ELECTRICAL INSULATING ASSEMBLY ON BASE ALUMINUM NITRIDE FOR THERMOELECTRIC BATTERIES

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Be received 5.09.2019

Abstract. *A SiGe alloy-based electrical insulation node of thermoelectric battery was built using graphite and AlN ceramic. Both of them have high thermal conductivity and are thermomechanically compatible with SiGe alloys within a wide temperature range. Vacuum soldering with Ti-Cu alloy anddiffusion welding were used in making the electrical insulation node. A metallographic and mechanical study of the produced contacts was carried out. The operation mode of the created electrical insulation node has been established*.

Key words: *Thermoelectricity, Silicon, Germanium, alloy, graphite, electrical resistance.*

Thermoelectric generator (TEG) converts heat energy directly into electrical energy. Thermoelectric batteries, comprising legs made of n-type and p-type thermoelectric materials, constitute its main component part. The legs are interconnected by means of switching plates and conductors. One end of the legs in the battery gets hot, while the other gets cold, which, by the Seebeck effect, produces the thermoelectric factor/driving forcein them [1], capable of generating electrical power of a definite strength. Heat is converted into electricity by the legs. The conversion efficiency is a value proportional to efficacy of the used thermoelectric material and a temperature difference between the hot and cold ends of the legs [2]. The potential efficiency of the known thermoelectric materials amounts up to 14 percent.

A definite part of the electrical power generated by the legs in the real thermoelectric battery is lost on the electrical and heat-transfer resistance of the switching plates, conductors and the produced contacts. These losses have been minimized as a result of appropriate studies.

To connect the thermoelectric batteries with the TEG heater and cooler, the leg ends are equipped with electric insulation nodes. They have a definite heat-transfer resistance that reduces the temperature difference between the leg ends and, correspondingly, the force of generated electric power. To reduce these losses, electric insulation nodes are manufactured using relatively higher heat-conducting ceramic materials (mostly: BeO, Al_2O_3, andAlN). Fig. 1 shows a schematic view of an electrical insulation node of the cold end of athermoelectric battery consisting of 32 (16 n-type and 16 p-type) legs connected in succession.

In order to build a heat-resistant battery, the materials of a collector and conductor - constituent parts of the insulation nodes, should be thermo-mechanically compatible with the thermoelectric materials used in the battery. In this respect, the use of graphite and AlN ceramic as a constructional material for the electrical insulation node of the SiGe alloy-based thermoelectric battery would be feasible. The linear expansion factor of them and of the SiGe alloys varies within 4–5.5 10^{-6} cm^{-1} in the 25-1200^{0}C temperature range [3,4]. Fig. 2 presents a schematic view of the electrical insulation node of the 32-leg SiGe alloy-based thermoelectric battery.

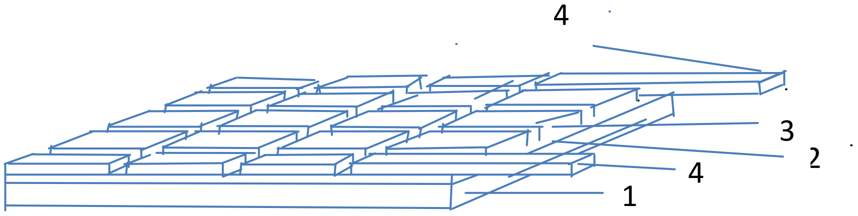


Fig. 1. Schematic view of an electricinsulation node of the cold side of a 32 - legthermoelectric battery:
1 - Collector; 2 - Ceramic plate; 3 - Conductors; 4 - Leads

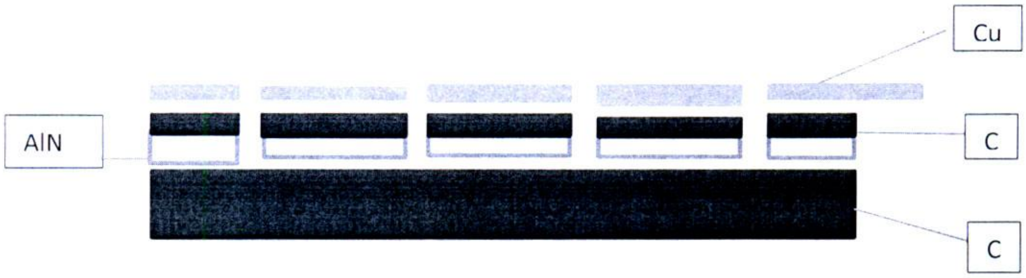
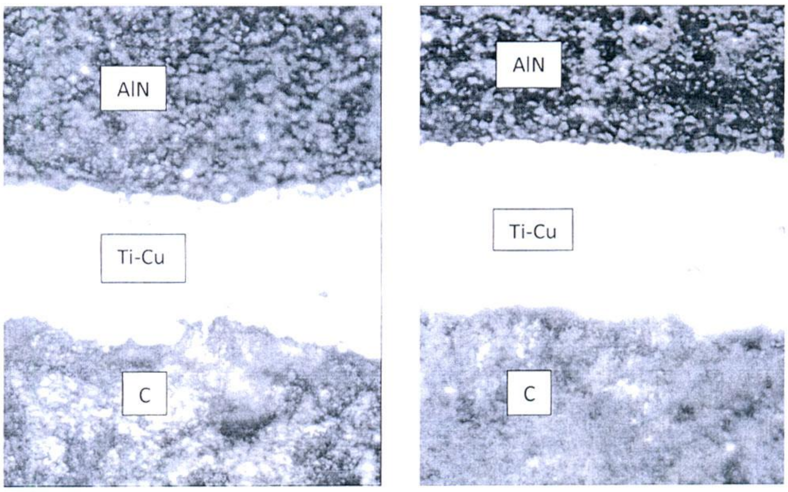


Fig. 2. Schematic view of the electrical insulation unit

Undoped graphite has relatively less strength and higher resilience as compared with the thermoelectric SiGe alloys and AlN [5]. Thanks to these characters, it is thermo-mechanically compatible with the both plain Si and thermoelectric SiGe alloys. The strain originated at their junction, which is conditioned by a difference in the linear expansion factors, lessens on the graphite. The graphite acts as a buffer between the SiGe alloys and the electrical insulation node. By using graphite, the switching junctions operating within a temperature range up to 900^{0}C have been produced as a switching material for the thermoelectric SiGe alloys [6,7].

Electrode graphite and 0.5-mm thick AlN plates were used in the works for making an electrical insulation node of the SiGe alloy-based thermoelectric battery. The Ti 67 % m + Cu

43% m alloy, whose whose melting temperature constitutes 960^{0}C, was selected for soldering them [8]. The test specimen represented a graphite plate and an AlN plate joined by soldering. The soldering took place in a quartz chamber of an induction vacuum oven, 10 Pa, at 1000-1150^{0}C temperature, during 5-10 minutes. Melted solder wets well both the graphite and AlN. Fig. 3,A demonstrates microstructure of the originated graphite-AlN contact. It is rather monolithic and crack-free. In the process of soldering, the solder intensively fills the open pores of the graphite. Figure 3**b** demonstrates microstructure of contact of the test specimen sintered at 900^{0}C temperature during 100 hours and placed in an evacuated closed ampoule. It differs insignificantly from the contact microstructure of the unsintered specimen. The contact's tensile strength of both the sintered and unsintered specimen is limited to the graphite strength and numerically exceeds 10 kg/cm^2.



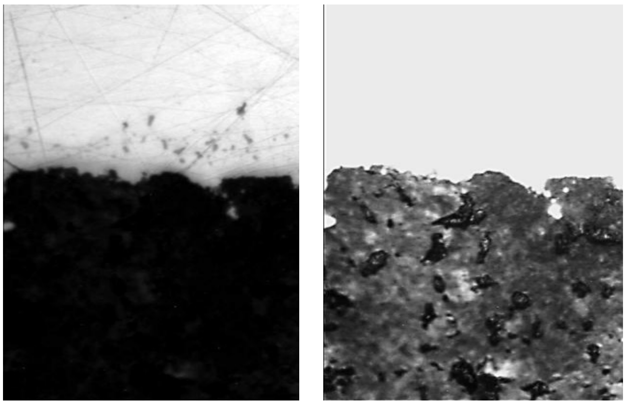
A **B**

Fig. 3. Microstructure of a contact originated between AlN and graphite plates
A - before sintering; **B** - after sintering

The electric insulation node (see Fig. 2) contains copper plates joined with graphite conductive plates. They are joined by means of diffusion welding, for which the contact surfaces of graphite plates are preliminarily galvanized with a thin nickel layer (10-20 μm). The test specimens of the C-Ni-Cu structure contact were manufactured using a 5 mm thick graphite plate and a 0.2 mm thick copper plate. In particular, a copper plate was placed between two nickel-plated graphite plates, the joining of which was carried out by diffusion welding in a vacuum chamber of an induction vacuum oven, in 10 Pa vacuum, at 850^{0}C temperature, at 200 kg/cm^2 pressure, during 30 minutes.

The produced contact microstructure is pore- and crack-free; the nickel layer is closely joined with graphite and copper; the tensile strength of the contact exceeds 10 kg/cm^2.

To determine the operating temperature of the contact, the test specimens placed in the evacuated open quartz ampoule were sintered during 100 hours at different temperatures. The contact microstructure and strength of the sintered specimens have remained practically unchanged. Fig. 4 shows the microstructure of the same section of the specimen sintered during 100 hours at a temperature of 700^0C, photographed under low lighting conditions – **A**, and under relatively high lighting conditions – **B**. In the first of them a layer of nickel placed between the graphite and copper plates can be seen;in the second, the contact surface of the graphite closely connected with the nickel layer is observable. The nickel layer of the specimen sintered at a temperature of 800^0C formed small-size pores, but its strength remained practically the same, whereas the contact of the specimen sintered at a temperature of 850^0C with graphite was dissociated with removal of the nickel-plated layer from graphite.



A **B**

Fig. 4. C-Ni-Cu contact microstructure of the same section after sintering

On the basis of the conducted studies it can be concluded that the electric insulation node built on the graphite and AlN substrate, aimed for the SiGe alloy-based thermoelectric battery, can be used at a temperature up to 700^0C in the case of operation in vacuum and inert gas environment. Its operation in the air is possible at a temperature of up to 300^0C. This limitation is conditioned by the construction materials used therein andoxidation resistanceof the produced contacts.

Sukhumi Institute of Physics and Technology has developed a thermoelectric battery built on the substrate of n-type and p-type $Si_{0.95}Ge_{0.05}$ alloys [9]. The battery' hot ends are switched by the boron- doped Si-Mo alloy that can operate in the air at a temperature of up to 1000^0C.

The battery's cold ends are graphite-switched. The battery's hot side is heated directly by the flare and does not require the use of an electric insulation node; as for the cold side, it is refrigerator-attached and requires the use of said unit. Its electric insulation node was built in accordance with the presented work results.

Fig. 5 demonstrates a photograph of the electric insulator of the 24-leg thermoelectric battery's cold side. It was manufactured as follows: 2mm and 4mm thick and 30x30 mm^2 sized graphite plates were produced. A plate of the same size was cut out from the 0.5 mm thick AlN plate. An AlN ceramic plate was placed between the graphite plates and they were joined by means of soldering. The 2 mm thick graphite plate surface of the produced pack was nickel-plated and the plate was cut by a diamond disk at the marked places. Thereafter, a 0.2 mm thick copper plate was joined to the nickel-plated surface of the pack by means of diffusion welding, which was then cut bya 0.7 mm thick bakelite disk at the marked places.

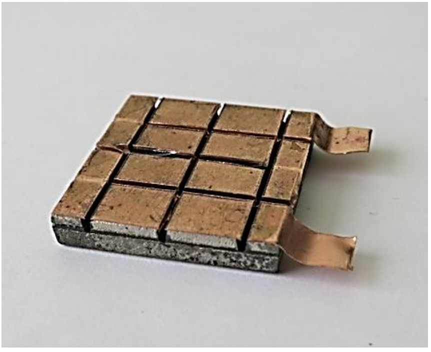


Fig. 5. Electric insulation node of a battery (1.3 x 1)

Fig. 6 shows an air-operated SiGe alloy-based thermoelectric battery, with an electric insulation node joinedto its cold end. Its joining is carried out by diffusion welding, for which purpose the graphite plates of the battery's cold end were preliminarily galvanized with a layer of nickel.

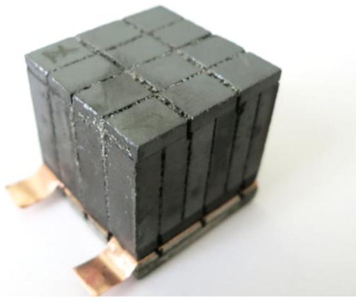


Fig. 6. 24-leg air-operated thermoelectric battery with an electric insulation node

The produced energy characters of the thermoelectric battery are given in Table 1 below.

Energydata of a thermoelectric battery

Table 1

T_h °C	T_c °C	T_h-t_c °C	E_v	R_{ohm}	V	Wt	Pd Wt/cm^2
580	55	525	1.45	0.2	0.71	2.5	0.33
689	55	634	1.91	0.3	1.07	3.8	0.51
777	58	719	2.41	0.3	1.31	5.7	0.76

840	60	780	2.8	0.3	1.49	7.4	0.99
880	63	817	2.95	0.3	1.57	8.2	1,09
912	65	847	3.2	0.3	1.65	9.0	1.2
962	68	894	3.4	0.3	2.06	14.7	1.96
990	70	920	3.6	0.3	2.16	15.5	2.07

Conclusion

An electric insulation node of the cold side of the SiGe alloy-based thermoelectric battery using graphite and AlN ceramic plates has been built. Its application in vacuum and in the inert gas environment is possible at a temperature of up to 700^0C, whereas in the air – at a temperature of up to 300^0C. The attachment of the electric insulation node to the cold side of the thermoelectric batteries does not affect its mechanical properties. The heat loss of the thermoelectric battery on the electric insulation node does not exceed 2%.

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