Interlayer architecture for diffusion welding of monocrystalline silicon with copper

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Abstract. In the production of silicon-based products, one of the main tasks is to create a reliable connection of monocrystalline silicon with metals. This article discusses the issue of obtaining a welded joint of monocrystalline silicon with copper using intermediate layers.

Currently, silicon is used in various industries, however, it is most widely used in instrumentation, electrical engineering and electronics, where it can be said that it serves as the basis for them. In the production of silicon-based products, one of the main tasks is to create a reliable connection of monocrystalline silicon with metals. For this purpose, the method of diffusion welding in vacuum is widely used, which is the most suitable for solving this problem. The flexibility of the diffusion welding process allows varying technological parameters of welding (pressure, time, temperature, vacuum degree) in a wide range, and in the case of a developed and properly activated contact surface, it guarantees a reliable connection while maintaining high electrophysical properties of the semiconductor–metal connection. This article discusses the issue of obtaining a welded joint of monocrystalline silicon with copper [1].

When combining silicon with copper, it is necessary to solve a number of problems related to their differences in physical and chemical properties and, above all, the coefficients of linear thermal expansion (CLTE): Si (2.3), Cu (16.6), which differ by a factor of 8. Stress will be created in the silicon–copper joint due to mismatch of the temperature coefficients of linear expansion, both during the connection and during operation, which will degrade the mechanical properties of the welded joint and may cause cracking of the silicon immediately after the welding process. In this case, the use of intermediate layers is the only option for obtaining a diffusion welding that meets the necessary requirements.

Intermediate layers are introduced to prevent formation of brittle phases that are formed along the contact surface; as activators of the interaction due to the higher plastic characteristics of the interlayer; as intensifiers of the mass transfer process due to the increase of diffusion coefficient; to reduce the pressure and temperature of the weld between the joined materials, and of course, interlayers-compensators (dampers) to reduce stresses caused by difference of coefficients of linear thermal expansion of the welded materials.

In addition, it should be noted that in the development of new connections a great importance have interfacial interaction, which affects the weld strength, the possibility of chemical reactions and the formation of new phases in the transition layer, forming such properties as heat resistance, resistance to aggressive environments, durability and other important performance characteristics of a welded
joint, therefore, in the development of new connections important role play phase state diagrams reflecting the interactions of the components, the formation of solid solutions, stabilization of various phases, formation of intermediate connections, and phase equilibria.

The above data allows us to formulate the following requirements when choosing interlayers for diffusion welding of monocrystalline silicon with copper: these are not only the damping properties of the interlayer, but also the metal of the interlayer must form a solid solution with silicon of at least limited solubility or eutectic, preferably with a zone of limited solubility [2].

In some cases, it is not possible to select an intermediate layer that meets these requirements, and then two or more layers are used.

Based on the crystal structure of metals, it can be predicted that the weldability of elements with a similar crystal structure will deteriorate as the difference in the parameters of their crystal lattices increases. Therefore, in pressure welding, including diffusion welding of two dissimilar metals, among other things, their crystal structure and atomic sizes are essential.

Ni, Cu, Ag – are well connected by pressure welding, since they have a FCC lattice whose parameters differ by less than 12%.

Figure 1 shows the connection diagram for diffusion welding of monocrystalline silicon with copper using a Cr–Ni–Ag interlayer.

![Figure 1](image)

**Figure 1.** Diagram of the Si–Cr–Ni–Ag–Cu diffusion welding. The dashed line shows the melting point. Areas of recommended diffusion welding temperatures are shaded.

Figure 2 shows the connection diagram for diffusion welding of monocrystalline silicon with copper using a Ti–Ni–Ag interlayer.

The strength of diffusion welded joints, as mentioned above, significantly depends on the stress-strain joint during the formation of the joint, including the cooling of the welded joint, due to the difference in physical and mechanical properties, primarily the temperature coefficients of linear expansion $\alpha$ and elastic modulus. If the difference in welding temperature exceeds the value $\Delta\alpha = 10^{-6} \, ^\circ\text{C}^{-1}$, then the connections are considered inconsistent. To reduce these stresses, it is recommended to ensure minimum temperature gradients in the joint during cooling by using special equipment and slowing down the heat sink to the minimum limits. Such connections are divided into compensated (type "silicon–relatively thin metal element(s)–silicon" and uncompensated (type "metal element–silicon"). The second type of joint, due to the uncompensated bending moments, is in less favorable conditions than the compensated ones [3].
Figure 2. Diagram of the Si–Ti–Ni–Ag–Cu diffusion welding. The dashed line shows the melting point. Areas of recommended diffusion welding temperatures are shaded.

Most metals and alloys are thermodynamically unstable and easily pass into an oxidized state, passivating the surface. Therefore, one of the conditions for transferring the surface to the active state is to clean the surface of oxides and destroy the bonds saturated with oxygen.

The main mechanisms for cleaning the surfaces to be welded from oxides during vacuum welding of metals are their sublimation, dissociation, restoration and dissolution in the metal base. Removal of metal oxides present in the interlayers is achieved due to:

- development of the sublimation process is most likely for metals such as nickel, chromium;
- dissociations for copper, silver, nickel;
- carbon restoration for chromium;
- dissolution of oxygen in a metal base for titanium.

The correct choice of diffusion welding modes involves not only obtaining the connection of components, but also achieving the necessary degree of interaction with minimal energy consumption without disturbing the structure of silicon.

The processes occurring in the silicon–interlayer–copper system are complex and in each practical case are determined by the properties of all materials involved in the interaction, their purity, the method of application and thickness of the interlayer, the values of the parameters of the diffusion welding mode, etc. The relative thickness and plastic characteristics of the interlayer(s) material determine the contact effects (hardening, softening) and the nature of the stress-strain state that occurs in the joint zone when external loads are applied.

However, it is practice that is the criterion of truth, so only experimental studies can answer the question of which interlayer architecture and type of connection will provide the required set of properties of a diffusion welded joint of monocrystalline silicon with copper.

References
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