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

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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

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 $\approx 0.0167 \times 10^{-6}$ Ohm-m². 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 POIN-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.

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.

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**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                                                 | MT 0.25±0.003                             | 130                  | 130                    | 0.265                   |
| 2    | 0.25±0.1                                                 | MT 0.25±0.003                             | 150                  | 100                    | 0.265                   |
| 3    | 0.25±0.1                                                 | MT 0.25±0.003                             | 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* mm/m² | Electrical resistance to direct current at temperature 20 °C, Ohm/m |
|-------------------------|-----------------------|----------------------------------------------------------------------------------|------------------------------------------------------------------|
| standard                | 1 2 3                 | standard 1 2 3                                                                     | standard 1 2 3                                                   |
| 200±20                  | 243                   | 220                                                                                 | 240                                                              |
|                         | 25±1.5                | 25                                                                                  | 21                                                               |
|                         | 0.017±0.002           | 0.018                                                                               | 0.019                                                           |
|                         | 0.35±0.03             | 0.35                                                                                | 0.35                                                            |

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

| Wire diameter, mm | Wire coating thickness, micron |
|-------------------|-------------------------------|
| standard          |                               |
| 0.25±0.010        | 0.257                         |
| 0.250             | 3.8                            |
| 0.250             | 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 |
|---------------------------------|----------------------|-----------------|----------------------|-----------------------------------------|
| 1000                            | 85±2                 | 85±5            | 7                    |

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

| WEEK | Pmax, Watt | Vpmax, V | Ipmax, 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 | Number of cycles | Cycle duration, hours | Frequency of unloading for tests, cycles |
|---------------------|------------------|-----------------------|-----------------------------------------|
|                     | 200              | 6                      | 40                                      |
|                     | 85±2             | -40±1                  | -                                       |

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

| Series       | Pmax, Watt | Vpmax, V | Ipmax, 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 |

### 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.
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Conflict of interest

The authors declare no conflict of interest.

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