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FEATURES OF THE TEMPERATURE SENSOR IN FIELD-EFFECT TRANSISTOR

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ABSTRACT

It is experimentally shown that the temperature coefficient of sensitivity of field-effect transistor in channel depletion mode is independent from the process parameters of the transistor structure. In this case temperature coefficient of sensitivity and the magnitude of base thickness growth by temperature for all field-effect transistors has the same value.

KEYWORDS: field-effect transistor, temperature coefficient of sensitivity, pinch-off voltage, wide temperature range.

INTRODUCTION

The rapid development of electronics, computing and communication technologies require extensive automation of various processes in industry, in research, in everyday life. Wide automation of technological processes and monitoring of objects is largely determined by the capabilities of the respective sensors. In turn, the sensor, converting measuring parameter into an output signal which can be measured and quantified, are like the sensory organs of modern technology.

Among the many measuring parameters one of the main parameters is the temperature. Its measurement is necessary in all complex technological processes in the most remote areas where other parameters cannot be measured.[1] For example, in the active zone of nuclear reactors, and in modules of solar cells there is a need of temperature control in the operating mode.

The need for diagnosing various parameters and processes in industrial facilities, nuclear reactors, scientific research and other areas of consumption requires the development of temperature sensors with improved functional characteristics and stable parameters.

As you know, as a temperature sensor are widely used diodes and transistors with a rectifying p-n-transitions, the voltage drop in which the limited current changed linearly with temperature. In particular, semiconductor diodes of the type КД503А and КД102А used for the manufacture of electronic thermometers. But they have some disadvantages associated with a significant current consumption to 10 mA, which leads to zero drift of the voltmeter and reduce the sensitivity of the device, which is 0.6÷0.7 mV/°C.[2]

In the present communication we present the results of the study a field-effect transistor as a temperature sensor. The choice of the field effect transistor as a temperature sensor due to the fact that the density of direct current in them is much smaller than in the diode structures, and operating currents can be selected in a wide interval, starting from the range of microamperes. In the mode of locking the channel voltage drain-gate operating currents in the tens of nanoamperes.

The experimental samples: The investigated silicon field-effect transistor with p-n-transition, shown in Fig. 1, contains low resistance substrate p-type with the lower electrode and the shutter is grown on the surface of the high resistance epitaxial layer of n-type, on whose surface formed an ohmic contact region of the drain and source, and between them lies the channel. The carrier concentration in the substrate is $1.0 \cdot 10^{19}$ cm^3, and the channel $2 \cdot 10^{15}$ cm^3. The thickness of the channel is ~1 μm and a length of 50 μm. The investigated transistors have a typical field-effect transistor sublinear current-voltage characteristics with the maximum drain current 400÷800 μA and voltage cutoff channel 0.6-2.0 V.

Dimensions of the case of transistors with a diameter of 5 mm and a height of 7 mm allow to use them for measuring temperature in the respective gaps of different objects.

The experimental technique: The sensitivity of the transistor structure to temperature was determined in a chamber with controlled temperature with accuracy of 0.1 degree Celsius.

Measure current and voltage was performed using a digital voltmeter with the minimal measured current value of 0.1 nA.

The study was performed in two modes, a limited direct current through the p-n junction when a falling voltage is used as a measuring parameter, and in the mode of locking the channel by voltage drain-gate (Fig. 2), during which as the measuring parameter used in the cutoff voltage of the channel.[3]

EXPERIMENTAL RESULTS AND THEIR DISCUSSION

Temperature sensitivity of the field-effect transistor in the forward bias p-n junction of the shutter

In fig.1 shows the current-voltage characteristic of p-n-transition (gate-source+drain) of the gate of a field effect transistor, where the drain is shorted to the source. In the region of small currents (20 µA) current value of the applied voltage is increased exponentially.

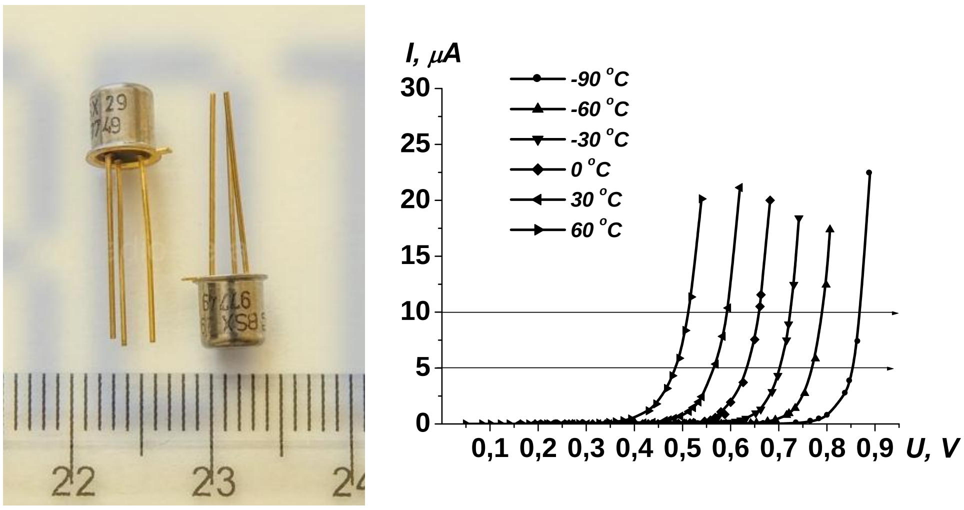

Fig. 1: The appearance of the body and is a direct branch of current-voltage characteristics of p-n junction of the gate-channel field-effect transistor.

The increase in temperature leads to a shift of voltage-current characteristics in the region of lower voltages. Operating current in p-n junction was measured by using a variable potentiometer.

For a given current limitation, for example 10 µA generated by the current limiter on the field-effect transistor, the temperature coefficient is the ratio of the difference of the falling voltages on the temperature difference:

$$\alpha = \frac{U_2 - U_1}{T_2 - T_1} = \frac{\Delta U}{\Delta T}.$$

Measured in the temperature range from -90 to +60 degrees Celsius have the the voltage drop from 0.858 V to 0.512 V for a temperature difference of 150 degrees, respectively temperature coefficient of voltage is 0.0023, i.e. 2.3 mV/deg, which is two or more times greater than in the diode structures. As can be seen from Fig. 1 the data values for the temperature coefficient remain unchanged in the interval of currents from 5 to 10 µA.

Thus, in the restriction mode of the direct current field effect transistor with a p-n junction has a temperature sensitivity determined by the process of the formation current and to some extent the level of injection of carriers. The obtained value of the temperature sensitivity of forward bias voltage is not inferior to the values occurring in the diode structures, and the miniature design of the MOSFET allows it to be used to determine the temperature in the narrow gaps of various devices and equipments.

Temperature sensitivity field-effect transistor in the cutoff mode of the channel

The sensitivity of the transistor structure to temperature was determined in a chamber with controlled temperature with accuracy of 0.1 degree Celsius. Measure current and voltage was performed using a digital voltmeter with the minimal measured current value of 0.1 nA. The study was carried out in the mode of locking the channel voltage drain-gate (Fig. 2), and as the measuring parameter used in the cutoff voltage of the channel.

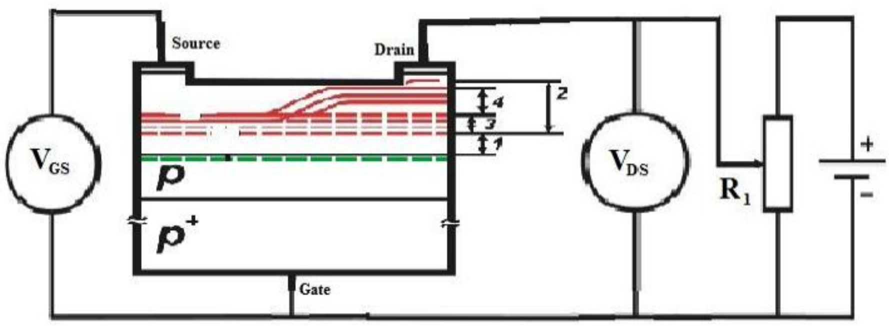

Fig. 2: The scheme of measurement of the voltage drop at the transition source-gate mode locking channel voltage drain-gate.

Studies have shown that in this mode the rise in temperature in a wide interval from minus 150 to plus 150 degrees as shown in Fig. 3, resulted in a linear increase in voltage cut-off.

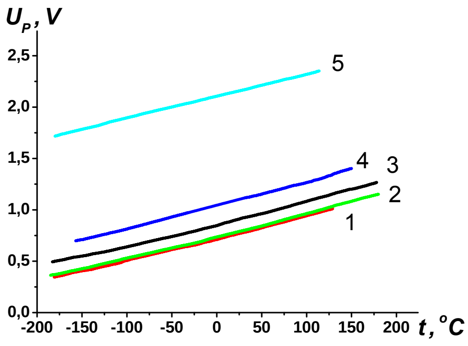

Fig. 3: The dependence of the tension cut-off channel field-effect transistors with different voltage cutoff.

The observed increase in voltage cut-off channel with temperature can be linked with the decrease of the contact potential difference of p-n junction (1), due to the increase of intrinsic concentration of carrier with increasing temperature.[4]

In this mode, the investigated field-effect transistor has a temperature sensitivity comparable to the sensitivity of the diode structures, but with the advantage that hardly consumes energy. The temperature coefficient of the voltage cutoff

$$\alpha_{co} = (U_{co}^2 - U_{co}^1)/(T_2 - T_1),$$

is 2.2 mV/degree, which is at the level of values occurring in the diode structures in the restriction mode of the direct current ~ 10 mA.[5]

Thus, the dependence of the tension cut-off temperature for field-effect transistors with different voltage cutoff in a wide range of temperatures (- 150 ^{o}C to + 150 ^{o}C) showed that their temperature coefficient of sensitivity does not depend on the technological parameters of the transistor structure (Fig. 3). So, the mechanism of temperature sensitivity obeys the same law, the magnitude of increase of base thickness on the temperature for all field-effect transistors has the same value. At the same time in a wide interval of temperatures, the dependence of the voltage cutoff on temperature is strictly linear.

CONCLUSION

A field-effect transistor as the temperature sensor exceeds its analogues on the basis of diode and transistor structures in which the maximum temperature is 125^{o}C. Developed in recent temperature sensors on field-effect transistors with low operating current will help in many specific cases, to replace the traditional diode and a metal (e.g., platinum) sensors and thereby reduce the cost of measurement and improve the reliability of systems.

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