Development of the Diagnostic Complex for the Analysis of Thermal Degradation of Semiconductor Structures

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Abstract. The present work was aimed at development of a diagnostic complex for studying the thermal degradation of metallization systems of semiconductor structures. The method consists of decoding the oscillogram $U(t)$ of the test structures during the passage through them of current pulses of different shape. The proposed method allows to detect the initial stages of melting in the metal-semiconductor systems.

Keywords: a semiconductor structure, metallization systems and contacts, the thermal degradation, diagnostic complex

INTRODUCTION

It is known that the reliability of semiconductor devices is determined by the reliability of the interconnects and contacts of metal-semiconductor. Reducing of the size of the p-n junctions contributes to local thermal overheating and accelerates degradation of the devices [1-5]. Therefore, the aim of this work is the development and creation of the diagnostic complex for the analysis of thermal degradation of semiconductor structures.

METHODOLOGY

The study of systems of metallization and contacts was carried out on the designed test structures (Fig. 1) by using the oscillograms $U(t)$ in the process of passing a single current pulse of different shapes.

The experimental setup (Fig. 2) was allowed to pass the current pulses of various shapes through the investigated samples. The duration of current pulses was set by a generator, and the amplitude was determined by the pulse shaper. It provided the following parameters: the current was up to 150 A, the load resistance was no more than 0.5 Ω; maximum pulse duration was not less than 1.5 ms.

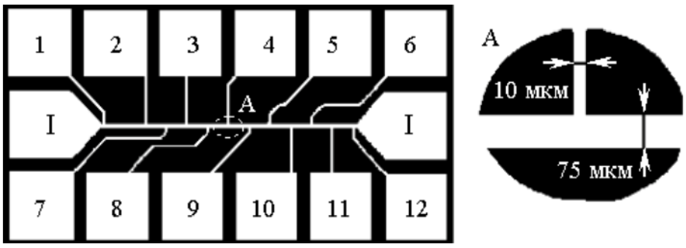

Figure 1. View of test structure with 12 potential and 2 current "I" contacts.
Inset A: fragment of the test structure, 21 times increase

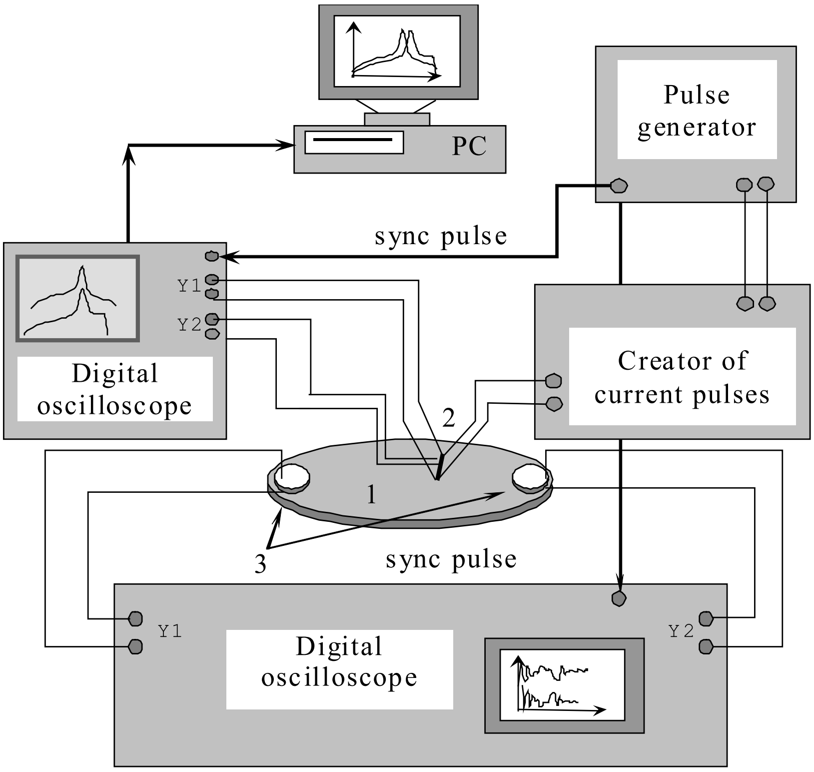

Figure 2. Structure of the experimental setup for research of thermal modes of operation, defect formation and thermally induced flexural vibrations in semiconductor structures under pulse current influences:
1 – single crystal silicon plate; 2 – test structure; 3 – piezoelectric sensors

The current that passed through the investigated test structure was determined by a calibration curve, which was received from the reference resistors. For registration of mechanical vibrations arising due to the surface thermal shock, piezoelectric transducers were used. They were located on the plate. The signal from them was also registered by oscilloscope. The electrical signal from the test structure was received from probes. Observation of the conductive paths was done by using the probe which was connected with the microscope digital eyepiece.

ANALYSIS OF EXPERIMENTAL RESULTS

Experimental study of heat regimes by using the diagnostic complex was carried out on test structures with aluminum film [6, 7].

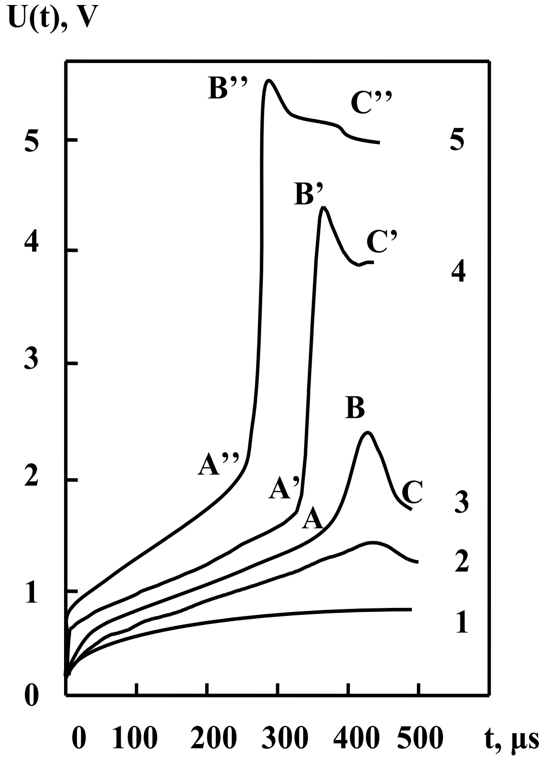

Figure 3. Voltage waveforms $U(t)$ (probes 1–12) during the passage of a current pulse through the aluminum metallization track lying on silicon. The pulse duration τ_i = 500 μs, the amplitude j (A/m^2): **1** – $4.5{\cdot}10^{10}$; **2** – $4.5{\cdot}10^{10}$ (contact melting, without melting Al); **3** – $5.2{\cdot}10^{10}$ (contact melting, partial melting Al); **4** – $4.5{\cdot}10^{10}$ and **5** – $4.5{\cdot}10^{10}$ (complete melting Al)

A monotonic increase of $U(t)$ at short times t after the pulse inclusion is associated with the heating of a thin film of metal and is determined by the heat removal mode in the semiconductor plate (Fig. 3). By using this setup the beginning of the phase formation on structures was recorded. It is associated with a fast increase of potential as a result of Al melting (when the temperature is 661 °C, AB, A'B', A''B'' in Fig. 3). Further decrease of $U(t)$ is associated with contact melting at the boundary of aluminum-silicon (melting point of eutectic Al-Si is 577 °C) and the extension of the conductive layer (Fig. 3, plots of BC, B'C', B''C'').

The increase in current density up to values of $j \sim 8{\cdot}10^{10}$ A/m^2 accelerates full melting of test structures. At the same time the processes of melting ($j > 5{\cdot}10^{10}$ A/m^2 and pulse durations $\tau_i \leq 300$ μs) dominate over the contact melting in the metallization systems. The presence of layers SiO_2 or Si_3N_4 of thickness ~ 0.1 μm on some of the plates prevents the development processes of contact melting.

The formation of melted areas had a random nature. After turning off the pulse, the melted areas crystallized. The fragment of structure after the passage of the current pulse is shown in Fig. 4. There are visible crystallized areas with a well-defined crystallization front. His form reflects temperature heterogeneity on the aluminum track width.

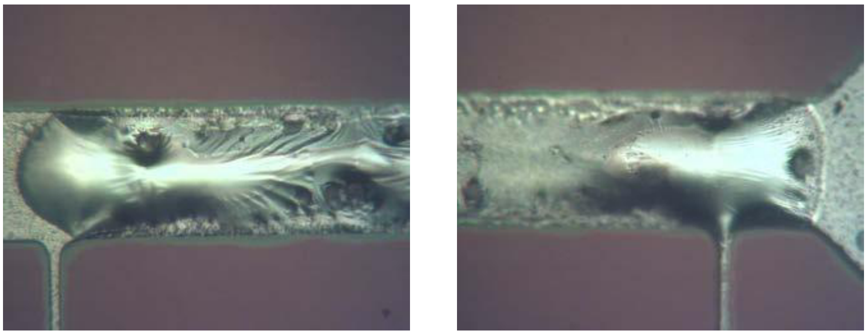

Figure 4. Photographs of a fused fragment of the test structure after passing of a rectangular current pulse with amplitude $j = 6 \times 1010$ A/m^2 and duration τ_i = 300 μs

CONCLUSION

Thus, the work describes the methodology of studying the processes of thermal degradation of the metallization systems and contacts. The basic mechanisms for moving interphase boundaries are associated with the heat generation at the interface of solid and liquid phases under conditions of thermal shock generated by a rectangular current pulse. The proposed method allows to analyze the length of the molten zone after pulsed current effects and to predict the safe operating area of metallization systems on silicon.

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