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Diffusion Welded Contacts and Related Art Applied to Semiconductor Materials

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Introduction

The solid-state welding as the blacksmith's or forging welding was known since the man learned the skill of thermal treatment of metals. However, the wide adoption and development of solid-state welding based on a new qualitative fundament has started after the World War II. The reason was the appearance of new materials demanding a new approach to their treatment. And only then the science-based approach to the solid-state bonding began to develop.

Metal-semiconductor solid-state bonding

The main types of solid-state welding may be classified as cold welding, pressing, ultrasonic welding and explosion welding. In all cases the main parameters determining the process are pressure, temperature and process duration.

The number of hypothesis of solid-state bonding most successfully can be explained by topochemical reaction, i.e. surface reaction.

The basis of any chemical substitution reaction is the destruction of the initial atomic linkage and formation of new atomic linkage, which results in new substance, i.e. every chemical reaction "has electron mechanism". The micro defects here play main role [1].

Topochemical reactions, as usual, have a few stages. Natural phenomena of each stage and the stages duration may be different depending on materials properties and technological process specifics [2].

The stages of metal-semiconductor interactions

The processes of solid state bonding for such dissimilar materials like metal and semiconductor can be subdivided into 3 stages:

- Intimate closing of materials (creation of physical contact);
- Contact area activation (generation of active centres);
- Development of bulk interaction.

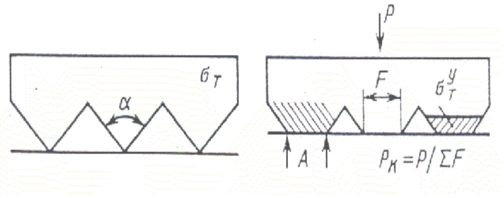
At the first stage the materials are closing together to a distance where van der Waals forces are acting, and slight chemical interaction is taking place due to the plastic deformation and dislocations outlet.

At the second stage active centres are formed on surface of the harder material, e.g. semiconductor or ceramics. The duration of this period is conditioned by specifics of plastic deformation, and by incubation period for creation of the centres.

The third stage begins from the moment, when the active centres are already formed. During this stage the interactions of bonding materials are developed both in interface and in bulk zones. This process is running, in particular, on the dislocations with surrounding stress fields. In the interface this process ends with conjunction of the interaction centres.

Since welding in vacuum is realized under pressure, so besides dissociation and oxide films dissolution, the process of collective activation is taking place and this process creates macro centres.

The real surfaces of the solids are rough. Therefore, the rapprochement of materials does not happen for all the contact area at one and the same time (Fig. 1).



(a) (b)

Fig. 1. The scheme of physical contact formation under the compressive load (P): a – before welding; b – during welding [2]

That means that for some contact areas the bonding process may be already finished and for the others it only begins. If we take the bonding stress (σ) as the criterion of welding, then the kinetic curve of the process of dissimilar materials solid-state welding can be represented as is shown in Fig. 2.

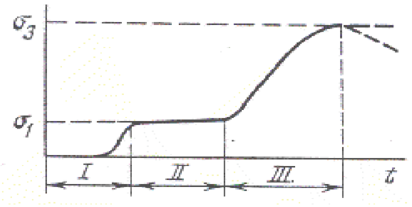


Fig. 2. The kinetic curve of the process of dissimilar crystalline materials bonding during diffusion welding [1]

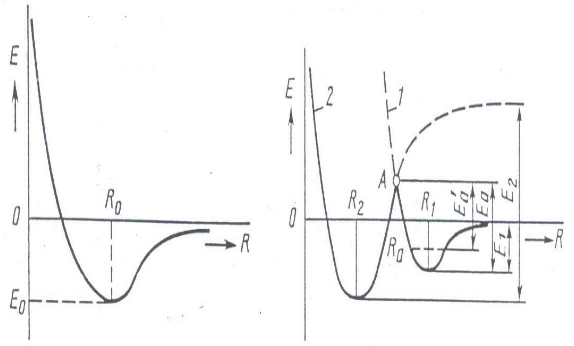
In Fig.2 σ_1 and σ_3 corresponds to the positions, when the first weak chemical bonds arise (σ_1), and when more durable bonds are created between the contact areas (σ_3).

In general such kinetic curve can be considered in the case, when each of mentioned stages is apparent. Sometimes the kinetic curve is compressed within the time axis and the second stage can be missed.

The surfaces of solid materials usually are inert because their surface atoms have saturated valences due to adsorption processes. Therefore, some energy should be spent for the activation process in every case.

Taylor [3], and then Lennard-Jones [4] have discovered the physical essence of the process of activation by use of potential variation.

The dependence of potential energy of interatomic interaction (E) in the space between the atoms (R) is shown in Fig. 3(a). The hypothetical model of gripping for two ideal crystals of the same nature is illustrated in Fig. 3(b). The lattices of the crystals are coherent and surfaces are free from any absorbed atoms (juvenile). It must also be taken into account that gripping happens at such low temperatures that diffusion mobility of atoms and thermal fluctuation is close to zero.



a) b)

Fig. 3. E (R) dependence for a) two atoms and b) two crystals [2]

In Fig. 3(b) the curve 1 shows the change of the potential energy of surface atoms under van der Waals forces. At the point R_1 potential energy reaches minimum, and the cohesion strength of two crystals is determined by energy E_1 with relatively small value, not more than 1kJ/mol. Such type of connection can be treated as physical contact between two surface atoms. Further approach of the crystals puts the repelling forces in action. The potential energy will change like the left side of the curve 1 in the direction to the point A and then like the curve 2. During the approach atoms must be activated to be ready for the interatomic interaction at the point A. It is supposed that the energy E_a is sufficient to overcome the repelling forces.

After chemical bonding between two surface atoms (distance R_2 are equal to crystal lattice parameter), the system reaches the minimum of potential energy E_2 and comes into balance. The boundary between two crystals disappears and the stable energy configurations of electron are formed between surface atoms. The effective activation energy of chemical bond E_2 for the considering model would be quite small.

The practical realization of diffusion welded contact for silicon semiconductor device

Investigations and developments carried out in the 90s of the last century by the group of researches of Tallinn University of Technology, Estonia, made it possible to design semiconductor devices with welded contacts and to provide their mass production based on the diffusion welding technique.

Diffusion welding is performed in a special cassette in the operating chamber under vacuum not worse that 0.07 MPa. The stack comprising an electrode support material 4 (Fig.4), a silicon structure 2 and two aluminium disks more that 5 microns thick (layers 1 and 3) is heated up to a temperature not exceeding 570°C and compressed under a pressure ranging from 10 to 50 MPa for about 300 seconds.

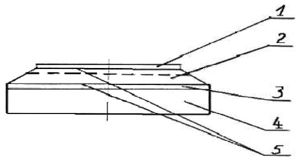


Fig. 4. Scheme of a clamp-type rectifying element of a power semiconductor device: 1 – metal layer 5-20 microns thick; 2 – semiconductor structure; 3 – layer of solder; 4 – heatsink; 5 – ohmic contacts

Such a scheme makes it possible to form simultaneously all contacts of the rectifying element of the modern semiconductor device instead of soldering, vacuum deposition of contact metals or other methods of metallization. Welding is performed in the solid state by use of commercial aluminium foil. That’s why, a highly uniform thickness independent of the structure diameter, is the characteristic of the process.

Vacuum diffusion welding of rectifying elements is performed in a specially designed, continuous-action, highly automated installation (Fig. 5). Such installation provides simultaneous welding of a number of rectifying elements in commercial production level.

In parallels to diffusion welded contacts to silicon rectifying elements the same method was successfully developed in application to GaAs structures [5, 6] and SiC large area Schottky diodes [7, 8].

The single rectifier elements based on GaAs epilayer structures as usual have the limited breakdown voltage (~600 V). One of the most effective ways to increase the breakdown voltage is the diffusion welding of single diode structures in series to provide high voltage combination (see the scheme in Fig.7).

Diffusion welding was also tested in the production of Schottky diodes. Defect density reduction techniques coupled with diffusion welded contacts have the potential for providing more effective use of large area Schottky diodes by increasing the forward current takeoff through reductions in overall resistance.

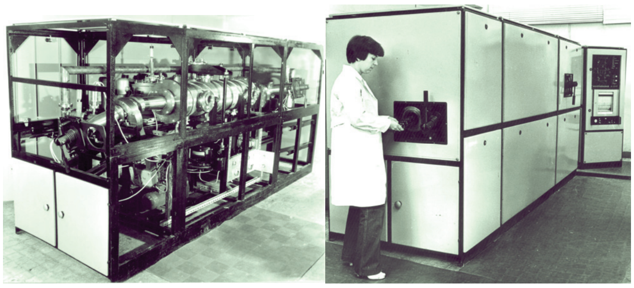


Fig. 5. Diffusion-welding machine adapted for manufacture of rectifying elements for semiconductor devices

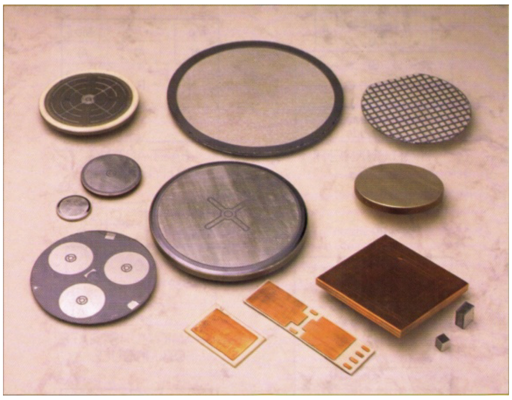


Fig. 6. The variety of diffusion welded multilayer contact compositions applied to semiconductor devices

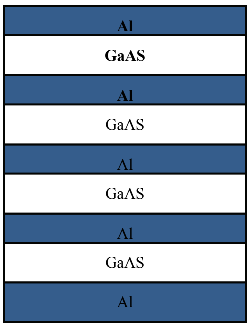


Fig. 7. Assembling scheme

Fig. 8. One of the modes of SiC diode clamp-packaging

Since for the metallization by diffusion welding is used relatively thick metal foil, it makes it possible to realize the clamp mode of packaging.. Use of clamp mode cases for heavy current Schottky diodes provides a commercially suitable package method. This method of packaging ensures effective current takeoff from large area contacts and the absence of solder connections provides the potential to raise the operating temperatures up to melting point of contact metals.

Conclusions

In this paper we have presented the basic principles and practical realization of diffusion welding technology for manufacturing contacts to semiconductors. Vacuum diffusion welding of rectifying elements is performed in a specially designed, continuous-action, highly automated installation. Such installation provides simultaneous welding of a number of rectifying elements in commercial production level. The method was successfully developed in application to GaAs structures and SiC large area Schottky diodes.

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Today the majority of the contacts for semiconductor devices are prepared by use of standard technologies, when the semiconductor wafer is subordinated to multiple deposition processes and thermal treatments. In this paper we present the basic physical principals and practical realization of diffusion welding technology for fabrication of high quality contacts to semiconductor materials. The paper gives brief details of our previous experience of diffusion welding in semiconductor manufacturing. Here are described the technology and equipment used in the production of power semiconductor devices based on silicon. In parallels to diffusion welded contacts to silicon rectifying elements the same method was successfully developed in application to GaAs structures and SiC large area Schottky diodes. Ill. 8, bibl. 8 (in English; abstracts in English and Lithuanian).

O. Korolkov, N. Sleptsuk, J. Toompuu, T. Rang. Difuzija sujungtų kontaktų taikymas puslaidininkiniuose dariniuose // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 5(111). – P. 67–70.

Puslaidininkinių darinių kontaktai paprastai formuojami taikant įprastines technologijas, tokias kaip užgarinimą ir terminį apdorojimą. Pristatomi difuzija sujungtų kontaktų formavimo pagrindiniai fiziniai principai ir praktinio pritaikymo pavyzdžiai. Tokie kontaktai yra puikios kokybės. Aprašoma pati kontaktų formavimo technologija gaminant galios puslaidininkinius darinius. Siūlomas metodas buvo sėkmingai taikomos GaAs struktūrose ir SiC Šotkio dioduose. Il. 8, bibl. 8 (anglų kalba; santraukos anglų ir lietuvių k.).