INCREASING RADIATION RESISTANCE OF MEMORY DEVICES BASED ON AMORPHOUS SEMICONDUCTORS

Vasyl Kychak, Ivan Slobodian, Victor Vovk
Vinnytsia National Technical University, Faculty of Information Communication, Radio Electronics and Nanosystems, Vinnytsia, Ukraine

Abstract. A memory cell structure is proposed that uses a Schottky barrier thin film transistor based on an amorphous semiconductor as a junction element, and a chalcogenide glassy semiconductor film as a switching element. A physical storage cell model has been developed. The dependence of the transistor and memory cell parameters on the dose of neutron flux and γ-quanta was investigated. It is shown that when the dose of neutron irradiation is changed, the steepness of the drain-gate characteristic (DGC) decreases by 50% at a dose of the order of 10^7 n/s, and at the same time, the transfer coefficient of the bipolar n-p-n transistor decreases by 20% at doses of 10^8 n/s, indicating a significant increase in the radiation resistance of the proposed memory cell. In the case of irradiation with γ-quanta in the range up to 2.6 M Rad, the steepness of the DGC of the proposed structure changes by only 10%. When used as an isolation element, a field-effect transistor with an insulated gate, the slope of the DGC is reduced by 50%. It is shown that the current of recording information of the proposed structure when changing the dose of γ-quanta to 2.6 M Rad changes by about 10%, and at the same time, in the case of using a field-effect transistor with an isolated cover, the information recording current changes by 50%. The study of the dependence of the gate current on the dose of the γ-quanta is shown. When the radiation dose changes from 0 to 2.6 M Rad, the gate current changes only by 10%, which indicates the high resistance of the proposed structure to the action of penetrating radiation. Also, studies of the dependence of the conductivity of single-crystal semiconductor on a radiation dose γ by neutron and flux show that a significant increase in the specific resistivity of amorphous semiconductors occurs at doses 2–3 orders of magnitude larger than in the case of single-crystal n-type conductivity semiconductors.

Keywords: amorphous semiconductor, chalcogenide glassy semiconductors, radiation resistance, memory cell

ZWIĘKSZENIE ODPORNOŚCI NA PROMIENIOWANIE URZĄDZEŃ PAMIĘCIOWYCH W OPARCIU O PÓŁPRZEWODNIKI AMORFICZNE

Streszczenie. Zaproponowano strukturę komórki magazynującej, która wykorzystuje barierowy cienki tranzytor Schottky’ego oparty na półprzewodniku amorficznym jako element łączący, a także chalcogenową szklistą błonę półprzewodnikową jako element przełączający. Opracowano fizyczny model komórki pamięci. Zbadano zależność parametrów tranzytora i komórki pamięci od dawki strumienia neutronów i promieni gamma. Pokazano, że przy zmianie dawki napromieniowania neutronowego stromość charakterystyki odpowiada drenu zmniejsza się o 10% przy dawkach rzędu 10^7 n/s, a jednocześnie współczynnik przenoszenia bipolarnego tranzytora npn spada o 20% już przy dawkach 10^8 n/s, wskazując znacznym wzrost odporności na promieniowanie proponowanej komórki pamięci. Po napromieniowaniu kwantami gamma w zakresie do 2.6 M Rad stromość charakterystyki dren-przepustnica proponowanej konstrukcji zmienia się tylko o 10%. W przypadku połączenia jako cienkowarstwowego tranzytora polowego z izolowaną kurtyną charakterystyka stromego spadku zmniejsza się o 50%. Wykazano, że prąd zapisu informacji o proponowanej strukturze przy zmianie dawki strumienia kwantowego gamma na 2.6 M Rad zmienia się o około 10%, przy jednoczesnym zastosowaniu cienkowarstwowego tranzytora polowego z izolowaną osłoną, prąd zapisu informacji zmienia się o 50%. Badanie zależności prądu kurtynowego od dawki promieniowania gamma – kwanty. Gdy dawka promieniowania zmienia się od 0 do 2.6 M Rad, prąd kurtyny zmienia się tylko o 10%, co wskazuje na wysoką odporność proponowanej struktury na działanie promieniowania przepuszczalnego. Badania zależności przewodności półprzewodników monokrystalicznych od dawki promieniowania γ przez kwanty i strumieni neutronów pokazują, że znacznym wzrost rezystywności właściwej półprzewodników amorficznych występuje przy dawkach 2–3 rzędów wielkości większych niż w przypadku półprzewodników przewodnictwa monokrystalicznego typu n.

Słowa kluczowe: półprzewodnik amorficzny, półprzewodniki szklisty chalcogenowe, odporność na promieniowanie, komórka pamięci

Introduction

An important prerequisite for the design of radio electronic systems for military and space purposes is the provision of high resistance to penetrating radiation, ionizing radiation and other external influences [1, 8].

It is known that under the influence of penetrating radiation on semiconductor electronic components made on the basis of single-crystal semiconductors, a large number of defects are produced which increase the electrical conductivity, which leads to their destruction [2, 10].

In the case of amorphous semiconductors (AS), there is a large degree of disordering of the atoms, the action of penetrating radiation does not significantly affect their electrical conductivity, and therefore provides high radiation resistance, which exceeds by 2–3 orders of magnitude the radiation resistance of components on the basis of single crystal semiconductor [9, 11].

In [3], a nonvolatile chalcogenide glassy semiconductor (CGS) storage device is proposed, which is a connection of a switch element on the basis of CGS and a decoupling element implemented on the basis of a unipolar transistor with an isolated gate. There are suggested as ways to increase the radiation resistance of the element.

However, the proposed methods for increasing the radiation resistance of a unipolar transistor junction provide the same results as for dielectric insulated bipolar transistors [6]. Therefore, it is advisable to develop structures that would significantly improve radiation resistance.

In this regard, the purpose of this work is to develop a memory cell structure in which the switching element and the junction element are made on the basis of AS, which makes it possible to increase the radiation resistance, and to investigate its effect on the steepness of the drain-gate characteristic (DGC) thin-film FET, recording current and reading information.

1. Development of structure and physical model of a memory cell based on AS

The structure of an elementary storage device (memory cell) which uses a thin film transistor with a Schottky gate based on AS as a switching element – CGS, and as a decoupling element – is shown in Fig. 1.
The memory cell is a transparent substrate of glass, on the surface of which is deposited a layer of AS 2, part of which is etched to produce local oxidation, resulting in the formation of a film of silicon dioxide 8. An electrode of source 3, gate 4 and drain 5 is then formed on the surface of the AS film. The drain electrode is partially placed on the surface of the silicon dioxide 8. After the formation of the electrodes, there is a local extension of CGS film 6 on the surface of part of the drain electrode (information recording electrode). In the next step, a CGS 7 electrode (information readout electrode) is formed. Molybdenum (information recording electrode). In the next step, a CGS 7 electrode (information readout electrode) is formed. Molybdenum (information recording electrode). In the next step, a CGS 7 electrode (information readout electrode) is formed. Molybdenum (information recording electrode). 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where \( N_r \) – the density of the surface states when the transistor is in saturation mode, and \( D_{\text{m}} \) – the rate of charge accumulation on the surface of the AS.

Unlike thin-film field-effect transistors with insulated shields, the processes of changing the surface states at the interface of the sub-gate layer – semiconductor, which is one of the main ones which significantly affect the parameters of the transistor under irradiation, are not taken into account here.

In [7], it is shown that the mobility of the charge carriers of CGS is much lower than the mobility of charge carriers in single-crystal semiconductors, and therefore the rate of charge accumulation on the surface of the AS will be much lower, and accordingly, the action of irradiation will be manifested here at higher doses. The dependence of the charge carrier mobility on the irradiated dose can be calculated by an expression similar to (4):

\[
\mu = \frac{\mu_0}{1 + \gamma \cdot N_r \cdot (1 - \exp \frac{D}{D_{\text{m}}})} \quad (7)
\]

where \( \mu_0 \) – the mobility of the charge carriers in the absence of irradiation; and \( \gamma \) – the proportionality factor.

In estimating the dependence of the DGC steepness on the action of irradiation by \( \gamma \)-quanta, it was taken into account that, unlike conventional MOS transistors, where significant changes occur due to charge accumulation in the volume of the sub-gate dielectric layer, in the case of a thin-film FET, there is a change of surface states at the boundary of the AS distribution - metal. Since there is a significant disordering of atoms in AS, this change is insignificant. At high doses, the surface states that are formed lead to the scattering of charge carriers in the channel and to a decrease in their mobility.

Due to this, the threshold voltage will be changed and the steepness of the DGC will decrease, as well as the information-recording current.

Fig. 4 shows the dose dependence of the steepness of the DGC, the recording current of the logical “1” and the gate current from the \( \gamma \)-quanta irradiating dose. For comparison, these graphs show similar dependencies of the same parameters for a conventional MOS transistor, taken from [5]. An analysis of the results shows that as the dose is increased, the steepness of the DGC of a thin-film FET based on AS changes to insignificant limits (up to 10%), while, in the case of traditional MOS transistors, it decreases by almost twice as much. Similarly, the drain current (logic entry “1”) increases for the AS-based transistor by about 10%, and for the traditional MOS transistor almost twice as much. Such a course of characteristics is caused by the fact that under the action of \( \gamma \) irradiation, in the case of traditional MOS transistors, the density of the surface states increases at the interface of the dielectric - semiconductor, and there is a charge accumulation in the volume of the sub-gate layer dielectric.

In the case of an AS-based transistor, there is a slight charge accumulation only at the metal-AS interface, and the mobility of the charge carriers is much lower so a significant increase in current and a decrease in the steepness of the DGC do not occur at relatively small doses.

The gate current changes little with an increasing dose. The slight increase is due to the fact that there is an increase in the density of the localized state, which is partially offset by a decrease in the mobility of the charge carriers and the diffusion coefficient, the dependence of which on the irradiation dose is determined by an expression similar to (5).

The following initial data were used in the calculations:

- \( l = 4 \mu m, \quad Z = 2 \mu m, \quad C_1 = 1 \text{ pF}, \quad E = 3, \quad N_r = 10^{15} \text{ cm}^{-3}, \)
- \( N_C = 10^{8} \text{ cm}^{-2}, \quad g_0 = 10^{10} \text{ eV}^{1/2} \text{ cm}^{-3}, \quad \mu_0 = 4 \cdot 10^{3} \text{ cm}^{2} \text{ V}^{-1} \text{ s}, \) and
- \( \gamma = 10^{6} \text{ cm}^{-2} \text{ s} \text{ eV}^{-1} \)

Only the dependence of the density of the surface states and the mobility of the charge carriers on the radiation dose was taken into account.

Studies of the dependence of the conductivity of single-crystal semiconductors on the dose of \( \gamma \)-quanta and neutron flux, performed by several authors, show that the change in conductivity occurs at doses of the order of \( 10^{4} \text{ Mrad/s} \) and \( 10^{6} \text{n/s} \). In the case of AS, the dependence of electrical conductivity on the radiation dose can be determined by the expression in [4]:

\[
\sigma(E, D) = \sigma(D) \exp \left( \frac{\sigma \cdot a \cdot E}{kT} \right) \quad (8)
\]

where \( \sigma(D) \) – the dependence of the electrical conductivity on the radiation dose in the absence of electric field strength, and \( a \) – the distance between the localized states.

The dependence of the electrical conductivity on the radiation dose taking into account (6) and (7) can be calculated by the expression:

\[
\sigma(D) = e \cdot N_r \cdot \sigma(D) \cdot (1 - \exp \left( \frac{D}{D_{\text{m}}} \right)) \cdot \frac{\mu_0}{1 + \gamma \cdot N_r \cdot (1 - \exp \left( \frac{D}{D_{\text{m}}} \right))} = e \cdot N_r \cdot \frac{\mu_0}{1 + \gamma \cdot N_r \cdot (1 - \exp \left( \frac{D}{D_{\text{m}}} \right))} \quad (9)
\]

Using (9) and the expression for the specific resistance given in [4], we can investigate the dependence of the specific resistance of a memory cell based on CGS on the radiation dose and the electric field intensity:

\[
\rho(D, E) = \frac{g \cdot \Delta T}{\sigma^2(D) \cdot \exp \left( \frac{2\sigma \cdot a \cdot E}{kT} \right) \cdot E^2} \quad (10)
\]

where \( g \) – the sample density, \( C_1 \) – the specific heat capacity of CGS, and \( \Delta T \) – the temperature change.

The dependence of the specific resistivity of AS and the typical single-crystal n-type conductivity semiconductor (MS) on the radiation dose is shown in Fig. 5.
The analysis of the obtained results shows that a significant increase in the specific resistivity of AS occurs at doses 2–3 orders of magnitude larger than in the case of a single-crystal n-type semiconductor.

When irradiated with the same radiation dose, single-crystal semiconductors with higher specific conductivity will significantly increase their own conductivity. For amorphous semiconductors, such a dependence is not observed, that is, different types of chalcogenide glassy semiconductor with different specific conductivities will respond to the same radiation doses approximately the same without significant changes in conductivity. This again proves the feasibility of using CGS as a memory and decoupling element in a thin-film FET.

3. Conclusions

1) A memory cell structure is proposed in which a thin-film field-effect transistor based on an amorphous semiconductor is used as a junction element and a switch element based on chalcogenide glassy semiconductor is used as a memory element. Such a structure makes it possible to increase the radiation resistance of storage devices based on such memory cells.

2) A physical model of the memory cell is proposed that takes into account the physical parameters of a thin-film field-effect transistor based on an amorphous semiconductor, the parameters of the switch element, the resistance and the capacitance of the Schottky lines and junctions.

3) The dependence of steepness of the drain-gate characteristics, the recording current of the logical “1” and the gate current on the radiation dose by neutron flux were investigated. Comparisons with similar dependencies for devices based on single-crystal semiconductors show that the use of amorphous semiconductor for the construction of the storage device provides increased radiation resistance.

4) The study of the dependence of the conductivity of single-crystal semiconductors on the dose of irradiation with neutron flux shows that for amorphous semiconductors, a significant change in conductivity occurs at radiation doses 2–3 orders of magnitude higher than is needed for a single-crystal n-type conductivity semiconductor. So the influence of penetrating radiation on the parameters of the switch element based on chalcogenide glassy semiconductor is not major.

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