

Silver-Coated Copper Paste: Properties, Preparation Techniques, and Applications in Solar Cells and Semiconductor Devices

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Received: 24 February, Revised: 11 April, Accepted: 13 May

Abstract— A new material that has been developed as a potential substitute for current applications such as solar cell and semiconductor application is silver coated copper paste because of its high conductivity and relatively low cost. This paper will also consider main preparation techniques and characteristics of such composition as silver-coated copper paste and main fields of its application. The paste is a hybrid one and incorporates a layer of silver because while copper's main benefit, conductivity, is extraordinary its drawback, corrosion, is a problem. Both electroplate and chemical reduction techniques are evaluated in terms of scalability and coating smoothness. Issues related to coating uniformity, sintering optimization, and the cost of production are cited as major limitations to the industrial application scale. It can be seen that the controlled microstructure, crystal structure and particle distribution in the product are critical in obtaining a high and stable performance at high operating temperatures in service. Potential uses in photovoltaic and semiconductor products are presented; it is shown that the introduced silver-coated copper paste has comparable electrical properties to conventional silver paste but requires considerably less money to purchase. To this end, the paper suggests improving the methods of applying the coating, optimizing the sintering process, and improving the ways to support environmentally friendly practices in the implementation of the technology.

Keywords— Conductive paste; Photovoltaic applications; Semiconductor technology; Particle distribution; Electroplating; Chemical reduction.

I. INTRODUCTION

• Background

Conductive pastes are very important in the field of solar cell and semiconductor technology. They promote conductivity of electricity, improve energy transducers and ensure optimized

functionality in an apparatus. Conductive pastes have mostly contained silver in the past because of its high conductivity and thermal stability, and this has set the industry standard for the material. Nonetheless, the high price of the pure silver pastes and the unsatisfactory characteristics of present pastes in selected applications have led to the search for viable alternative materials which could offer a measure of sufficient performance at a reasonable cost [1][2].

• Purpose of the Review

The present review focuses on the topic of absorbing substance called silver-coated copper paste – a relatively new material that combines the conductivity of silver with cost-effective copper. The purpose of this paper is to identify and synthetically review the various properties, preparation methods and every aspect of the applications of this material in the field of solar cells and semiconductor devices [3], [4].

• Structure of the Paper

The paper is organized as follows: Section 2 gives an introduction of conductive pastes and their development. Section called 3 is devoted to both, individual and collective properties of silver and copper. In section 4, there are descriptions of different types of preparation for silver coating copper paste. Uses in solar cells as well as semiconductors are demonstrated in sections 5 and 6 respectively. Section 7 raises several technical and environmental issues of which they identify technical constraints in the large-scale preparation. The implications for future research are discussed in Section 8 while Section 9 concludes with an outline of the study's major conclusions.

II. OVERVIEW OF CONDUCTIVE PASTES

• Types of Conductive Pastes

Conductive pastes are relevant products in electronic industry especially in applications that demand high electrical conductivity. These pastes comprised of metal particles dispersed in an organic matrix; the thick film pastes can be

applied directly onto different substrates. The primary types of conductive pastes used in the industry include:

- Silver-Based Pastes: Well, known for their high conductivity and ability to resist oxidation, silver pastes have long formed the high standard within such fields as solar cells and circuits. However, high silver costs have driven the search for substitutes [5], [6].

- Copper-Based Pastes: Copper can be a more cost-effective solution here providing a reasonably high conductivity. Nevertheless, its low oxidation resistance and less heat endurance than silver again makes its application possible only through protective measures [7], [8].

- Hybrid Pastes (e.g., Silver-Coated Copper): These pastes seek to blend the advantages of both materials, a silver layer on copper particles that conduct better and avoid oxidation concerns, which are cheaper than recharge silver pastes [5], [6].

- Key Properties Required for Applications

For conductive pastes to perform effectively in solar cells and semiconductor applications, several critical property requirements must be met:

- Electrical Conductivity: Ac current control demands high conductivity since it influences current performance on devices. Conductive pastes must allow low resistivity paths to be formed and must be stable over a period [5], [6].

- Thermal Stability: The paste has also to endure high processing temperatures during sintering and other operation phases. It also reduces thermal degradation hence ensures high durability and performance is not affected [7], [8].

- Adhesion: A firm clinging to substrates including silicon or ceramic is desirable to hold onto in an individual life of the device. It has been suggested that poor adhesion results to mechanical failure and compromised efficiency [5], [6].

- Mechanical Properties: Conductive pastes need to be capable of maintaining integrity in terms of both cracking and delamination which occurs due to thermal and mechanical loading. This makes it both reliable especially as it may be used

in areas of temperature fluctuation or mechanical vibration [5], [6]. Silver is highly recognized for its conductivity to both electricity and heat making it ideal for use in electronics. Poor adhesion can lead to mechanical failure and reduced efficiency [5], [6].

III. SILVER-COATED COPPER: MATERIAL PROPERTIES

- Properties of Silver

Silver is renowned for its exceptional electrical and thermal conductivity, making it a prime choice for electronics applications. It possesses the highest electrical conductivity of all metals, which facilitates efficient current flow—crucial for devices such as solar cells and semiconductors [9]. Additionally, silver exhibits oxidation resistance, allowing it to retain its conductive properties over time and under various environmental conditions. This resistance minimizes the risk of surface degradation, which can compromise the performance of electronic devices [10].

- Properties of Copper

Copper is widely utilized in electronic applications due to its good electrical conductivity and significantly lower cost compared to silver. While copper's conductivity is slightly less than that of silver, it remains adequate for many applications where cost efficiency is prioritized[11]. However, copper is susceptible to oxidation, which can limit its use in environments requiring stable long-term performance. Its high availability and affordability make copper an attractive alternative in applications where cost is a critical consideration [12].

- Advantages of a Copper Silver Coating

Copper plated with silver is an alloy formed when joining the characteristic of copper and silver, so it has the better of the two metals. The silver on the surface enhances the conductivity of the wire and acts as an oxidation layer thereby shielding the copper interior, therefore avoiding the formation of a layer that would greatly degrade the circuit. This hybrid approach offers several key benefits:

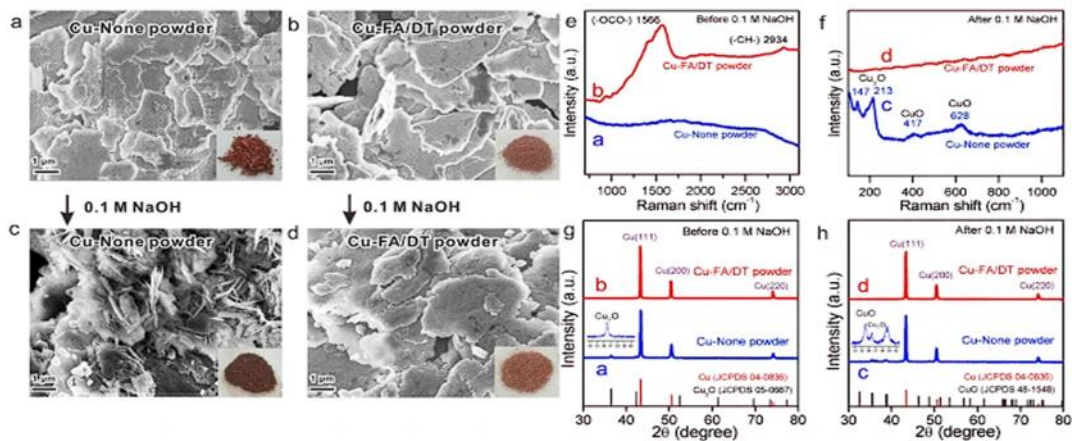


Figure 1: Properties and mechanism of Silver – copper-based pastes (Source: Hyung et. Al., 2018)

The provided figure illustrates the effects of FA/DT surface passivation on commercial copper micro flakes. The SEM images show a significant difference in the morphology of the Cu-None and Cu-FA/DT powders before and after exposure to 0.1 M NaOH. The Cu-None powder exhibits severe corrosion and pitting after alkali treatment, while the Cu-FA/DT powder remains relatively intact. Raman spectroscopy and XRD analysis further confirm the protective effect of FA/DT, as the characteristic peaks of CuO, indicative of copper oxide

formation, are significantly reduced in the Cu-FA/DT powder after alkali treatment. These results demonstrate that FA/DT surface passivation effectively enhances the alkali resistance of copper micro flakes.

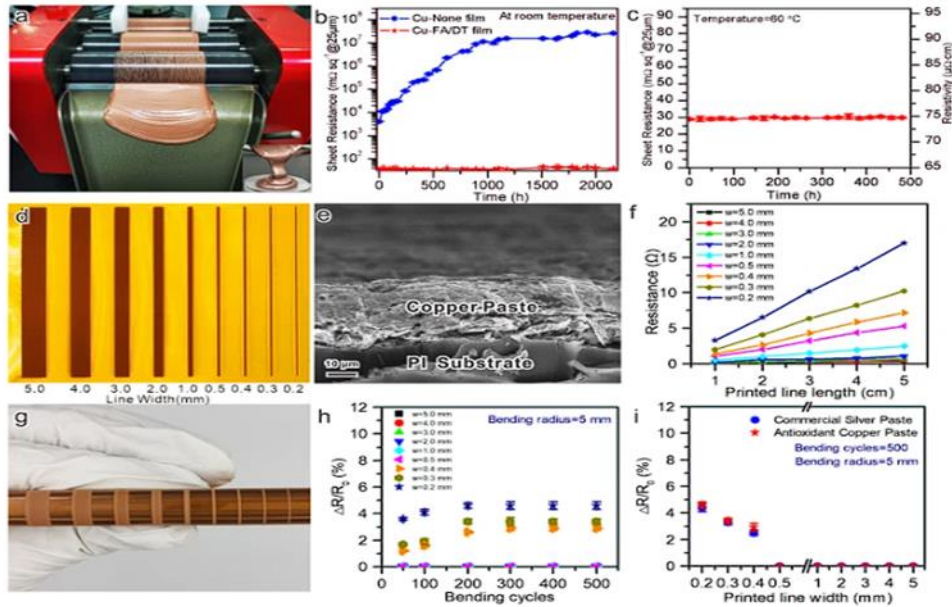


Figure 2: Electrical and mechanical properties of an antioxidant copper paste (Source: Hyung et. Al., 2018)

Electrical Properties:

- Crystalline Properties of Silver and Copper:
- Crystalline Structure of Silver:

Silver has an FCC crystal structure that results in high formability, as well as electrical and thermal conductivity. This structure enables formation of closely packed lattice for silver atoms that conduct electric charges and are essential for high conductivity use.

- Crystalline Structure of Copper:

Similar with silver, copper also has an FCC crystal structure and it possesses almost equal mechanical and thermal properties. This structure is beneficial in the sense that, when bonded together, the two phases are brought into an equivalent lattice and hence no lattice dislocations are present at the interface, thus comes out with a stable silver-coated copper material.

- Lattice coherency of crystalline structures in silver coated copper paste:

The FCC structure of the silver and copper approach results reliable interfacial adhesion and compatibility. This structural conformation improves the electric conductivity and thermal performance of the paste while minimizing problem such as de laminating or crack during thermos-mechanical cycling.

- Long-term stability: The copper films exhibit excellent long-term stability at room temperature and elevated temperatures (60°C).

- Line width dependence: The electrical resistance of the printed conductive lines decreases with increasing line width.

- Bending resistance: The copper paste demonstrates good bending resistance, maintaining low resistance even after 500 bending cycles at a 5 mm bending radius.

Mechanical Properties:

- Adhesion: The copper paste exhibits good adhesion to the PI substrate, as evidenced by the cross-sectional SEM image.

- Flexibility: The printed conductive lines can be bent without significant loss of electrical conductivity.

- Enhanced Conductivity: The silver coating on copper particles ensures high conductivity, approaching that of pure silver paste, while keeping material costs lower.

- Oxidation Resistance: The silver layer shields the copper core from oxidation, which significantly improves the longevity and stability of the conductive paste in various applications.

- **Cost-Effectiveness:** By using a copper core, the amount of silver required is reduced, resulting in a more affordable solution compared to using pure silver paste. This cost efficiency is particularly valuable in large-scale applications like solar cell manufacturing.

This, therefore, makes silver coated copper paste meet both the performance and cost requirement for industries. As a combination of silver and copper pastes, this material could surpass on performance the use of either one of them independently, especially if an application needs to be designed for long-term stability.

IV. PREPARATION METHODS FOR SILVER-COATED COPPER PASTE

- **Overview of Synthesis Techniques:**



Figure 3: Process of Electroplating and its complex machinery (Source: Wikipedia contributors 2024)

- **Chemical Reduction:** In this technique, the reduction is employed where a reducing agent deposits the silver over copper islands. This is preferable than electroplating since it is easier to perform, convenient when it comes to batch production.

Various methods are employed to coat copper particles with silver, each presenting unique benefits and challenges that influence the final quality of the paste. Common techniques include:

- **Electroplating:** This method simply involves passing an electric current with the aim of adding layer of silver onto copper particles. Electroplating is well suited to achieving a consistent thickness of the coating and is excellent in terms of conductivity. However, it may be time consuming and may involve demanding equipment's arrangements [9], [13].

On the other hand, it is difficult to control the coating thickness and consistency of the distribution which in turn affects the paste efficiency [10], [14], [15].

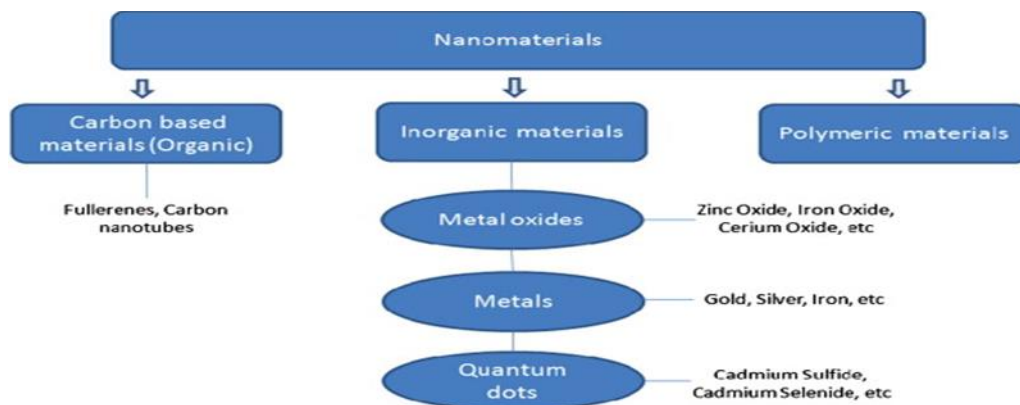
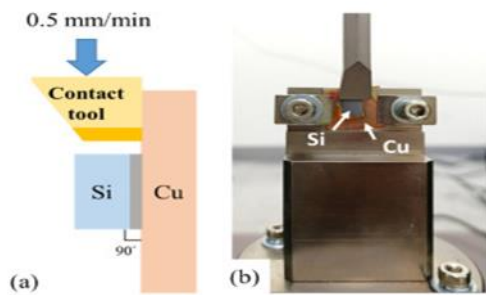


Figure 4: Chemical reduction of Ag and Al nanoparticles and Nano-alloys by chemical reduction (Manikam et al. 2010)

- **Mechanical Mixing:** This method entails physical mix of silver and copper particles thus resulting to a coated surface/bearing. Although widely used, it tends to produce lower



coating uniformity and thickness control and thus yields lower paste quality than other methods [9].

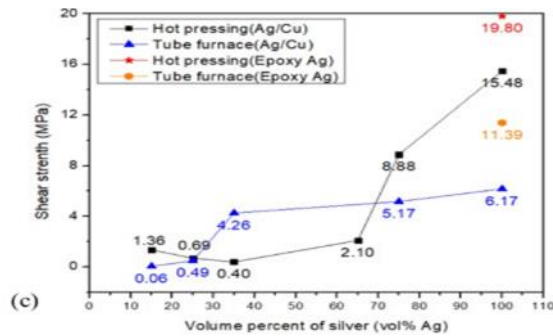


Figure 5: Mechanical mixing of Silver–Copper pastes for die attach bonding using percolation theory for enhancing thermal and electrical conductivity (Cheng et al. 2023)

- **Most Feasible Option in Preparation:** Largely discussed electroplating and chemical reduction methods as the available techniques today with optimal explanations regarding their effectiveness and shortcomings when it comes to scaling [16]. They described issues like uniform coating of products and the high cost of precision instruments that also affect quality and company production capacity in a business.

- **Factors Affecting Quality and Performance:**

The effectiveness and performance of silver-coated copper paste are influenced by several critical factors during the preparation process:

- **Coating Thickness:** It is found that the thickness of the silver layer has a direct proportional relation to conductivity and is directly proportional to the oxidation resistant property. A heavier layer of silver will protect the copper core more effectively but at a higher material expense, whereas leaner layers are cheaper yet considerably less resilient [10]

- **Uniformity:** Uniformity of coating in all areas of the copper particles guarantees stable performance in regard to conduction and oxidation. These differences in coating thickness distributions can cause problems with the performance of the conductive coating and increase an object’s likelihood of oxidation [9]

- **Sintering Conditions:** The paste’s mechanical and conductive characteristics are influenced by the sintering process by which the paste is heated to achieve a solid connection. Proper heat treatment parameters for sintering aid in the formation of conductive and strong layer on the surface without the detriment of strength. However, when very high-power levels are used during sintering, then the copper workpiece absorbs the silver, and this lowers its conductivity and the cost of production [9], [15]

Achieving a balance between these factors is crucial for producing high-quality silver-coated copper paste that meets industrial requirements. Proper synthesis and processing

conditions enhance the paste’s reliability, durability, and overall performance in solar and semiconductor applications.

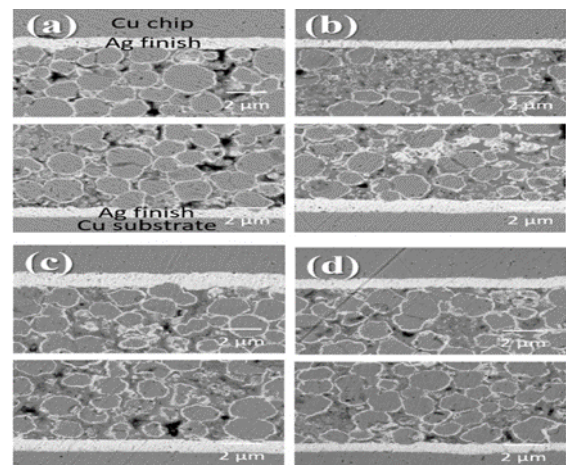


Figure 6: Improved sinter-bonding properties of silver-coated copper flake paste in air by the addition of sub-micrometre silver-coated copper particles (Kim et al. 2020)

- **Characterization of Crystalline Structures**

Characterization of the crystalline properties of silver-coated copper paste involves advanced techniques:

- **X-ray Diffraction (XRD):**

Confirms the FCC crystal structures of silver and copper and also different phase formed during coating or sintering.

Representative WAXD patterns generally exhibit distinctive peaks characteristic of the Miller indices of the planes of both materials to confirm the crystalline nature.

- **Scanning Electron Microscopy (SEM):**

It was used to view topography of the surface and to check uniformity of silver layer.

The morphology of the coated particles is resolved and can be used to assess coating thickness and homogeneity using SEM.

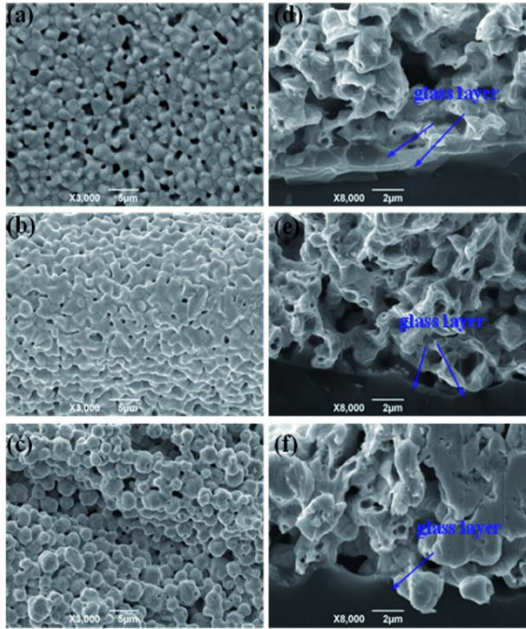


Figure 7: SEM images of crystalline structures in silver – copper paste (Ma et al., 2017)

- Transmission Electron Microscopy (TEM):

Grants the opportunity to get high magnification images to compare the interfacial metallurgical bonding between silver and copper.

Aids in establishing compatibility, as well as establishing structural homogeneity at the nanoscale level.

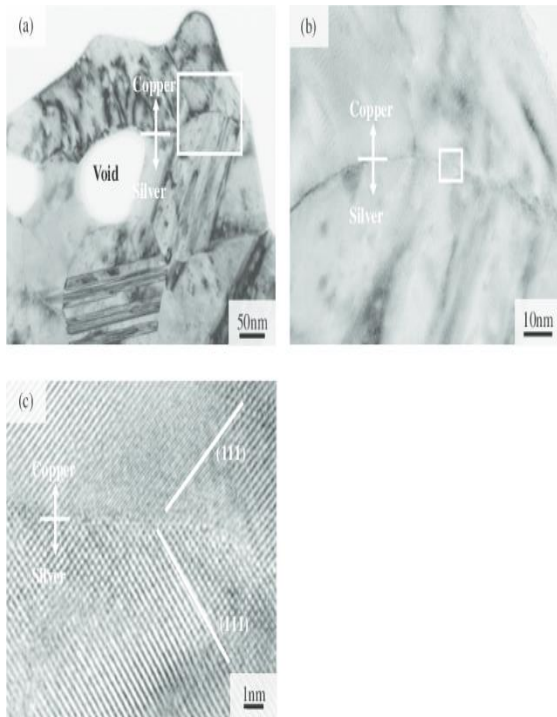


Figure 8: TEM images of silver – copper paste interface bonded at 673 K (Akada et al., 2008)

V. APPLICATIONS IN SOLAR CELLS

- Role of Conductive Pastes in Photovoltaics

Conductive pastes are crucial in photovoltaic (PV) solar cells, as they form the front and rear contacts that collect and transmit electric current. These pastes are applied to the cell's surface and, upon sintering, create highly conductive paths that directly influence the cell's efficiency and overall performance [17]. Traditional silver pastes have dominated the industry due to their excellent conductivity and oxidation resistance, which contribute to high energy collection efficiency. However, the high cost of silver has led to a growing demand for more affordable alternatives [10], [18]–[20].

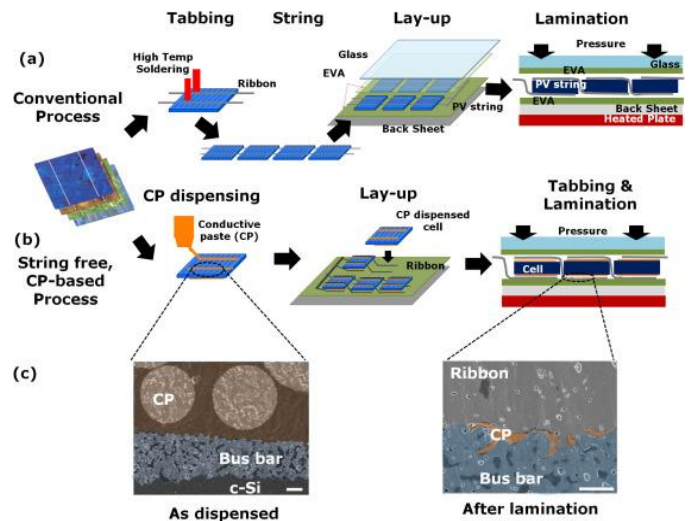


Figure 9: Conductive-paste-based high-yielding interconnection process for c-Si photovoltaic modules with 50 μm thin cells (Hyung et al., 2018)

- Performance Comparison

For the PV applications, the silver coated copper paste has been reported to be an effective alternative to the pure silver paste by providing good performance control at relatively cheaper costs. Studies comparing silver-coated copper paste with traditional silver paste reveal several insights:

- Electrical Efficiency: Silver sintered paste reveals electric conductivity slightly smaller than that of the pure silver paste, ensuring high energy collecting efficiency. Due to this, it can be a drop-in replacement for silver paste, especially in high volume solar cell production [10], [21].

- Cost Efficiency: The incorporation of a copper centre lowers dependency on silver drastically hence lowering material expenses. This reduction make silver coated copper paste very attractive to many PV manufacturers desiring to equally cutting down on production costs while at the same time improving the efficiency [20].

- Durability and Stability: Incorporation of copper particles is protected by a silver coating that affords anti oxidation, which is essential for the balance and stability in the solar cell. Despite the fact that, the pure copper paste tends to oxidize and degrade very fast as compared to other materials, while the Ag layer

works as a shield, provide continuous conduction and efficiency throughout the life cycle of the solar cell [10], [21].

Silver-coated copper paste in this view is economically competitive for PV applications and provide high performance solution at lower material cost. However, the further improvement of paste formulation and the excellent application technology is challenging to maintain the quality and durability.

VI. APPLICATIONS IN SEMICONDUCTOR INDUSTRY

• Use Cases in Semiconductor Devices

In semiconductor production, conductive pastes are widely used in molding of electronics parts such as in the integrated circuits, transistor as well as diodes. These pastes deposit conductive patterns on circuit boards and in the interior of devices for signal conduction. The type of conductive silver pastes remain a traditional type of pastes due to its superior conductivity and heat stability which is crucial for the effective functioning of delicate electronics. However, its high cost due to the use of silver is a major demerit which is especially impactful when the use of paste is high [9], [10], [22].



Figure 10: General scheme for fabricating antioxidant copper paste and screen-printing flexible electronics. (Source: Hong et al., 2022)

• Advantages of Silver-Coated Copper Paste

Silver-coated copper paste presents several advantages in semiconductor applications by combining the benefits of silver's conductivity with the cost-effectiveness of copper:

- **Enhanced Conductivity at Reduced Cost:** Silver plating on copper paste gives conductivity similar to silver paste needed for signal connection and low energy loss in semiconductor circuits [23]. It also means that the use of this paste will be cheaper compared to before reducing dependency on silver making it easier for the manufacturers to manage on the expenses without affecting the quality [10], [20]

- **Thermal Stability:** Thermal stability becomes of essence in semiconductors since the devices produce heat which may affect the performance if the material is not thermally stable. The silver layer on copper gives the needed thermal coefficient of expansion to paste to remain steady and electrically conductive at high temperature regimes characteristic to semiconductor use [9], [24], [25].

- **Oxidation Resistance and Longevity:** The layer of silver plays a role of shield over the layer of copper, so that does not rust and remains conductive during necessary usage. This oxidation resistance is important for semiconductor devices because it helps to increase the overall life of products due to lowered chances of conduction intrusion from corrosion. Copper paste, coated with a layer of silver provides considerably better durability in comparison with pure copper paste, especially when it is used in conditions, which promote oxidation, such as humidity [10], [20].

This material, known as silver-coated copper paste is ideal for manufacturing a variety of semiconductor devices due to the right combination of performance/ cost ratios. Nonetheless, there are certain concerns regarding compatibility with other parts and processes for which this technology could be used – especially as far as adhesion and incorporation into manufacturing pipelines is concerned – so that must be worked on in order to fully benefit from all of the above-mentioned advantages.

VII. CHALLENGES AND LIMITATIONS

• Technical Challenges

Despite the numerous advantages of silver-coated copper paste, several technical challenges must be addressed to facilitate its widespread adoption in industrial applications:

- **Production Scalability:** Large scale production of silver-coated copper paste used in manufacturing requires certain difficulties, such as homogeneity of the coating and equal thickness for a considerable number of items. Evaluations of electroplating and chemical reduction techniques can be challenging for optimization, which affects the repeatability and effectiveness of the materials [10], [20].

- **Cost of Production Equipment:** Electroplating as well as precise chemical reduction which are commonly used in preparation of the silver-coated copper can be rather resource intensive and calls for controlled environmental conditions. These extra expenses can counterbalance some of the conspicuous cost advantages of copper utilization, significantly for producers with minimal money for structure advancement [10], [20].

- **Material Compatibility:** Combining silver-coated copper paste with other components in solar cell and semiconductor devices posed compatibility problems. Issues like delamination or problems with the conductivity of the composite must be considered and controlled with regard to adhesion to different substrates, sintering conditions, and interactions with other materials used in device fabrication [10], [21].

• Environment

While silver-coated copper paste reduces the amount of silver used, there are still environmental implications associated with its production and use:

- **Silver Usage and Environmental Impact:** However, extraction and purification of silver has impacts in terms of environmental impact in terms of energy as well as chemical output. This makes it necessary for researchers to look at other

better ways or methods that reduce even more the uses of silver without compromising its performance [10].

- Disposal and Recycling: The concern on the management of e-waste specializing in the corners that involve conductive paste made from metals such as silver and copper. Safe elimination of these metals into the surroundings must be apparently deem meaningful to check polluting transmission. Furthermore, as the use of these materials increases, so will the need for environmentally sound end-of-use solutions [10], [21].

- Limitations on Industrial Preparation

The shortcomings of industrial preparation are really big issues that inhibit the utilization of silver-coated copper paste. Key issues include:

- Uniform Coating and Quality Control: Another problem with using silver is that to achieve a uniform and homogeneous layer of silver covering all the particles of copper is herculean, especially when working with the mass production. Both, uniformity in coating or non-uniformity in the coating thickness can also influence coating electrical and mechanical characteristics which in turn affects the device performance predictability [9], [10].

- Sintering Process Optimization: The sintering process is important for the materials bonding and conductivity but it is quite challenging to control. Over sintering may result in disappearance of silver in copper circuit and may lower the overall conductivity of the material while on the other hand, under sintering may cause poor sintering between the materials and may also lower the mechanical strength of the material. This need for accuracy is problematic for the industrial manufacturing of CIGS solar cells and may take more analysis to set a standard sintering practice [9], [10].

Solving all these technical and environmental issues is crucial for optimising silver-coated copper paste usage in solar and semiconductors. Further studies into the optimisation of process, selection of appropriate material and adoption of sustainable solutions will go a long way to put this material into industrial use.

- Matters of Crystal Structure

During the coating process, the pyrolytic crystal growth may not be uniform and this results to formation of grain boundaries or dislocations which can hamper conductance and imperishableness.

Sharing the same FCC structure means that total lattice mismatch is slightly low, nevertheless, if the coating process is not well conducted, the interfacial strength is low as is the performance.

VIII. FUTURE DIRECTIONS

Currently, the function development and application of silver-coated copper paste have a promising prospect; however, it is in the space for optimization and creativity. Future research can focus on the following areas to address current limitations and maximize the potential of this material in solar and semiconductor industries:

- Advancement in Coating Techniques: Further research on optimising coating techniques is necessary in order to obtain well-developed, homogenous Ag metallic silver layer on copper particles. To address these issues, further investigation of other approaches in deposition that may have less of an issue regarding thickness and distribution at large scale is suggested, like ALD or better CVD techniques. This could contribute to overcoming the problem of the low scalability of performance while providing a constant level of performance.

- Optimization of Sintering Processes: Taking more attention to unique feature of sintering parameters like temperature, pressure and time the ideal ways and norms of implementing the sintering process could be developed more sharply. Other strategies such as microwave sintering or laser sintering are promising to achieve better control and reduced silver diffusion as well as to get improved bonding strength. New sintering technologies may lead to some reductions in cost of production and achieve enhanced quality [15], [20].

- Exploration of Hybrid and Composite Materials: To decrease the dependency on silver, researchers may possibly look for composite materials containing low ratios of other conductive elements as a part of copper alloy with material like nickel or graphene to increase conductivity and stability. These hybrid materials may be potential candidates of the conductive pastes other than carbon nanotubes especially with specific performance characteristics for specific applications.

- Environmental Sustainability Initiatives: With the increasing need for conductive pastes, issues to do with sourcing the raw materials, the process of production, and the disposal of the products will be of immense importance. Again, more studies into recycling procedures of silver and increasing the use of bio-degradable or recyclable paste formulations can be of benefit in eradicating the effects of this material. Further, if the silver content can be decreased without a drop in efficiency, then the sustainability of such devices could be greatly improved [9], [10].

- Application-Specific Formulation Development: The type of conductive paste used will depend on the specific application is for example the solar cells, semiconductor devices or the other electronics devices.

Some Advantages: Although there are many ways to paste formulation, modifying it for certain applications can boost the effectiveness and reduce the amount of waste. For example, the formulations that are specifically used for essential high-temperature stability can be fit to the semiconductors while the others that are cheap with average stability can be used fit to other applications [15], [20].

The following future directions give direction towards better use of silver coated copper paste towards sustainability, improved efficiency and usability. These gaps define the current issues in enabling the full utilization of this material for advancing the field of solar energy and semiconductors.

CONCLUSION

Incorporating such copper paste in the solar and semiconductor industries can be cost efficient and highly

effective as an alternative to conventional silver pastes. When the aspects of excellent conductivity and oxidation resistance of silver and the cost advantage of copper are both considered, the silver-coated copper paste provides a relatively suitable solution for mass application economy.

From this review, the following facts are main findings: It is evident from this work that it is possible to get a conductivity of coated material equal or almost equal to that of a material coated with pure silver at a considerably inferior cost. Moreover, its composition improves its sturdiness, thanks to the oxidation function, which is vital for stability in photovoltaic and semiconductor systems. But there are still some technical issues that cover the coating non-uniformity, the best sintering regime, and the environmental issue of silver utilization which is identified to be the future research challenges [9], [10].

Nevertheless, given that it can be prepared from copper plates and nitric/sulfuric acids, it holds potential for general use if its industrial preparation may be optimised. Possible future developments involve the development of new coating methods, better sintering conditions, and incorporating hybrid materials and eco-friendly methods to make the silver-coated copper paste industry friendly to implement for the future years [15], [20].

REFERENCES

- [1] American Elements. (2024). Silver Coated Copper Powder. Retrieved from <https://www.americanelements.com/silver-coated-copper-powder-7440-50-8>
- [2] ResearchGate. (2023). Preparation of silver-coated copper powders and its application in conductive adhesives . Retrieved from https://www.researchgate.net/publication/363425058_Preparation_of_silver-coated_copper_powders_and_its_application_in_conductive_adhesives
- [3] SpringerOpen. (2021). Improvement of the thermal stability of dendritic silver-coated copper. *Nano Convergence*. Retrieved from <https://nanoconvergencejournal.springeropen.com/articles/10.1186/s40580-021-00265-8>
- [4] Henkel. (2024). Electrically Conductive Adhesives. Retrieved from <https://www.henkel-adhesives.com/in/en/products/industrial-adhesives/electrically-conductive-adhesives.html>
- [5] Kaken Tech. (2024). What are conductive adhesives (silver paste/conductive glue)? Retrieved from https://www.kakentech.co.jp/english/trouble/conductive_paste/
- [6] Nano Convergence. (2021). Improvement of the thermal stability of dendritic silver-coated copper microparticles by surface modification based on molecular self-assembly . Retrieved from <https://nanoconvergencejournal.springeropen.com/articles/10.1186/s40580-021-00265-8>
- [7] Trumony Techs. (2024). What are the Different Types of Thermal Pastes? Retrieved from <https://www.trumonytechs.com/what-are-the-different-types-of-thermal-pastes/>
- [8] J. S. Nevid et al., "An introduction to the psych package: Part II. Scale construction and psychometrics," *Sci. Educ.*, vol. 1, no. 1, 2011, doi: 10.1017/CBO9781107415324.004
- [9] TaiyangNews. (2023). Silver Coated Copper Pastes For HJT. Retrieved from <https://taiyangnews.info/technology/silver-coated-copper-pastes-for-hjt>
- [10] Hongwu Nano. (2024). Conductive Paste Silver Coated Copper Powder Ag Coated Cu . Retrieved from https://www.hwnanomaterial.com/conductive-paste-silver-coated-copper-powder-ag-coated-cu_p103.html
- [11] Wu, M., Lin, B., Cao, Y., Song, J., Sun, Y., Yang, H., Zhang, X. (2013). Preparation and sintering properties in air of silver-coated copper powders and pastes. *Journal of Materials Science: Materials in Electronics* , 24(12), 4913–4918. <https://doi.org/10.1007/s10854-013-1497-3>
- [12] Hong, S., Liu, C., Hao, S. et al. Antioxidant high-conductivity copper paste for low-cost flexible printed electronics. *npj Flex Electron* 6, 17 (2022). <https://doi.org/10.1038/s41528-022-00151-1>
- [13] Khayati, Gholam & Janghorban, Kamal. (2013). Preparation of nanostructure silver powders by mechanical decomposing and mechanochemical reduction of silver oxide. *Transactions of Nonferrous Metals Society of China*. 23. 1520-1524. 10.1016/S1003-6326(13)62625-4.
- [14] Patents Google. (2023). Process for the production of a silver coated copper powder Retrieved from <https://patents.google.com/patent/US4652465A/en>
- [15] Kim, MI, Choi, EB & Lee, J-H. 2020. Improved sinter-bonding properties of silver-coated copper flake paste in air by the addition of sub-micrometer silver-coated copper particles. *Journal of Materials Research and Technology*. 9(6):16006–16017. doi.org/10.1016/j.jmrt.2020.11.069
- [16] Lee, Sang & Lee, Soo. (2019). Conductive Copper Paste for Crystalline Silicon Solar Cells. 10.5772/intechopen.78604.
- [17] Venkata Krishna Rao. Dr, Rama & K, Venkata Abhinav & Ps, Karthik & Singh, Surya. (2015). Conductive Silver Inks and its Applications in Printed and Flexible Electronics. *RSC Advances*. 5. 77760-77790. 10.1039/C5RA12013F.
- [18] Koga, H, Inui, T, Miyamoto, I, Sekiguchi, T, Nogi, M & Suganuma, K. 2016. A high-sensitivity printed antenna prepared by rapid low-temperature sintering of silver ink. *RSC Advances*. 6(87):84363–84368. doi.org/10.1039/c6ra19687j.
- [19] Maysun Solar. (2024). Photovoltaic Silver Paste: An Innovation for Improving Solar Cell Efficiency . Retrieved from <https://www.maysunsolar.com/blog-photovoltaic-silver-paste-innovation-for-improving-solar-cell-efficiency/>
- [20] KJMM. (2017). Review of Conductive Copper Paste for c-Si Solar Cells . Retrieved from <http://kjmm.org/upload/pdf/KJMM-2017-55-9-637.pdf>
- [21] Joo, Sung-Jun & Park, Sung-Hyeon & Moon, Chang-Jin & Kim, Hak-sung. (2015). A Highly Reliable Copper Nanowire/Nanoparticle Ink Pattern with High Conductivity on Flexible Substrate Prepared via a Flash Light-Sintering Technique. *ACS applied materials & interfaces*. 7. 10.1021/am506765p.
- [22] Panek, P. & Socha, Robert & Putynkowski, Grzegorz & Slaoui, Abdelilah. (2016). The New Copper Composite of Pastes for Si Solar Cells Front Electrode Application. *Energy Procedia*. 92. 962-970. 10.1016/j.egypro.2016.07.108.
- [23] Li, H.; Zhu, X.; Li, Z.; Yang, J.; Lan, H. Preparation of Nano Silver Paste and Applications in Transparent Electrodes via Electric-Field Driven Micro-Scale 3D Printing. *Nanomaterials* 2020, 10, 107. <https://doi.org/10.3390/nano10010107>
- [24] ProPlate. (2024). Silver Plating for Efficient Heat Dissipation in Semiconductor Devices . Retrieved from <https://www.proplate.com/silver-plating-for-efficient-heat-dissipation-in-semiconductor-devices/>
- [25] Hyung-Jun Song, Tae Hee Jung, Soo Min Kim, Woo Gyun Shin, Ga-Eon Jin, Young Chul Ju, Kyung Taek Jeong, Hee-eun Song, Min Gu Kang, Jeong In Lee, Gi Hwan Kang, Conductive-paste-based high-yielding interconnection process for c-Si photovoltaic modules with 50 μm thin cells, *Solar Energy Materials and Solar Cells*, Volume 180, 2018, Pages 148-157, ISSN 0927-0248, <https://doi.org/10.1016/j.solmat.2018.02.032>. (<https://www.sciencedirect.com/science/article/pii/S0927024818300928>)
- [26] Wikipedia contributors. 2024. Electroplating. Available from: <https://en.wikipedia.org/wiki/Electroplating>
- [27] Manikam, VR, Cheong, KY & Razak, KA. 2010. Chemical reduction methods for synthesizing Ag and Al nanoparticles and their respective nanoalloys. *Materials Science and Engineering B*. 176(3):187–203. doi.org/10.1016/j.mseb.2010.11.006
- [28] Cheng, Y-T, Lin, K-L & Lin, C-C. 2023. Preparing Silver–Copper pastes following percolation theory for die attach bonding. *Materials Chemistry and Physics*. 297:127391. doi.org/10.1016/j.matchemphys.2023.127391
- [29] Kim, Nara & Kang, Hongkyu & Lee, Jong - Hoon & Kee, Seyoung & Lee, Seoung Ho & Lee, Kwanghee. (2015). Highly Conductive All-

Plastic Electrodes Fabricated Using a Novel Chemically Controlled Transfer-Printing Method. *Advanced Materials*. 27. 10.1002/adma.201500078.

- [30] Ma, Qian & Ma, Shenghua & Bai, Jintao & Wang, Hui. (2017). Influence of lead-free glass frit in the front contact paste on the conversion efficiency of polycrystalline silicon solar cells. *RSC Adv.* 7. 47500-47506. 10.1039/C7RA07574J.
- [31] Akada, Yusuke & Tatsumi, Hiroaki & Yamaguchi, Takuto & Hirose, Akio & Morita, Toshiaki & Ide, Eiichi. (2008). Interfacial Bonding Mechanism Using Silver Metallo-Organic Nanoparticles to Bulk Metals and Observation of Sintering Behavior. *Materials Transactions - MATER TRANS.* 49. 1537-1545. 10.2320/matertrans.MF200805.

How to cite this article:

Shaikh Sabieh, Longbing He, Aurangzaib Muhammad "Silver-Coated Copper Paste: Properties, Preparation Techniques, and Applications in Solar Cells and Semiconductor Devices" *International Journal of Engineering Works*, Vol. 12, Issue 05, PP. 81-90, May 2025. <https://doi.org/10.34259/ijew.25.12058190>.

