

Ge films on GaAs: low-temperature electrical properties and application to cryogenic resistance temperature sensors

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This report presents our results of both investigation of electrical conduction mechanisms in Ge films on GaAs at low temperatures and designing thin-film Ge resistance thermometers. The electrical properties of Ge films on GaAs are determined by potential fluctuations caused by random inhomogeneous distribution of impurities. At low temperatures the conduction through the localized states in the vicinity of the Fermi level prevails. In this report we discuss the electrical conduction mechanisms of such films. Three types (TTR-1, TTR-2 and TTR-3) of thin-film Ge thermometers were fabricated. These temperature sensors may be used in the temperature ranges 1.5 to 350, 77 to 400 and 200 to 450 K, respectively.

1. INTRODUCTION

Investigation of Ge/GaAs heterosystem is of interest for, at least, two main reasons. It is an ideal thermocouple whose components have close lattice constants and thermal expansion coefficients. When depositing Ge onto the GaAs substrate in vacuum under certain conditions, an intense diffusion of Ga and As atoms from the substrate occurs into the growing Ge film. This diffusion essentially depends on the epitaxy conditions. One can control diffusion processes in Ge/GaAs heterostructure and produce both p- and n-films of Ge of different doping levels and compensation degrees. Besides, one can modify the film structure from poly- to single - crystalline. All the above factors enable one to realize a wide range of electrical parameters for Ge films and to use these films as a versatile sensitive material for various physical sensors [1, 2].

This paper deals with investigation of the conduction mechanisms in Ge films which are suitable for designing the wide-range (1.5 to 350 K) resistance thermometers.

2. RESULTS AND DISCUSSION

Shown in Fig.1 are the resistance versus temperature curves for two types of films produced under different conditions and dedicated to fabrication of temperature microsensors.

It is well known that at low temperatures conduction in doped and compensated, as well as disordered, semiconductors is determined by various hopping mechanisms. The general form of the

temperature dependence of semiconductor resistivity is such:

$$\rho = \rho_0 T^m \exp(T_x/T)^x \quad (1)$$

for $x = 1$ this expression corresponds to the activation conductivity, the activation energy being $\varepsilon = T_x \cdot k$.

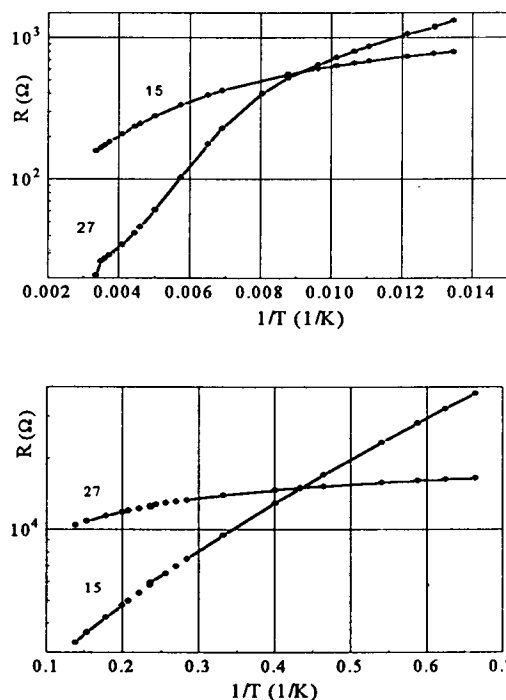


Fig.1 Dependencies of resistance on the temperature for two types of films in the temperature range 70 to 300 and 1.5 to 10 K, respectively.

The variable activation energy corresponds to the variable hopping range. By this x may take different values depending on the density of state, $g(\varepsilon)$, near the Fermi level: $x = 0.25$ (Mott model [3]) or $x = 0.5$ (Shklovskii model [4]).

Shown in Fig. 2 is the temperature dependence of the reduced activation energy

$$W = (1/T)(d \ln \rho / d \ln T) \quad (2)$$

for Ge films of two types. One can see that at low temperatures the conductivity versus temperature curve cannot be represented as an exponential with constant activation energy. This indicates at the variable range hopping.

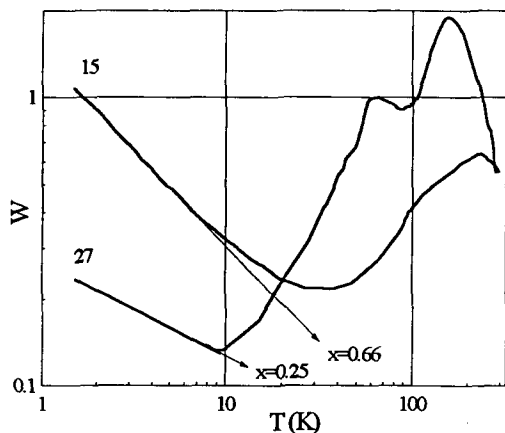


Fig. 2 Dependence of the reduced activation energy on the temperature

At $T < 10$ K x takes essentially different values (~ 0.25 and ~ 0.66) for the samples of different types. This indicates that density of state, $g(\varepsilon)$, is different for these samples. The fact may stem from the distinctions in both doping levels and compensation degrees, as well as in spatial correlation between the impurity atoms. All the above factors are due to the film formation conditions. Thus one can get films with different temperature dependencies of conductivity by varying these conditions, and hence design temperature sensors operating in different temperature ranges. The film studied had rather low compensation degrees. By increasing this degree one can raise thermosensitivity at high temperatures. (By this the operating temperature range becomes narrower due to a drastic increase of resistivity at low temperatures.)

For heavily doped and highly compensated films the resistivity depends exponentially on the temperature. One can vary the corresponding activation energy from 0.07 to 0.4 eV, depending on the film deposition conditions.

3. THERMOMETRIC CHARACTERISTICS OF THE THERMOMETERS

We have fabricated the resistance thermometers on the base of the films studied using a microelectronic technology. The crystals measured $0.5 \times 0.5 \times 0.2$ and $1.0 \times 1.0 \times 0.2$ mm, the packages measured $3.0 \times 1.5 \times 1.2$ and $\varnothing 1.6 \times 3.5$ mm. The thermometer characteristics are given in Fig. 3.

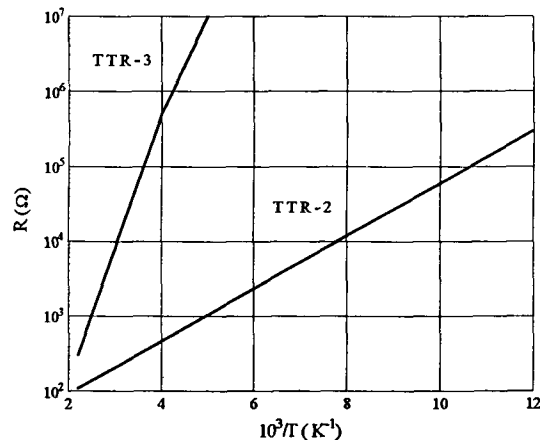
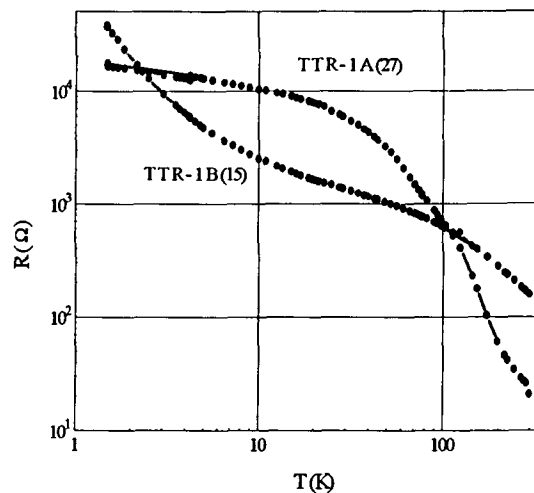


Fig. 3. Characteristics of resistance thermometers.

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