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ANALYSIS OF THERMO KINETIC PROCESSES IN LASER BONDING, CONDUCTING GREAT ELECTRIC CURRENT DENSITY

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In the paper the thermal phenomena in laser material treatment have been presented. An impact of the main factors, which accompany creation of laser welded connection and can have an effect on the temperature distribution of the semiconductor device during the current flow, has been analysed. The results of some experiment investigations and results of computer modelling have also been presented.

1. INTRODUCTION

The aim of this study was to investigate the usefulness of the laser welding technology for the realization of wire connections: "semiconductor structure-outside leading out" in power devices. Thermal phenomena, in the area of connection of power devices in operating conditions, were subjected to special analysis. In the process of investigations the manner in which the technology of creating laser welded connections influences the distribution of the temperature in the device was determined. The main factors which accompany the creation of a laser welded connection and can have the effect on the temperature distribution in the device during a current flow was analysed. To prove the thesis of this work, diverse research methods were used, among others: structural examinations/investigations and microhardness measurements, thermographic examinations and the measurement of resistance of connections.

A physical model of the semiconductor device, including laser welded wire leads, was built and a relevant computer model, coupling electrical, thermal and mechanical durability phenomena, was elaborated.

To achieve the assumed aim and to prove the theses of this work, the following plan of examinations was carried out:

- the analysis of the assembly technology of connections in power devices,
- the material analysis of power transistors (IGBT),
- determining the effect of the laser beam parameters on the properties of laser welded connections and the optimization of laser welding processes,
- making laser connections for semiconductor test structures,
- experimental research on the properties of connections,
- the construction of a physical model of the connection and computer simulations of the heating process.

2. THE REASONS FOR FAILURE IN WIRE BONDING IN SEMICONDUCTOR POWER DEVICES

An important problem in power devices is the necessity to lead off an electric current of a value of several tens of amperes through a single assembly connection. At present, such connections are made by ultra-compression and thermosonic methods. Unfortunately, these connections are not sufficiently reliable. The problem is especially important in power modules, where the number of single connections increases by about 1000. Failure mechanisms are physical, chemical, but other processes can also result into a failure [1,2]. A "heel cracking" and a "lift off" are two main failures in wire leads of power modules. They are presented in Fig. 1.

a) b)

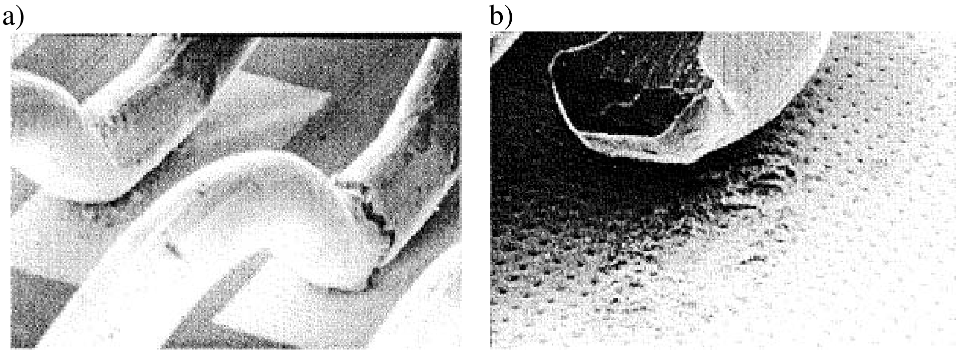


Fig. 1. Failure mechanism in wire bonding : a) "heel cracking", b) bond wire "lift off"

The unreliability of ultrasonic connections forces one to search for a new, more reliable method of connection. A laser method of producing a connection can be one of the possibilities.

3. LASER METHOD OF PRODUCING CONNECTIONS

Recently, laser technologies were increasingly used in technological processes. In this section/chapter of the paper a new laser wire-bonding method has been presented. In this method, a laser beam is used as a precise source of energy. Laser bonding does not require large modification in the construction of a power device [3]. The laser technology demands using suitable materials for wire connections. A laser beam of a wavelength of 1.06 μm cannot be well absorbed by all materials. Because of a specificity of laser radiation absorption, nickel was used as a material for wire leads. An intermediate plate (Molybdenum) between the semiconductor structure and the wire was additionally placed. The wire was welded directly to this plate. This is shown in Fig. 2.

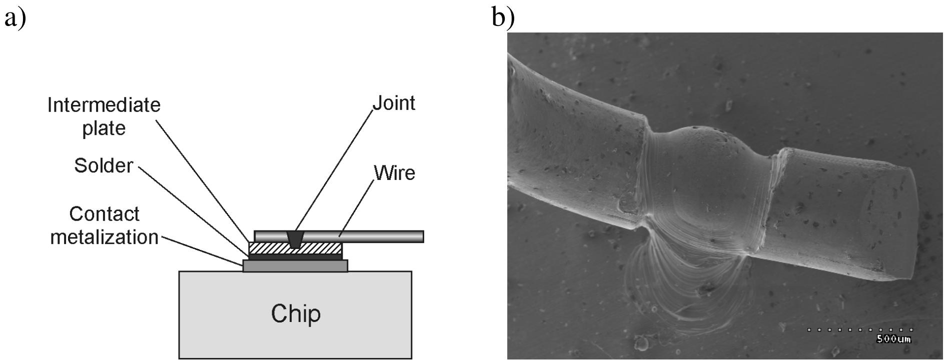


Fig. 2. Laser bonding: a) schematic diagram of laser connection, b) picture of laser welded connection

A laser weld has very good mechanical and electrical properties and good electrical stability. The temperature distribution in materials during a laser treatment is described by the equation:

$$k\frac{\partial^2 T}{\partial x^2} + q_v = \frac{\partial}{\partial t}(\rho \cdot C_p \cdot T) \tag{1}$$

where: k – the thermal conductivity, T – the temperature, q_v – the heat source, t – the time, ρ – the material density, C_p – the heat capacity.

This equation describes the temperature distribution before the material reaches a melting temperature. Above this temperature liquid material properties should be taken into consideration [4]:

$$\frac{\partial \rho}{\partial \tau} + \nabla \cdot (\rho \cdot v) = 0 \tag{2}$$

$$\rho \frac{Dv}{D\tau} = \rho \left[\frac{\partial v}{\partial \tau} + (v \cdot \nabla) \cdot v \right] \tag{3}$$

$$\frac{\partial (\rho \cdot u)}{\partial \tau} = -\nabla \cdot (\rho\ u\ v) - \nabla q - p(\nabla v) \tag{4}$$

where: v – the liquid velocity, τ – the time, ρ – the material density, q – the heat flux, p – the pressure.

4. EXPERIMENTAL RESEARCH ON THE PROPERTIES OF LASER CONNECTIONS

Experimental research into laser welded connections was carried out: resistivity measurements, structural examinations and thermographic examinations. The main purpose of this research was to evaluate which factor increases the temperature of the connection.

The electrical resistance of a connection depends on material resistivity and the cross section area of the conducting path. If the energy of the laser beam is bigger than 6J (for wire of a diameter of 0.5 mm), at the bottom of the molten pool an area of high resistivity is formed and the welded connection manifests a big technological narrowing (Fig. 3a). If the energy of the laser pulse is between 4J and 6J (Fig. 3b) a connection without an area of high resistivity and without a significant narrowing is formed [5,6].

a) b)

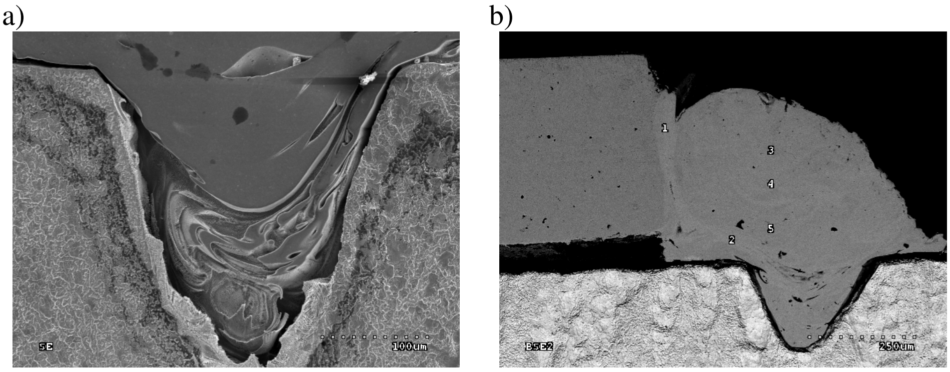
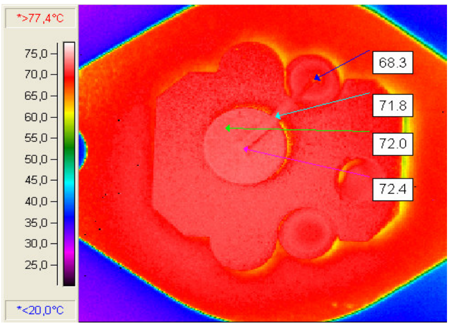


Fig. 3. Cross section of laser connection: a) deep connection with a high resistivity area, b) till bonding without a high resistivity area

A laser welded connection made using optimum laser parameters does not include an area of high resistivity and a technological narrowing. The thermographic analysis of the same laser connections has proved that the technological narrowing formed in the vicinity of the weld of less than 80% of the cross section cannot create an additional source of heat [7]. The result of this investigation is shown in Fig. 5.

a) b)



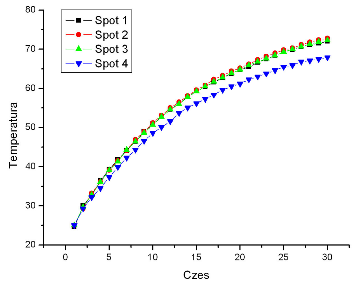


Fig. 4. Thermographic studies of heating of laser connection (I = 3A): a) thermographic diagram, b) temperature versus time for several points

5. MODELLING OF THERMAL PHENOMENA IN THE CONNECTION

In order to calculate the temperature distribution in the vicinity of a laser weld resulting from the conducting current, a computer simulation was carried out. The model describing and coupling mutually the electrical, thermal and mechanical phenomena was created. Software package FEMLAB 3.0 was used for these calculations using the finite elements method. The assumed geometry of the connection, presented in Fig. 5a, allowed one to take into consideration all regions typical of laser welded connections:

- the region of a technological narrowing,
- the area of high resistivity,
- the main area of a laser weld.

The calculated temperature distribution resulting from the 10A current flow in a laser connection without a narrowing is presented in Fig. 5b [8]. It is visible that the main source of the heat is the semiconductor structure. The temperature distribution for the same current but in a connection with an area of high resistivity is shown in Fig. 5c. In this case, the temperature increases insignificantly, by about 0.5K. Only in the connection with a narrowing bigger than 80% of the cross section (Fig. 5d) the temperature increases by about 5K.

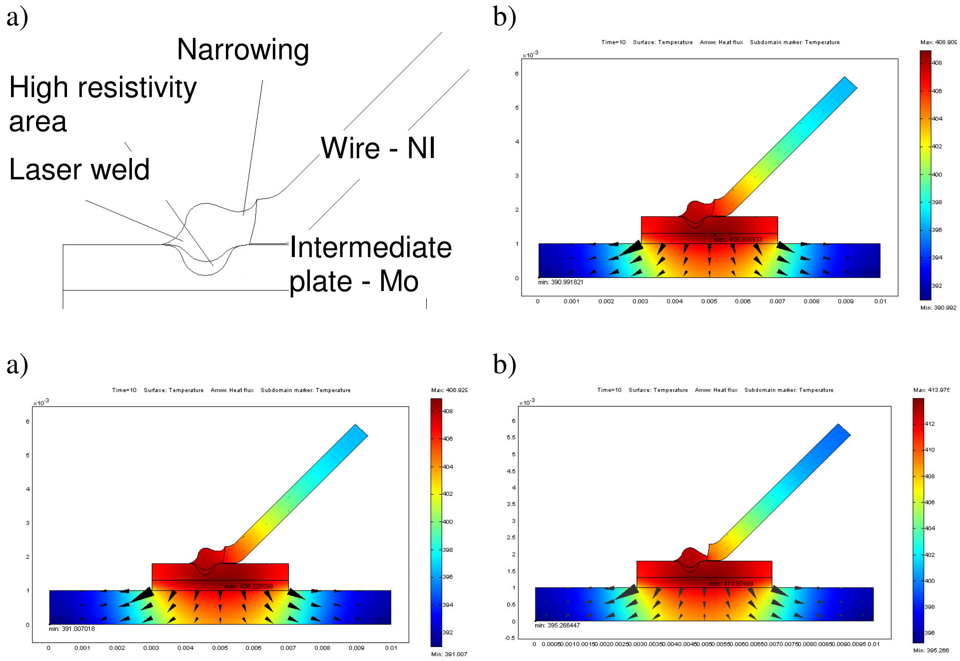


Fig. 5. Modelling of a laser welded connection: a) geometry of a laser connection, b) temperature distribution in a deep weld, c) temperature distribution in a shallow weld, d) temperature distribution in a deep weld with a narrowing

5. CONCLUSIONS

The good thermal properties of laser connections confirmed the usefulness of the application of a laser beam for producing leads in power devices. The proper laser weld without a big narrowing did not create an additional source of heat. The greater resistance of nickel wire, in comparison with traditional aluminium ones, can be compensated by increasing the wire diameter or the number of leads. Strong connections, possessing good mechanical properties and well electrical conductance were obtained as result of the application of the laser technology. The obtained results have confirmed that laser connections in power devices can increase their reliability.

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ANALIZA PROCESÓW TERMOKINETYCZNYCH W OBSZARZE POŁĄCZEŃ, PRZEWODZĄCYCH PRĄDY O DUŻYCH GĘSTOŚCIACH, WYKONANYCH TECHNIKĄ LASEROWĄ

Streszczenie

W pracy przedstawiono właściwości cieplne spawanych laserowo połączeń drutowych przewodzących duże prądy. Sprawdzono jakie czynniki, wynikające z zastosowanej technologii, mogą spowodować wzrost temperatury połączenia. W tym celu wykonano szereg badań: obrazy termowizyjne, pomiar rezystancji połączenia, badanie struktury połączenia oraz wykonano model komputerowy. Na tej podstawie dokonano oceny przydatności połączeń spawanych laserowo do wykonywania wyprowadzeń ze struktur półprzewodnikowych przyrządów mocy.

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