Chimica Techno Acta
published by Ural Federal University
eISSN 2411-1414; chimicatechnoacta.ru

LETTER
2022, vol. 9(2), No. 202292S1
DOI: 10.15826/chimtech.2022.9.2.S1

Development of technology for obtaining electrodes based on copper wire used in the manufacture of solar modules

M.S. Illarionova *, K.Yu. Ivanova, M.V. Kuzmin, A.O. Patianova, V.L. Semenov

Chuvash State University named after I. N. Ulyanov, 428015 Cheboksary, Russia
* Corresponding authors: illarionovamarina1995@mail.ru

This paper belongs to the MOSM2021 Special Issue.

Abstract

To optimize the technological process of manufacturing copper wire coated with solder of the POIN-52 brand, the optimal modes for the tinning temperature, linear velocity, diameter of the diamond die and flux were identified. It was found that the best wire tinning process is achieved when cleaning the surface of a copper wire by the method of electrochemical degreasing. The results of the tests showed that, in terms of mechanical and electrical parameters wire meets the requirements for electrodes in the manufacture of solar modules. The results of climatic tests of solar modules showed a high degree of reliability with a power loss of 0.86% and thermal cycling tests with a power loss of 0.4%, which is within tolerance.

Keywords

smart wire connection technology
POIN-52 brand tin-indium alloy
copper wire
mechanical and electrical parameters
solar module

Received: 09.11.2021
Revised: 01.12.2021
Accepted: 28.03.2022
Available online: 31.03.2022

1. Introduction

In modern conditions of the Russian economy development, one of the most important tasks is implementing the import substitution for reducing the cost of manufactured products. This issue is also relevant in the field of alternative energy sources, i.e. in the transition from non-renewable to renewable energy sources [1, 2]. It is known that photovoltaic solar modules are manufactured using Smart Wire Connection Technology (SWCT). On both surfaces of the photovoltaic cells, a film-wire electrode is glued, which consists of a wire and a film for the electrode. Using a film-wire electrode, photovoltaic cells are connected in series [3].

One of the important tasks of increasing the efficiency of photovoltaic solar modules is the search and development of new electrodes that provide high reliability of contact with crystalline silicon, as well as charge transfer in the cell [4]. Tinned copper wire, which is currently one of the main materials in electrical engineering, is widely used as conductive electrodes. The use of tinned copper wire ensures the reliability and protection of solar modules from any external influences and, as a result, increases the durability of the product itself [5]. The use of low-melting solder on the surface of the copper wire makes it possible to obtain reliable electrical contact with the siver-containing contact grid, which helps to reduce the ohmic resistance between the photovoltaic cells [6].

2. Experimental

As a rule, tinning in the manufacture of wire is performed by the galvanic method. However, practice has shown that the necessary qualities of electrodes are achieved via hot tinning [7]. The continuity of the electrode contact with monocrystalline silicon directly depends on the surface quality of the tinned wire and the thickness of the solder based on the POIN-52 alloy, which ultimately affects the efficiency of transferring the converted light energy into electricity [8]. In accordance with the requirements of the normative and technical documentation, hot tinning on the coating of copper wire of MT 0.25 brand with POIN-52 brand solder was carried out on a hot tinning unit.

At the first stage, we prepared the surface of the copper wire in order to remove oxides from the surface. We used the electrochemical degreasing to prepare the surface of the wire. The initial parameters of the wire were as follows: diameter – 0.25±0.001 mm; elongation –

25%; specific electrical resistance – 0.0167·10^{-6} Ohm·m^2. Wire degreasing parameters are shown in Table 1.

Hot tinning was carried out using flux deposition technology. A composition developed by a team of authors in work [9, 10] was used as a flux. The technological modes of hot tinning are given in Table 2. During the coating process, it was found that the wire stretches slightly. The coating of the wire is even, smooth, shiny, the quality of adhesion is satisfactory.

3. Results and Discussion

We experimentally studied the possibility of using wire as electrodes using SWCT technology in the manufacture of solar modules. Reliability tests of soldering joints were carried out by testing for exposure to high humidity at high temperature and by thermal cycling. The results of the tests showed that, according to mechanical and electrical parameters, the wire coated with solder of the POINT-52 brand meets the requirements for electrodes in the manufacture of solar modules. The results of climatic tests of solar modules for exposure to high humidity at high temperature showed a high degree of reliability with a power loss of 0.86% and thermal cycling tests with a power loss of 0.4%, which is within tolerance.

Mechanical and electrical parameters of tinned wire are presented in Table 3.

The data in Table 3 show that the mechanical parameters (mechanical strength and relative elongation) and electrical parameters (electrical resistance to direct current and specific electrical resistance) are within the specified tolerance ranges or within the normal range.

The design parameters of the copper wire coated with POIN-52 alloy is presented in Table 4.

The thickness of the coating was determined by metallographic method according to clause 3.14 of GOST 9.302-88 Unified system of protection against corrosion and aging (ESZKS). Metallic and non-metallic inorganic coatings. Control methods (as amended). Data analysis Table 3 and 4 indicates that the most optimal characteristics are obtained with technological mode No. 2.

The obtained sample of tinned wire is recommended as a current conducting electrode in the manufacture of solar modules using SWCT technology.

At the next stage we carried out climatic tests of solar modules in order to determine the possibility of using tinned wire coated with POIN-52 alloy according to IEC 61215-1: 2016 “Photovoltaic modules. Assessment of compliance with technical requirements. Test requirements". Two different climatic tests were performed. The first test method involves exposure to high humidity at high temperatures. The test conditions are presented in Table 5. The results of the tests are presented in Table 6. Table 6 shows that the power loss was 2.71 watts or 0.86%. The photo of the electroluminescence of the module at the end of the tests is shown in Fig. 1.

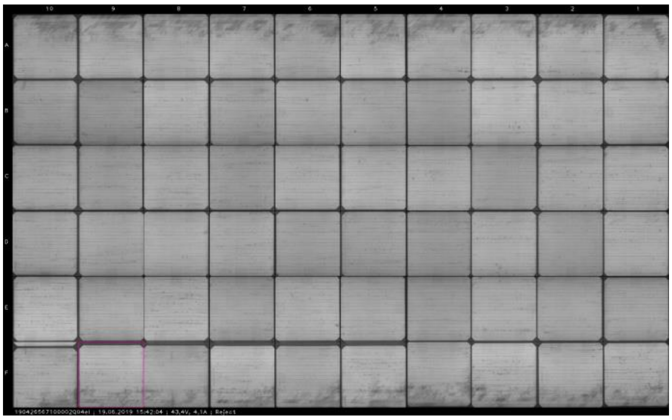

Fig. 1 Photo of the electroluminescence of the module at the end of the tests

The second method of climate testing involves thermal cycling. The test conditions are presented in Table 7.

The results of the tests are presented in Table 8. Table 8 shows that the power loss was 1.29 W, or 0.4%. The photo of the electroluminescence of the module at the end of the tests is shown in Fig. 2.

Table 1 Technological mode of electrochemical degreasing

Brand and nominal diameter of copper wire, mm	Degreasing solution	Temperature, °C	Electric current, A	Speed, m/min	Wire diameter after degreasing, mm
MM 0.25±0.001	TG-19	38	20	50	0.25±0.001

Table 2 Technological mode of wire coating with POIN-52 solder

Mode	Copper wire diameter according to technical specifications	Copper wire brand and actual diameter, mm	Melt temperature, °C	Linear Velocity, m/min	Diamond die diameter, mm
1	$0.25^{+0.1}_{-0.1}$	MT $0.25^{+0.003}_{-0.001}$	130	130	0.265
2	$0.25^{+0.1}_{-0.1}$	MT $0.25^{+0.003}_{-0.001}$	150	100	0.265
3	$0.25^{+0.1}_{-0.1}$	MT $0.25^{+0.003}_{-0.001}$	175	105	0.278

Table 3 Mechanical and electrical parameters of copper wire coated with POIN-52 solder

Tensile strength, H/ mm²				Relative extension, %				Specific electrical resistance to direct current at temperature 20 °C, Ohm× mm²/m				Electrical resistance to direct current at temperature 20 °C, Ohm/m			
standard	1	2	3	standard	1	2	3	standard	1	2	3	standard	1	2	3
200-290	243	220	240	25 ± 15	25	21	21	0,017±0.002	0.018	0.019	0.017	0.35 ± 0.03	0.35	0.35	0.35

Table 4 Design parameters of copper wire coated with POIN-52 solder

Wire diameter, mm				Wire coating thickness, micron			
standard	1	2	3	standard	1	2	3
0.25±0.010	0.257	0.257	0.250	$3.5^{+1.5}_{-1.0}$	3.8	4.5	<1.0 (≈0.8)

Table 5 High humidity / high temperature test conditions

Exposure in the climate chamber	Exposure time, hours	Temperature, °C	Relative humidity, %	Frequency of unloading for testing, days
Exposure conditions	1000	85±2	85±5	7

Table 6 Test results of volt-ampere characteristics before and after the tests

WEEK	P_{max}, Watt	Vp_{max}, V	Ip_{max}, A	*Voc*, V	*Isc*, A	*Rs*, Ohm	*Rsh*, Ohm	*FF*, %	*Eta*, %
0 (loading)	317.354	36.33	8.74	43.87	9.25	0.46	687.7	78.20	19.00
6 (discharge)	314.64	36.21	8.69	43.80	9.21	0.46	666.8	77.97	18.84

Table 7 Test conditions by thermal cycling

Exposure in the climate chamber	Number of cycles	Cycle duration, hours		Frequency of unloading for tests, cycles
	200	6		40
Exposure conditions	Temperature, °C		Relative humidity, %	
	at the top point	at the bottom point	at the top point	at the bottom point
	85±2	–40±1	–	–

Table 8 Test results of volt-ampere characteristics before and after the tests

Series	P_{max}, Watt	Vp_{max}, V	Ip_{max}, A	*Voc*, V	*Isc*, A	*Rs*, Ohm	*Rsh*, Ohm	*FF*, %	*Eta*, %
0 (loading)	316.76	36.26	8.74	43.88	9.26	0.461	537.7	77.97	18.97
200 (discharge)	315.47	36.19	8.72	43.89	9.24	0.473	546.2	77.83	18.89

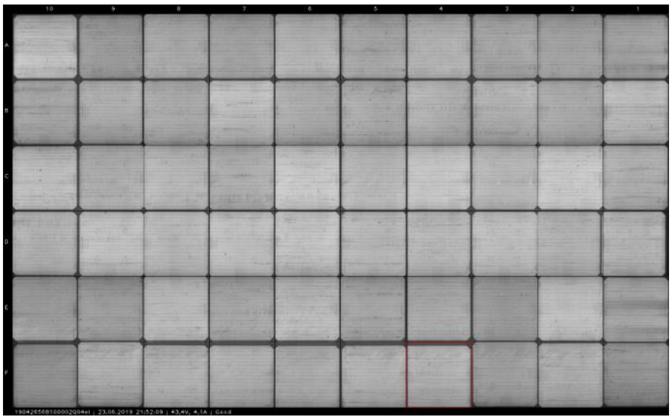

Fig. 2 Photo of the electroluminescence of the module at the end of the thermal cycling tests

4. Conclusions

The technological modes of hot tinning of copper wire with the POIN-52 alloy considered in this work with the identification of optimal conditions for the tinning temperature, linear velocity and diameter of the diamond drawing allow us to confirm the reliability of the contact electrode with the connecting busbar of solar modules. It is confirmed by the successfully conducted climatic tests of the solar modules by the thermal cycling methods and the method of exposure to high humidity at high temperature. The results of the climatic tests of solar modules comply with the requirements of regulatory and technical documentation and vary within the tolerance ranges.

Supplementary materials

No supplementary data are available.

Funding

The research was carried out by Chuvash state University within the implementation of a comprehensive project under the contract No. 2019/0837/1202-19 dated September 19, 2019 with the financial support of the Ministry of Education and Science of Russia under the Agreement No. 075-11-2019-047 dated November 25, 2019 and Russian Foundation for Basic Research (RFBR, https://www.rfbr.ru/rffi/eng), project No. 20-33-90269.

Acknowledgments

None.

Author contributions

Conceptualization: M.S. I., K.Yu.I., A.O.P., M.V.K.
Data curation: M.V.K.
Formal Analysis: K.Yu.I., A.O.P.
Funding acquisition: M.V.K., V.L.S.
Investigation: M.S. I., K.Yu.I., A.O.P.
Methodology: M.V.K., V.L.S.
Project administration: M.V.K., V.L.S.
Resources: M.S. I., K.Yu.I., A.O.P.
Software: M.V.K., V.L.S.
Supervision: M.V.K., V.L.S.
Validation: M.V.K., V.L.S.
Visualization: K.Yu.I., A.O.P.
Writing – original draft: M.S. I., K.Yu.I., A.O.P.
Writing – review & editing: M.V.K., V.L.S.

Conflict of interest

The authors declare no conflict of interest.

Additional information

Authors' Ids:

Illarionova, Marina S., Scopus ID 57203511906;
Ivanova, Kristina Yu., Scopus ID 57222369362;
Kuzmin, Mikhail V., Scopus ID 55758896300.
Patianova Alice O., Scopus ID 57202283653
Semenov Vladislav L., Scopus ID 57190025583

Website of

Chuvash State University named after I.N. Ulyanova https://www.chuvsu.ru.

References

1. Maronchuk II, Sanikovich DD, Mironchuk VI. Solnechnye elementy: sovremennoe sostoyanie i perspektivy razvitiya. Energetika [Solar cells: current state and development prospects. Energy] Izvestiya vysshih uchebnyh zavedenij i energeticheskih ob"edinenij SNG. 2019;62(2):105–123. Russian. doi:10.21122/1029-7448-2019-62-2-105-123
2. Prospects for Energy Technologies 2008. Scenarios and Strategies until 2050 [Internet]. International Energy Agency. OECD / IEA, 2008. p. 10–15 [cited 29.07.2021]. Available from: https://iea.blob.core.windows.net/assets/0e190efbdaec-4116-9ff7-ea097f649a77/etp2008.pdf
3. Larionov VR, Malevskij DA, Pokrovskij PV et al. Izmeritel'nyj kompleks dlya izucheniya kaskadnyh solnechnyh fotoelektricheskih elementov i koncentratornyh modulej na ih osnove [Measuring complex for the study of cascade solar photovoltaic cells and concentrator modules based on them] Tekh Fiz. 2015;60:891–896. Russian. doi:10.1134/S1063784215060158
4. Semenov VL, Aleksandrov, RI, Kuzmin MV, Rogozhina LG, Ivanova KY, Patianova AO, inventors; Chuvash State University named after I. N. Ulyanov, assignee. Method for producing copper wire coated on the basis of an alloy of tin-indium. Russian Federation patent RU 2764277 C1. 2022. Russian.
5. Vinokurov EG, Margolin LN, Farafonov VV. Elektroosazhdenie kompozitsionnykh pokrytiy [Electrodeposition of composite coatings]. Izvestiya vysshikh uchebnykh zavedeniy. Seriya: Khimiya i khimicheskaya tekhnologiya. 2020;63(8):4–38. Russian.
6. Ivanova KYu et al. Synthesis and research of polyfunctional silylureas used in electric deposition of tin-indium alloy. Chim Techno Acta. 2021;8(3):20210305. doi:10.15826/chimtech.2021.8.3.05
7. Socolowski N. Lead free alloys and limitations for surface mount . Proc Surf Mount Int. 1995;477–480. doi:10.1134/S0031918X09090105
8. Csincse J, Janjun S, Uisang Q, Stewart V, Graham A, inventors; Wuxi Suntech Power Co, assignee. A method of producing electrode of solar cell and device for electrochemical deposition. Russian Federation patent RU 2399119 C2. 2010. Russian.
9. Semenov VL, Aleksandrov, RI, Kuzmin MV, Rogozhina LG, Ivanova KY, Patianova AO, inventors; Chuvash State University named after I. N. Ulyanov, assignee. Flux for soldering and tinning of copper wire. Russian Federation patent RU 2741607 C1. 2021. Russian.
10. Patianova AO, Ivanova KYu, Rogozhina LG, Kuzmin MV, Semenov VL. Improving the environmental production of electrodes for solar panels. Chim Techno Acta. 2020;7(4):186–191. doi:10.15826/chimtech.2020.7.4.09