Analysis of the Induced Photothermal Conduction in the Mn$_4$Si$_7$–Si(Mn)–Mn$_4$Si$_7$ and Mn$_4$Si$_7$–Si(Mn)–M Heterojunctions

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Abstract—The kinetics of photocurrent is studied in the presence of the intrinsic irradiation at $h\nu \geq 1.12$ eV in the Mn$_4$Si$_7$–Si(Mn)–Mn$_4$Si$_7$ and Mn$_4$Si$_7$–Si(Mn)–M heterojunctions at relatively high applied voltages. It is demonstrated that photocurrent, scattered power, and temperature at the reverse-biased contact of the heterojunction depend on time at dc applied voltage, low temperature, and irradiation at $h\nu \geq 1.12$ eV. The analysis of the temperature dependences of the photocurrent growth with time is used to demonstrate that the photocurrent pulses consist of two fragments: the first one corresponds to a slowly increasing relatively low current with a slope of $(2–4) \times 10^{-4}$ A/s and the second fragment is characterized by a sharp increase in the current with a slope of 0.1–1.0 A/s. Based on the slopes, the heating rates ($\beta_1 = 42$ deg/s and $\beta_2 = 3 \times 10^3$ deg/s) and temperature gradients across the transient layer that corresponds to the Mn$_4$Si$_7$–Si(Mn) interface ($\Delta T/\Delta x = 6.3 \times 10^6$ K/cm for $\beta_1 = 42$ deg/s and $\Delta T/\Delta x = 1.5 \times 10^8$ K/cm for $\beta_2 = 3 \times 10^3$ deg/s) are estimated. It is demonstrated that the Joule self-heating allows relatively high heating rates in the reverse-biased contact of heterojunction, which provides rapid heating similar to the rectangular step excitation that is equivalent to the activation of the long-wavelength (extrinsic) irradiation.

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INTRODUCTION

In [1–3], we studied the photo-$I$–$V$ characteristics of the Mn$_4$Si$_7$–Si(Mn)–Mn$_4$Si$_7$ and Mn$_4$Si$_7$–Si(Mn)–M heterojunctions, interpreted the photocurrent in the presence of irradiation at $h\nu \geq E_g$ and analyzed the role of the Mn$_4$Si$_7$ contact in relatively high photosensitivity in the presence of the irradiation of the diode base at $h\nu \geq 1.12$ eV and low temperatures ($77–220$ K). Based on the photo-$I$–$V$ characteristics, we constructed the energy bands in the presence of the photocurrent flow. The saturation of the photocurrent and the negative differential photoconductivity in such heterojunctions were demonstrated in [3].

This work is a continuation of the previous works aimed at the interpretation of the induced photothermal conduction in the Mn$_4$Si$_7$–Si(Mn)–Mn$_4$Si$_7$ and Mn$_4$Si$_7$–Si(Mn)–M heterojunctions.

EXPERIMENTAL RESULTS

The heterojunctions under study and the experimental methods are similar to those from [3]. In this work, we study the temperature dependence of the thermal excitation of the attached electrons at the donor levels of manganese due to the preliminary intrinsic irradiation of the base region of the hetero-junction at $h\nu \geq 1.12$ eV. In accordance with the results from [4], the thermal excitation of the attached electrons on the Mn levels in the base region of the heterojunction must lead to the induced thermal conduction (by analogy with the induced photoconduction [3]).

In this work, the rapid (instantaneous) heating to a certain level is reached due to the Joule self-heating in the presence of the high-voltage dc bias across the diode and the Π-shaped pulsed irradiation (regime A in Fig. 1) or continuous wave (CW) irradiation and Π-shaped high-voltage pulse (regime B in Fig. 2). In both regimes, pulse duration $t_p$ is significantly less than pulse time $t_\Pi$. The repetition rates of the radiation and voltage pulses are chosen in such a way that the amplitudes and shapes of the photocurrent pulses are independent of the repetition rate. Figures 1 and 2 demonstrate the photoconductivity (PC) kinetics versus temperature for pulsed regimes A and B. The amplitudes and shapes of the current pulses on the oscillograms depend on the temperature of the heterojunction. The analysis of the PC kinetics (current pulses) on the oscillograms for regime A shows that duration of the leading edge $t_1$ over which the current reaches the maximum (peak) level increases from 0.5 to 0.8 s when the temperature of the heterojunction increases from 80 to 130 K. Duration $t_1$ and shape of the trailing edge
remain unchanged (oscillograms 1–5, regime $A$ in Fig. 1). In temperature interval $T = 143–175$ K (oscillograms 6–10, regime $A$ in Fig. 1), we observe the photocurrent jump, a linear increase in the current, a decrease over an interval of no greater than 1 s, and an almost stationary current up to the moment when irradiation is terminated. In the absence of irradiation, we observe a decrease in PC with a relaxation time of $\tau = 0.2–0.5$ s, which can be due to the thermal equilibration of the diode. In temperature interval $T = 175–203$ K, we