

ELECTROPHYSICAL PROPERTIES OF Ge IN THE FREQUENCY RANGE $10^{-1} - 10^5$ Hz

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Recently, considerable attention of researchers has been focused on the development of terahertz (THz) technologies, in particular the manufacturing of THz range modulators [1]. For the production of efficient THz photomodulators, it is crucial to study the photoelectric properties of materials. High photosensitivity is characteristic of semiconductors such as Ge, Se, and Si, etc. In the manufacturing of Ge-based semiconductor devices, Ge is doped with electrically active impurities, which can form both shallow and deep levels in the band gap. While deep levels do not have a decisive influence on Ge conductivity, they can be crucial in the processes of recombination and photoconductivity. Photoconductivity involves several key stages: carrier generation due to energy absorption, carrier movement in an applied electric field, and the system's return to an unexcited state. THz photomodulators require a high switching speed, which can be provided by a material with a short lifetime of non-equilibrium charge carriers. This requirement has been met, for example, by Ge hyperdoped with Au [2]. Au dopants create effective recombination centres in Ge. Gold dopants create effective recombination centres in Ge, forming energy levels near the center of the band gap [3]. This results in a low thermal ionization rate [4], enabling infrared photodetection at room temperature. It has been found [2] that 1) the composition of the Ge: Au lattice, the optical absorption in the band gap and the carrier dynamics strongly depend on the hyperdoping conditions; 2) the lifetime of charge carriers is 0.86, 1.00, 0.95 and 0.18 ns for the studied samples, which is higher than in similarly hyperdoped silicon systems [5]. The study of hyperdoped Si: Au shows an extremely short carrier lifetime of the order of 10 ps [5]. Thus, further research into alternative Ge modification methods is necessary to enhance the efficiency of THz photomodulators.

We studied the changes in electrical conductivity of both original and modified Ge samples (Table 1) at room temperature upon laser irradiation with a wavelength of 660 nm and a power of 32 mW using impedance spectroscopy in the frequency range of $10^{-1} - 10^5$ Hz on an Autolab spectrometer (Metrohm Autolab B.V., the Netherlands). The amplitude of voltage applied to the sample was 5 mV. To modify the surface properties of Ge—critical for THz photomodulators—we proposed a surface modification technique based on **chemical etching in a KOH+H₂O₂ solution**. Metal contacts were deposited on the chemical etched Ge surface and on the ends of the original Ge samples. The relaxation time of charge carriers was determined from impedance spectroscopy data [6].

Table 1. – Parameters of Ge

Material	Thickness d , cm	Length h (distance between contacts of the original Ge sample), cm	Width l , cm
Ge	0.57	1.70	2.00

At the first stage, measurements were carried out to determine the dark resistance. The conductive properties of the original Ge samples are presented in Fig. 1. The value of impedance real part ($\text{Re } Z(f)$) indicates that the sample resistance is nearly frequency-independent and reaches 691 Ohm. The bulk resistivity $\rho_v(f)$ is 46 Ohm·cm. Such frequency independence most likely indicates the presence of delocalized charge carriers. Impedance studies of the material upon laser irradiation showed that the original Ge single crystal is not photosensitive at room temperature.

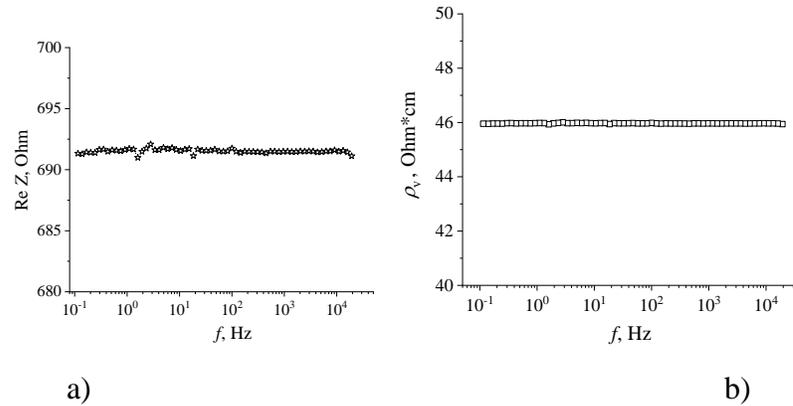


Figure 1. – Frequency dependence of impedance real part $\text{Re } Z$ (a) of Ge samples and its specific resistivity ρ_v (b) before modification

After chemical treatment of the material surface, the $\text{Re } Z(f)$ value at high frequencies became frequency-dependent, indicating that **charge carrier hopping contributes to the increase in conductivity**. Further studies of the material’s photosensitivity were carried out on chemically etched Ge. A significant photoresistive effect was observed, confirming the potential for **THz photomodulation**.

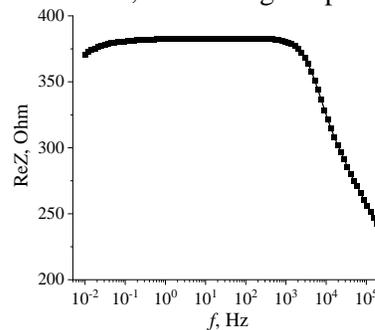


Figure 2. – Frequency dependence of impedance real part $\text{Re } Z$ (a) of a chemically etched Ge sample

Using the method described in [6], the average relaxation time τ was determined from the frequency dependence of impedance imaginary part ($\text{Im } Z(f)$) by the formula $\tau=1/(2\pi f_{\max})$, where f_{\max} is the frequency corresponding to the maximum of $\text{Im } Z(f)$.

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