Application Note

Attracting Tomorrow TDK

AN0001 - Requirements and Procedures for Attaching Copper Electrodes to FleClear®, TDK's Ag Transparent Conductive Film

Purpose

This document will provide the reader with instructions for one proven method on how to attach copper electrodes to FleClear® (called Ag film hereafter), a transparent conductive film produced by TDK. Included will be a list of materials, needed equipment and special tools, and a detailed description of all processes. Each material will have a listed supplier and part number provided but equivalents are acceptable as long as there is no impact to mechanical bonding strength or electrical conductivity. It is also well understood that there are alternative methodologies to perform the same process and it is up to the end-user to decide the manner in which the electrode attachment will be performed.

Background

TDK's Ag film is a transparent, electrically conductive film used in a variety of applications. It is an alternative technology to metal mesh screens, ITO films, CNTs, AgNW, PEDOT and other transparent conductive film materials. For Ag film, the electrical conductive material is a silver (Ag) alloy that is deposited, via a sputtering process in the micron level (~3 um), onto a PET carrier tape and then, with the addition of optical correction layers and protective hard coats, a robust, highly flexible transparent film is produced. Figure 1 shows the basic layering of the complete Ag film material. The optional layer, shown in green, is to be peeled off prior to use and is solely to protect the film from scratches, dust, dirt, oils, lint and other small particulates and contaminants during shipment and handling.

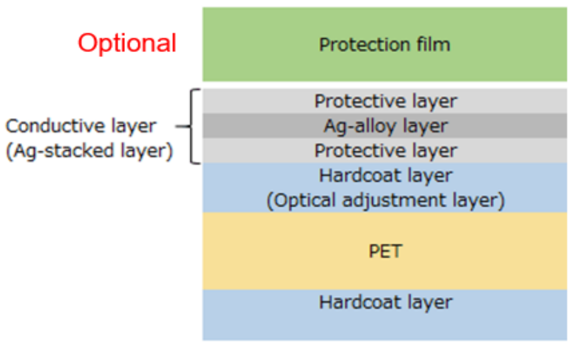

Figure 1 – FleClear® layers and function

In Figure 1, the uppermost light gray shaded layer, labeled "Protective layer" just under the optional removable layer in green, is electrically conductive and is the layer needing to be contacted with by the copper electrode via any acceptable method.

For those not familiar with TDK's Ag film, there are numerous use cases for these materials. Some of the more common ones are:

- Transparent electrodes for "privacy" glass, PDLCs, OLEDs and electrochromic materials
- Transparent antennas applied to or embedded in windows, windshields, goggle lens, etc.
- Blocking of infrared (IR) for smart homes and energy savings, automotive glass shading
- Transparent heating elements for auto glass defrosting, ADAS lens, headlights, security camera lens, etc.
- Transparent EMI screen for displays, monitors, screens
- Transparent electrodes for capacitive touch screens

There is a trade-off between surface resistivity and optical transparency. Each application has its own priorities and therefore, Ag film comes in:

- Two standard nominal surface resistivities (per square) – 4 Ω and 12 Ω
- Two thicknesses – 50 um and 125 um PET substrates
- Two package formats – on a roll or in A4 sized sheets from Digi-Key and Mouser
- Two standard roll widths – 500 mm and 1500mm
- Two standard transmittance levels – ~82% and ~86%

Ag film's material characteristics are provided in Table 1. This table includes electrical, optical and physical properties and values.

Structure	Units	Type "G"	Type "D"
Substrate	[-]	PET	PET
Surface Resistivity	[Ω/☐]	12	4
Total Light Transmittance	[%]	86	82
Haze	[%]	0.5	0.5
Value of b* (CIE Lab, transmission)	[-]	4.0	5.0
Surface roughnes: Ra	[nm]	1.0	1.0
Water Vapor Transmission Rate	[g/m²/day]	1.0×10^{-2}	1.0×10^{-2}
Work Function	[eV]	4.7	4.7

Table 1 – key parameter values of both 4 Ω and 12 Ω FleClear® materials

One of the most frequently asked questions by end-users is how to make electrical contact with the conductive surface of the film with good mechanical adhesion. The following sections will address the steps required to perform this process.

FleClear® Part Numbering

TDK's Ag film material has two different part numbering designations. The first part numbering scheme relates to sample sheets that are available from catalog distributors, e.g. Digi-Key and Mouser, and are A4 sized sheets. A4 sheets are 210 mm x 297 mm (8.268" x 11.693"). The part numbers for the two standard 125 um thick materials are:

- AG-SAMPLESHEET-4
- AG-SAMPLESHEET-12

Where the "-4" and "-12" represent the respective nominal surface resistances in ohms per square (Ω/sq.).

The second part numbering scheme addresses mass production material provided on a roll format. The official part number includes the Ag film's width and length within the roll and thus has numerous possible part numbers. A detailed material roll description is provided for part number AS-G125A2F0500-AD, as an example, and all other material options are listed in Table 2.

Example: AS-G125A2F0500-AD

Character(s)	Designation		
A	Ag film material designator		
S	Previously application information, now fixed		
G	Surface resistance (ohms/sq):		
		D - 4 ohms	**G - 12 ohms**
125	Thickness of PET substrate:		
		050 - 50 um	**125 - 125 um**
A2	Structure and material of Ag-stacked film		
F	Protection film:		
		N - nothing	**F - 50um thickness protection film**
0500	Roll width in millimeters (mm)		
		0500 - 500 mm	**1000 - 1000 mm**
		0750 - 750 mm	**1500 - 1500 mm (maximum)**
A	Presence or absence of slit in the width direction:		
		A - with slit	**B - without 1580mm width slit**
D	Length of roll in meters (M):		
		A - 1,000	**G - 2,000**
		B - 300	**J - 400**
		D - 100	

Table 2 – TDK's Ag film part number construction

In addition to the standard roll lengths and widths, sample rolls are available in 10 M and 20 M lengths and 0.375 M wide rolls have been produced previously.

List of Materials

The recommended method for making electrical contact with TDK's Ag film is by use of a copper (Cu) bus bar or Cu tape. This approach requires electrically conductive adhesive to be used and will be the method exclusively detailed in this Application Note.

Required materials are:

- Sheet of TDK's Ag film cut to size and shape
    - TDK P/N AS-Dxxx or AG-SAMPLESHEET-4 for 4 Ω/square material
    - TDK P/N AS-Gxxx or AG-SAMPLESHEET-12 for 12 Ω/square material
- Isopropyl alcohol, weak acetone or similar cleaning/non-smearing solutions
    - Millipore Sigma, P/N MFCD00011674 or equivalent
- Copper bus bar or tape without adhesive (shown in Figure 2)
    - Aurum C Series copper bus bars or equivalent 10 mm wide and 1 mm thickness maximum
    - 3M™ Copper Foil Tape 1181 or AS ONE 1-9682-01 or equivalent (shown in Figure 2)
- Conductive adhesive
    - Ag Paste: Toyobo, P/N DW-440L-29 or equivalent

Figure 2 – copper bus bars (left), copper foil tape (right)

List of Equipment

- Punch tool or cutter to obtain desired size and shape of Ag film
- Copper electrode alignment tool/jig (optional)
- Controlled light weight press machine (optional)
- Ohmmeter or continuity tester (many suppliers)
- Industrial box oven for adhesive curing (many suppliers)
- Industrial screen printing machine or adhesive dispenser (many suppliers)
- Shear/force gauge
    - Mark-10 Series 2 or equivalent

- Protective gloves for handling

Copper Electrode Attachment Process

The following is a systematic process on how to attach the copper bus bars or tape to TDK's Ag film. While there are many methods of performing this task, the one described here is the recommended approach. The following steps are the key procedures and the required order for attaching the copper electrodes to the Ag film and creating robust conductive terminations:

1) Cut or punch out Ag film from roll or sheet to required size and shape
2) Clean Ag film sheet to remove dirt, grime, oils and other contaminants
3) Apply layer of conductive adhesive in a controlled uniform layer via screen printing process
4) Cure Ag film with the applied adhesive in oven
5) Cut Cu bus bar/tape to desired length and width
6) Clean Cu electrode with approved cleaning solution
7) Attach Cu electrode to cured conductive adhesive
8) Perform electrical test to ensure adequate contact
9) Perform mechanical shear test (optional) to ensure adequate adhesion
10) Store sheets in secured, enclosed, dust-free environment until ready for use

Step 1: Whether the Ag film is obtained on a roll or in A4 sheet size, the material will need to be cut or punched to the required configuration. The first step is to have a hard tool made to perform this task if the quantity of Cu electrode attachments will be large. It will be a time consuming manual process if done with scissors or some other cutting tool. If the attachment is to be for testing of limited samples, then hand-cutting operations would be satisfactory.

Step 2: While performing the cutting/punching process, the hand operation typically leads to physical touching of the film by the operator's hands and thus leaving oils and other contaminants on the Ag film's conductive surface. These contaminants can be removed by use of isopropyl alcohol or some other weak acetone cleaning solution and allowed to dry in a dust/lint free area. The use of protective gloves is suggested for this step.

Step 3: After the Ag film has been cleaned, the next process is to apply the conductive adhesive to the conductive side of the Ag film. The key point for this step is to make sure the copper electrode makes electrical contact with the conductive side of the Ag film. For material on rolls, the inner side is the conductive surface. The more difficult identification is for the A4 size sample sheets. In this case, there is a corner cut out to help the user identify the conductive side. The identifiers for both are shown in Figure 3. The conductive adhesive, with TDK's recommendation being Toyobo, P/N DW-440L-29 or equivalent, is recommended to be applied with a screen printing process to ensure that a thin, uniform, and continuous layer is created. If a spray adhesive is used, a template will be required to ensure that the adhesive is only applied where desired on the Ag film. If a dispenser is used, then the applied bead will need to be converted into a thin layer. For best results, an adhesive layer of around 10 mm wide and 10-30 um thick should be applied. The length will be dictated by the sheet size. This step is shown in Figure 4. As in Step 2, protective gloves are recommended during this step.

Step 4: Once the adhesive has been applied to the Ag film, it needs to go through a curing process. This can be performed using any industrial type oven. The required curing conditions for Toyobo, P/N DW-440L-29 are:

- Temperature: 120°C
- Duration: 15 minutes

Each specific adhesive will have its own requirements for curing and therefore, it is recommended to follow the respective supplier's guidelines for each particular adhesive.

Step 5: The next process is to cut the copper bus bar or tape electrodes to the required length while the adhesive is curing. This can be done by use of a saw or a wire cutter but all sharp edges, burrs and non-planar surfaces need to be remove and/or corrected.

Step 6: After the electrode cutting and needed physical modifications have been completed, it is recommended to clean both copper bus bar or tape sides if no conductive adhesive is on either side. Again, like with the Ag film cleaning process, use of isopropyl alcohol or similar cleaning solution is suggested as well as the use of protective gloves. If there is already a conductive adhesive layer present, when using copper foil tape, then only clean the non-adhesive side.

Step 7: Once the adhesive has cured, and the Ag film sheets have been removed from the oven, the copper electrodes need to be attached. Allow at least 5 minutes for the Ag film to cool down. If the quantity of electrode attachments is low, then a careful hand-eye coordinated process can align the copper electrode to the cured adhesive on the Ag film. However if the quantity of attachments is high, indicative of mass production, it is suggested to create an alignment jig to assist in the accuracy and speed of the electrode attachment process. A manual operation is shown in Figure 5. Here, again, protective gloves are recommended.

One other consideration is to apply minimal uniform pressure to the electrode after it is attached to the Ag film sheet. This is not required but can be performed to ensure complete contact over the length of the copper electrode and to make sure a co-planar electrode attachment is achieved. Maximum pressure would be 2-3 newtons (N) to ensure flatness.

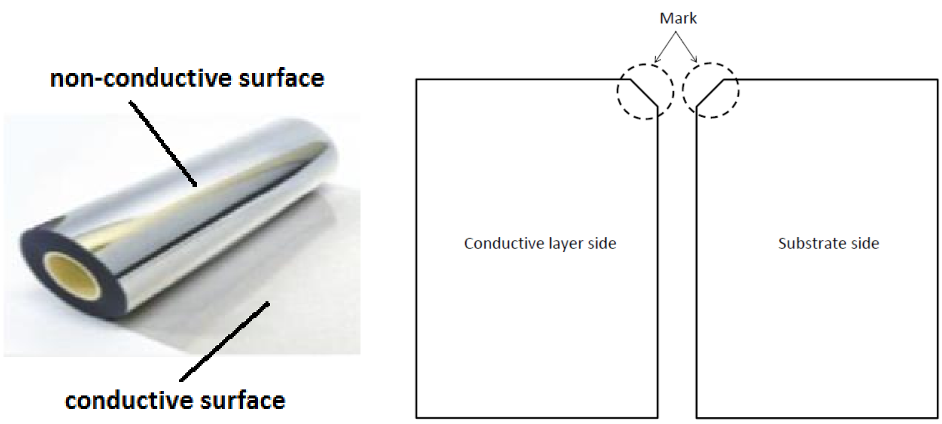

Figure 3 – conductive surface designations: roll (left), A4 sample sheet (right)

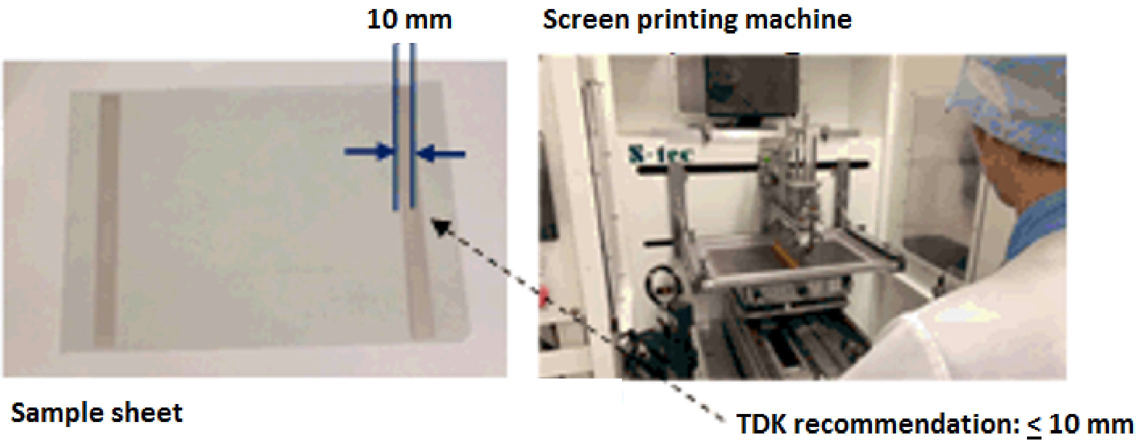

Figure 4 – application of electrically conductive adhesive

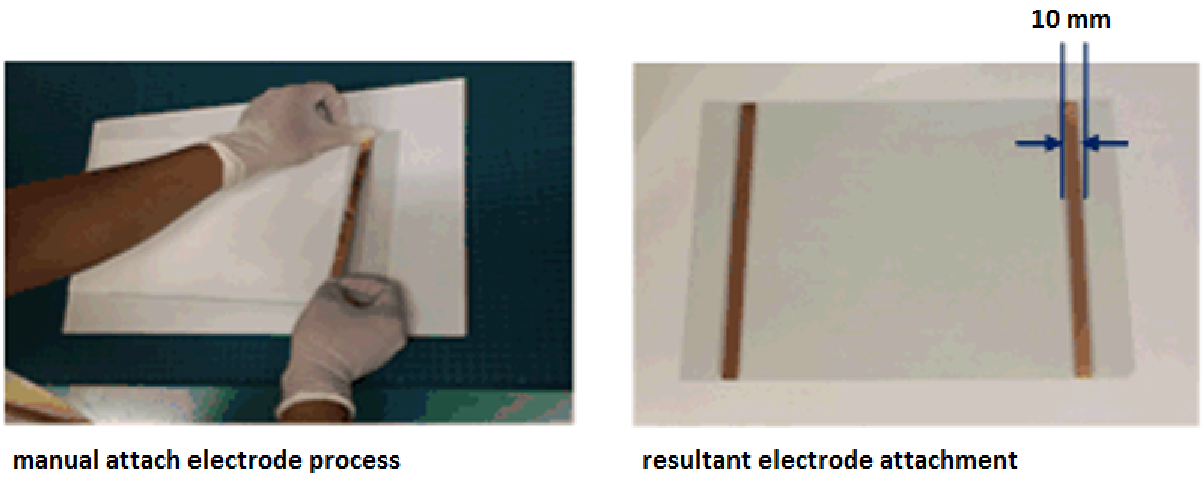

Figure 5 – Cu electrode attachment process (left), Ag film with attached Cu electrodes (right)

Step 8: Copper electrode attachment and subsequent contact with the conductive layer of the Ag film can be confirmed by performing a simple continuity check. We know that the surface resistance is given as ohms per square. The term “square” is an open-ended dimension, meaning that if one measures the resistance for a 1 inch by 1-inch sample, the 4 Ω/sq. material will yield 4 ohms. The same would be true if the measurement size was 10 inches by 10 inches.

Therefore, the continuity can be easily measured by using an ohmmeter (provides a resistance value) or continuity checker (beeps to indicate electrical contact). If there is a copper electrode attached to both ends of the Ag film sheet, the ohmmeter probes can be contacted to each electrode and the expected measured resistance will be:

$$R_M = R_S \times (L/W) \qquad \text{Equation 1}$$

Where:

R_M = measured resistance (Ω)

R_S – nominal surface resistance (Ω /sq)

L = length of sheet

W – width of sheet

As an example, the configuration shown in Figure 6, has two copper bus bars adhered to a 12 Ω/sq. sheet. The length is 8" while the width is 4" and by using Equation 1 above, the expected measured resistance would be 24 ohms.

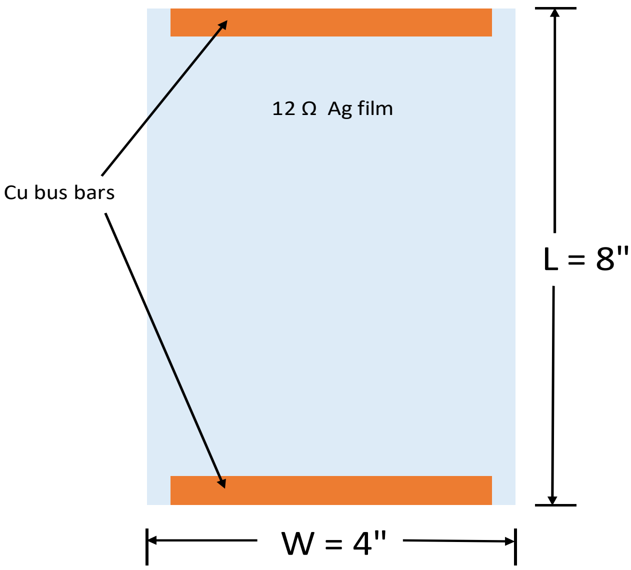

Figure 6 – continuity check example

In the event that only one copper bus bar is attached directly to the Ag film sheet, then a "dummy" electrode will need to be utilized. This can be achieved by sandwiching and compressing (to ensure good electrical contact) the non-terminated end of the Ag film sheet between two rigid planar objects with one being conductive and contacting the conductive side of the Ag film sheet. Best practices would have the conductive dummy electrode being the same width as the Ag film sheet. A good approach would be to use a non-attached copper bus bar or tape equal to the one already attached on the other end. Additionally, it is imperative that neither of the compressing objects have rough surfaces and must be co-planar to ensure optimum surface contact.

Step 9: If the bonding strength of the adhesive to both the Ag film and to the copper electrode needs to be ensured, it is recommended to verify the adhesive, the curing process, the attachment process and the size and shape of the copper electrodes used. To do this, a strain/force gauge can be used and provide a force value in newtons (N) or pound-force (lbf in English units). This test may only be required to be performed one time as a proof of concept validation test, on a lot-by-lot basis or not at all if the electrode attachment is only for testing purposes and not intended for the end application.

Step 10: Once all needed testing is completed, it is recommended that the Ag film sheets be stored in a protective and clean area until use. Additionally, the film may still require additional clearing due to contact with hands and other surfaces that may introduce contaminants.

Conclusion

As shown in this Application Note, the process of attaching copper electrodes to TDK's FleClear® transparent conductive Ag film is straightforward but there are many ways to perform this operation. This paper addresses the preferred methodology of TDK's thin film group. It also highlights areas that need to have cleanliness as a key consideration as oils, dirt, lint and other contaminants can have an impact not only of the optical properties, but also on the strength and resistivity of the bond to both the Ag film and the copper electrode.

The end user will need to determine their preferred method of making electrical contact to the attached copper electrodes. Whether this is soldering of wires, pogo pins, spring contacts, etc., the method will depend on their preference and the end product needs.

Glossary of Terms

3M™ – #M Corporation, supplier of copper foil tape

ADAS – Advance driver assistance system

Ag – silver

AgNW – silver nano-wire

Aurum – Aurum Alloys & Engineering, supplier of copper bus bars

CNTs – carbon nanotubes

Cu – copper

Digi-Key – Digi-Key Electronics

Electrochromic materials – materials that exhibit color and optical changes in an electrical field (E)

EMI – electromagnetic interference

FleClear® - is a registered trade mark product name of TDK Corporation

ITO – indium tin oxide, an optically transparent conductive thin film technology

LBF – pound-force in English units

Mark-10 – Mark-10 Corporation, maker of force gauges and meters

Metal mesh screen – "window screen" thin metal layers that have openings for optical performance

mm – millimeters

Mouser – Mouser Electronics

Newton (N) – force unit in metric system, 1 newton = 0.224808943 pounds-force (lbf)

OLEDs – organic light emitting diodes

PDLC – polymer dispersed liquid crystal

PEDOT - conductive polythiophene materials

PET - Polyethylene terephthalate, a thermoplastic polymer resin material

TDK – Tokyo based electronic component and material manufacturer of FleClear®

um – micrometers

Related Link and Contact

TDK Product Center

https://product.tdk.com/en/techlibrary/developing/agstack/index.html