists of three periods: i) the initial period with a decreasing failure frequency followed by ii) the normal period of service (also known as useful period) with a low, relatively constant frequency of failures, and iii) the final period or the wear-out period, which exhibits an increasing failure frequency.

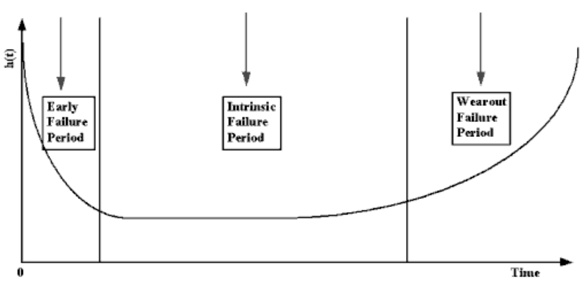

Fig.1. Schematic diagram of detector lifetime stages

In long-term stability tests of semiconductor detectors and in the determination of their lifetimes the technique is used, which makes it possible to reject inadequate-quality detectors at the initial stage of detecting module production, and also to establish the reasons of their failure.

The essence of the technique consists in the following. It is known [3] that under the action of elevated temperature and bias voltage the probability that defects will manifest themselves in a semiconductor crystal increases. The tests of the kind, where nonstandard modes of semiconductor operation are used, are referred to as "accelerated tests".

Accelerated lifetime tests are generally used to obtain more quickly the information on the life expectancy of products and materials, and also to simulate the mechanisms of failures that may occur throughout the service life of the product. The accelerated test implies that the products will be subjected to the conditions which will be more severe than normal ones, and which would be never attained at ordinary use of the product. If there is a speed-up effect, then the variation in the stress is equivalent to the time scale transformation.

Let us briefly consider the basic failure mechanisms of semiconductor products. There are three main causes of semiconductor failures: the failures associated with electrical voltage, internal failures and external causes of faults.

The failures due to degradation of the semiconductor itself are called internal failures. These mechanisms are generally connected with the process of wafer production and involve crystal defects, dislocations and process-induced defects, oxide breakdown, ionic soil, surface charge propagation, etc. The mentioned defects generally result either from a poor processing of a crystal, or from a nonuniform growth of the oxide layer. On the contrary, the soiling is usually a consequence of environmental influences, human factor (surface contact, etc.), processing or packing. The external causes of failure are connected with the external conditions. The failures generally result from a wrong stacking of semiconductor products, and also from the interaction of structural materials.

The model approximations used to simulate the accelerated lifetime include Arrhenius model [5], Airing model [6], and others.

Arrhenius model describes relationship between the failure occurrence time of electronics components and the temperature. According to this model, relationship between the stress and the lifetime is given by

$$L(T) = Ce^{\frac{E_a}{KT}}.$$

Here C is the parameter to be estimated, E_a is the activation energy (eV), and k is the Boltzmann constant ($8.617 \cdot 10^{-5}$ eV/K).

With the use of the maximum likelihood theory [7], the parameters of the Arrhenius model are estimated in the assumption that the basis for the lifetime distribution of the sample is the Waybull distribution [8].

The acceleration factor is determined in this case as

$$AF = \frac{L_{use}}{L_{accel}}.$$

It shows the ratio of the lifetime at normal conditions to the lifetime at accelerated tests.

As the activation energy can be calculated, we have

$$AF = e^{\left(\frac{E_a}{KT_{use}} - \frac{E_a}{KT_{accel}}\right)} = e^{\frac{E_a}{K}\left(\frac{1}{T_{use}} - \frac{1}{T_{accel}}\right)}.$$

Here T_{use} is the temperature at normal operating conditions; T_{accel} is the temperature at accelerated tests.

The humidity and the bias voltage of the detector play an important role in many mechanisms responsible for the abnormal performance of semiconductor products. The general model that includes three parameters (temperature, bias voltage and humidity) has the following form [9]:

$$t_f = Ae^{\frac{\Delta H}{kT}} V^{-\beta} RH^{-\gamma}.$$

Here RH denotes the percentage of humidity, ΔH is the activation energy, and V is the bias voltage.

In the general case, the Airing model can be used to simulate acceleration when many stress factors are taken into account.

At present, there is an extensive software base that makes it possible to simplify the calculations and provides an easy-to-use interface [10].

3. TEMPERATURE EFFECT ON THE CHARACTERISTICS OF PLANAR DETECTORS

In spectrometry measurements carried out with semiconductor detectors, the working temperature of the detector is one of the key factors that limit the possibility of attaining high energy resolution. In the present work most attention has been given to the temperature dependence of dark leakage current of the p-n junction of the planar silicon pin-detector. Previously, we have measured the temperature dependence of leakage current of detector structure elements having different active zone areas and different current-voltage characteristics, and have demonstrated that the energy resolution of the detector is mainly determined by dark leakage currents of the active area of the detector.

To investigate the influence of temperature on the static characteristics of detectors, a multichannel stand was used as a basic setup, while a special probe adapter was used to investigate spectral characteristics.

It should be specially noted that the temperature dependence of leakage currents is individual for each detector, and to estimate correctly the temperature effect on the energy resolution and dark leakage currents, it is necessary to know the specific dependence I(T) for each detector.

Using the thermocycling technique we have found an unstable operation of the p-n junction of a pin-detector having a low prebreakdown voltage. The instability manifests itself in the variation of the leakage current of the active area depending on the number of heating cycles.

Fig.2 shows the behavior of the leakage current at the maximum bias voltage after different stages of detector heating.

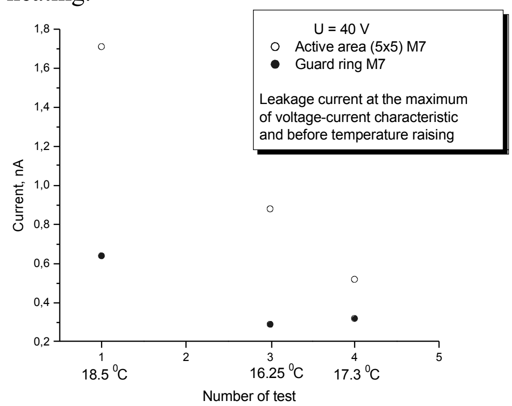

Fig.2. Leakage currents of the active area and the guard ring at the working bias voltage at different stages after annealing

It can be seen that the leakage current of the active area, measured at room temperature, falls off with an increasing number of heating cycles. Since the range of working temperatures in different experiments varies within wide limits (from liquid nitrogen temperatures up to ~ 50°C and higher), there arises the question about the behavior of the leakage current at temperatures different from room temperature.

Experiments show that the leakage current of the active area substantially increases after a few heating cycles.

Fig.3 shows the rise in the leakage current of the active area at the working bias voltage and a temperature of 40°C as a function of the number of heating cycles. It is obvious that the dark leakage current of the p-n junction has substantially increased. This instability is inadmissible for operation of the detector at different ambient temperatures. Consequently, with the help of the technique described, it appears possible to reject the defective detectors at the initial stage of detecting module production.

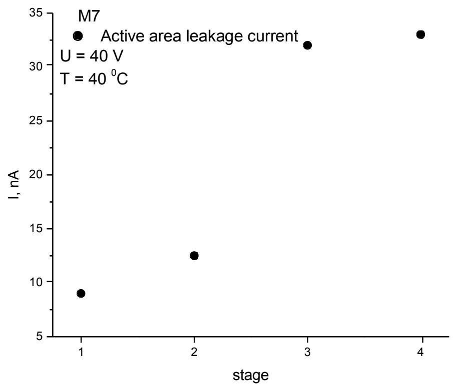

Fig.3. Leakage current of the active area at 40°C at different stages of heating

4. CONCLUSIONS

It has been shown that the temperature is an essential parameter that must be taken into account at operation of semiconductor detectors. By using specially developed methods it is possible to determine the degree of the temperature effect on an individual detector, and to properly correct the energy resolution with due regard for temperature variations. The accelerated test technique can be used to determine the lifetime of a semiconductor detector, and also to establish the main mechanisms of abnormal operation of the detector under examination.

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ВЛИЯНИЕ ТЕМПЕРАТУРЫ НА ХАРАКТЕРИСТИКИ И ВРЕМЯ ЖИЗНИ ПОЛУПРОВОДНИКОВЫХ ДЕТЕКТОРОВ

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Приведены результаты исследования воздействия температуры на характеристики планарных кремниевых детекторов, спроектированных и изготовленных в ННЦ ХФТИ. Показан ряд методик, позволяющих проводить измерения влияния температуры на различные статические и спектральные характеристики одноканальных планарных детекторов. Рассматривается связь статических характеристик детекторов с долговременной стабильностью и временем жизни детекторов.

ВПЛИВ ТЕМПЕРАТУРИ НА ХАРАКТЕРИСТИКИ ТА ЧАС ЖИТТЯ НАПІВПРОВІДНИКОВИХ ДЕТЕКТОРІВ

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Приведені результати досліджень впливу температури на характеристики пласких кремнієвих детекторів, спроектованих та виготовлених у ННЦ ХФТІ. Продемонстровано ряд методик, які дозволяють проводити вимірювання впливу температури на різні статичні та спектральні характеристики одноканальних пласких детекторів. Розглянуто зв'язок статичних характеристик детекторів з довгостроковою стабільністю та часом життя детекторів.