International Journal of Engineering

Journal Homepage: www.ije.ir

New Application of Electrically Conductive Adhesive as a Transistor-based Electrical Circuit under AC and DC Currents

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PAPER INFO

Paper history:
Received 18 April 2021
Received in revised form 28 May 2021
Accepted 03 July 2021

Keywords:
Conductive Adhesive
Silver-coated Copper Filler
Transistor Circuit
Electrical Resistivity

ABSTRACT

Electrically conductive composite adhesives containing 70, 75 and 85 wt% of filler particles (Cu@Ag) and polymer matrix were prepared. Thermal stability and morphology of the prepared adhesives were examined using TG (Thermo-Gravimetry), DSC (Differential Scanning Calorimetry), and SEM (Scanning Electron Microscope) techniques. In the next step, a transistor-based electrical circuit using self-biased common-emitter combination was made from the prepared conductive adhesive as well as a copper board. All of the prepared boards were subjected to DC (8-30 V) and AC (1 kHz) currents to evaluate their performance. For these circuits, parameters such as transistor operating points and the voltage gain of the amplifier, were measured. TG and DSC analyses showed that increasing the filler amount from 70 to 85 wt%, reduces the weight loss of the adhesive from 15.48 to 11.35 wt%. Also, effect of increasing the silver amount in Cu@Ag particles on the thermal stability of adhesives at temperatures below 350 °C showed that by increasing of the amount of silver from 20 to 40 wt%, has a negligible effect on weight change (about 2 wt% at 250 °C). Both samples showed almost the same overall weight loss at 350 °C. Evaluation of circuit performance showed that the changes in circuit width (1, 1.5, and 2 mm) has no significant effect on the V–I characteristics and voltage gain. The value of these two parameters for all three circuits and also the copper board circuit were the same which indicates the high conductivity of the prepared conductive adhesive.

***doi**: 10.5829/ije.2021.34.08b.02*

NOMENCLATURE

V_{CC}	Supply voltage	Ic	Collector-emitter current (operating point current)
V_B	Base pin voltage	V_{RC}	Dropped voltage across Rc
V_E	Emitter pin voltage	V_{CE}	Collector-emitter voltage (operating point voltage)

1. INTRODUCTION

One of the outcomes of rapid growth of technology is the short lifetime of electronic devices and consequently, generating avalanche of electronic scraps. These electronic scraps contain large amounts of lead due to the lead-containing materials (lead-tin solders) in them. Lead in these scraps can be released into the environment if stored improperly. Lead is a toxic metal and can cause irreparable damage on the environment and living creatures. For this reason, the use of lead-containing solders has been severely banned in many European countries, and especially in Japan. Electrically conductive adhesive is a suitable alternative to lead-based solders. The adhesive composed the components of a polymer matrix, conductive filler, curing agent, catalyst, and additives. Performance of a conductive adhesive depends on the amount, type of filler and polymer matrix. Due to the variety of components mentioned, there are many different types of conductive adhesives [1-3]. Electrically conductive adhesives can be used in a variety of electronic equipments. Some of these adhesives are designed only for the specific applications, while others have more general applications. For example, high temperature thermal stability is not very important for ordinary computers, but it is very critical

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Please cite this article as: Z. Sahebi Hamrah, M. H. Doost Mohammadi, M. Pourabdoli, V. A. Lashgari, New Application of Electrically Conductive Adhesive as a Transistor-based Electrical Circuit under AC and DC Currents, International Journal of Engineering, Transactions B: Applications, Vol. 34, No. 08, (2021) 1819-1826

for avionics, sensors, and car engine electronics. Adhesives are divided into isotropic and anisotropic conductive adhesives. Isotropic conductive adhesives are used in electronic packaging, circuits and electronic devices. applications of anisotropic conductive adhesives include flat panel displays, fine pitch interconnection, highly reliable flip chip assemblies, high frequency inter-connection, high current density inter-connection and wafer level packages [4-6]. Various aspects of type, preparation, and characterization of electrically conductive adhesive such as effect of silver content on shear mechanical properties [7], using recycled resources for development of electrically conductive adhesives [8], effect of graphene filler structure on electrically conductive adhesive [9], properties of graphene based epoxy adhesive [10], DTT functionalization of Ag particles for conducting adhesive [11], adhesives prepared from epoxy and silver-coated copper particles [12], adhesives prepared from mixture of silver nanowires and nano-silver-coatd copper [13], novel electrically conductive epoxy/reduced graphite oxide/silica hollow microspheres adhesive [14], silver nanostructures for high-performance composite conductive adhesive [15], stretchable conductive adhesives [16], silver coated nano-graphite filled conductive adhesive [17], and conductive adhesive prepared with silver coated graphite nano-sheets [18] have been studied. An important category of electronic circuits is amplifier circuits whose main task is to amplify the amplitude of the input signals and convert them into larger signals. Amplifier circuits can exhibit specific AC performance under DC operating conditions. Therefore, using these amplifying circuits, the performance of DC and AC can be simultaneously evaluated. One of the basic transistor-based amplifier circuits is the self-biased common-emitter circuit that is capable of amplifying both the voltage and the current signals [19]. Transistor is sensitive to its operating point (DC parameters), that is an important point in using transistor-based amplifiers. If its operating point changes, its amplification parameters will also change. Therefore, it can be said that they are sensitive to environmental factors. This type of circuit to evaluate the performance of conductive adhesives can be very valuable because performance of this circuit is very sensitive to environmental parameters. Therefore, the difference in the performance of conductive adhesive in comparison with copper wire can be evaluated. On the other hand, if the performance of the conductive adhesive is acceptable, it can greatly help electronic circuit designers in terms of prototype design and fabrication speed. Also, using conductive adhesives instead of printed circuit boards (PCBs) results in achieving prototypes of many circuits and systems with lower fabrication costs, higher production rates and improved flexibility.

In the present study, an electrically conductive adhesive was made using epoxy resin and Cu@Ag particles as a polymer matrix and a conductive filler, respectively. Then it was practically used to build an emitter-joint circuit. The innovation of current research is the practical use of electrically conductive adhesive to make a self-biased common-emitter amplifier circuit and evaluating its performance with respect to the similar circuit made on a copper board.

2. MATERIALS AND MEHTODS

2. 1. Raw Materials and Method of Preparing Conductive Adhesive All chemicals were of analytical grade and used as received without any further purification. To prepare the conductive adhesive, Cu@Ag particles (< 30 µm) were washed with the alkaline solution (mixture of 0.5 M ammonium sulfate and 1 M sodium hydroxide solutions) for 2 minutes to remove possible surface impurities. Then, 1.4 wt% stearic acid was dissolved in ethanol and added to the filler and placed in an oven at 50 °C until its ethanol completely evaporated. Subsequently, the epoxy resin (Epoxiran 8126 equivalent to Epon 826) with ethanol (0.5 ml per 1 g of adhesive) was added to the filler particles and thoroughly mixed to obtain an almost homogeneous mixture. After this step, the resulting material was placed in an oven at 80 °C for complete ethanol removal from the resin. Then, a hardener (curing agent:3895 epoxiran equivalent to LS-81K) was added to the resin and mixed. The prepared conductive adhesive was cured in an oven at 77 °C for 30 minutes [2]. Table 1 summarizes the specifications of the prepared adhesives. To study the structure and morphology of adhesives, JEOL JSM-840A Scanning Electron Microscope (SEM) was employed.

2. 2. Thermal Stability of Conductive Adhesives The thermal stability of conductive adhesives was studied using Thermo-Gravimetry (TG) and Differential Scanning Calorimetry (DSC) analyses with TA Instruments model SDT Q600 in the temperature range

TABLE 1. Specification of prepared adhesives

Code	Filler wt%	Ag in filler wt%	Epoxy wt%	Curing agent wt%
CA7520	75	20	15.7	7.9
CA7530	75	30	15.7	7.9
CA7540	75	40	15.7	7.9
CA7030	70	30	19.1	9.5
CA8530	85	30	9.1	4.5

of 25-350 °C and heating rate of 10 °C/min in laboratory air atmosphere.

2. 3. Performance of Conductive Adhesive as a Transistor Circuit under AC and DC Currents

To study the practical application of prepared adhesives, a circuit according to Figure 1 was assembled from CA7530 adhesive in three different widths of 1, 1.5, and 2 mm and with the same thickness of 0.5 mm. Then, the performance of the prepared circuits was evaluated under DC and AC currents. For this purpose, a circuit was used that is capable of evaluating the AC and DC parameters. This is important since the adverse environmental parameters, commonly referred to as ambient noise, have different effects on the AC and DC parameters of the electrical circuits. Also, due to the different nature of the AC and DC parameters, the conductive adhesive might have been appropriate for one parameter and inappropriate for another. Since the main application of this adhesive is in the electrical and electronic industries, its performance in all possible situations and under real environmental conditions should be considered. The used circuit was a single-stage transistor-based electronic circuit and a bipolar junction transistor (BJT). With 3 terminals assigned to a BJT, it becomes possible to configure these devices in 3 unique ways in a circuit depending on the application requirement. These configurations are called common-emitter (C.E.), common-base (C.B) and common-collector (C.C.) configurations. The main characteristics of a BJT in the three configurations (single stage) are given in Table 2.

The common emitter amplifier construction delivers the very best current and power gain among the 3 bipolar transistor designs which is, therefore, the widely used type [19, 20]. It should be noted that there are much more powerful multi-stage amplifiers (Darlington, Cascade, Differential, Power, etc.) which are also designed and built based on these three single-stage configurations. For this reason, one of these three basic configurations (BJT-based) is used in this work [21-23]. So, the used circuit was a single-stage BJT-based circuit known as the self-biased Common Emitter Amplifier. This circuit can amplify the input signal (AC parameter) based on a specific operating point (DC parameter). A practical pre-designed circuit was used in this study because the aim was the performance test of the prepared conductive adhesive. To observe and measure the input and output parameters of the circuit, a digital multimeter GW Instek model GDM-8145 and an oscilloscope GW Instek model GOS-653G were used. Furthermore, a DC power supply (Azma Electronic model JPS-303D) and an AC signal source (GW Instek model SFG-1013) were employed to supply direct and alternating currents, respectively. As shown in Figure 1, this circuit consists of an NPN transistor (with the part number 2SC945), a 10 kΩ resistance attached to the collector pin, a 1 kΩ resistance attached to the emitter pin, and two resistances, namely 10 kΩ and 1 kΩ attached to the base. A DC power supply is used to create the desired operating point of the transistor. The adhesive performance was evaluated by applying a variable DC voltage of 8 to 30 V to the circuit as a power supply. Since this is a DC test, the most important parameters to consider are the collector current (I_C) and the collector-emitter voltage (V_{CE}), which indicate the operating area of the transistor (Active linear, Saturation, Cut off). The calculation of these two parameters is based on Equations (1) to (3) [19]. Writing Kirchhoff's voltage equation in the clockwise direction for the input loop, we obtain:

$$V_B = \frac{R_1}{R_1+R_2} \times V_{CC} \tag{1}$$

$$V_B - (R_1 \parallel R_2) \times I_B - V_{BE} - R_E I_E = 0 \tag{2}$$

$$I_B = \frac{I_E}{(1+\beta)} \tag{3}$$

where I_E is the collector current, V_{BE} is the base-emitter voltage with a practical value of 0.62 V, and the β is *common-emitter*, *forward-current*, *amplification factor*, since the collector current is usually the output current for the CE configuration and the base current is the input current. For practical devices, the level of b typically ranges from about 50 to over 400, with the most in the midrange. This parameter can be determined at a particular operating point on the BJT characteristics [19]. The practical value of the β was 270 for 2SC945 transistor at room temperature.

Substituting for I_B in Equation (2) result in:

$$V_B - \frac{(R_1 \parallel R_2)}{(1+\beta)} I_E - V_{BE} - R_E I_E = 0 \tag{4}$$

Grouping terms then provides the following:

$$V_B - V_{BE} - \left[\frac{(R_1 \parallel R_2)}{(1+\beta)} + R_E\right] \times I_E = 0 \tag{5}$$

and solving for I_E gives:

$$I_E = \frac{V_B - V_{BE}}{R_E + \frac{(R_1 \parallel R_2)}{(1+\beta)}} \tag{6}$$

if β times the value R_E is at least 10 times the value of R_2, the approximate approach can be applied with a high degree of accuracy. Once V_B is determined, the I_E can be calculated from Equation (7):

TABLE 2. Transistor Configuration Summary

BJT Configurations	C.E (bypassed/un-bypassed)	C.B	C.C
Voltage Gain	High/Medium	High	Low
Current Gain	High	Low	High
Power Gain	High	Low	Medium
Input Resistance	Medium/High	Low	High
Output Resistance	Medium	High	Low

$$I_E \cong \frac{V_B - V_{BE}}{R_E} \tag{7}$$

The collector-to-emitter voltage is determined by Equation (8) as follow:

$$V_{CE} = V_{CC} - (R_C + R_E)I_C \tag{8}$$

where I_C is the collector current, V_{CE} is the collector to emitter voltage [19]. The obtained results of these parameters using the variable power supply (from 8 to 30 V) for the circuit's root width of 1, 1.5, and 2 mm were recorded. The reference circuit for checking the operation of these circuits was the same circuit implemented on a copper board. The results of the copper board implemented circuit are presented in Table 4. The active linear is the main area of transistor performance evaluation. Therefore, according to the combination of circuit resistors in Figure 1, the minimum supply voltage required to set the transistor within the active linear area was 8 V. Hence, the circuit test started using 8 V as the initial voltage.

The second step in the evaluation of the conductive adhesive performance was to figure out the AC performance of the circuit. To achieve this goal, the signal generator was connected to the transistor's base pin using a capacitive connection. The use of capacitors is to prevent any undesired change of the DC operating point after applying the AC input. The AC output of this circuit is the collector pin, which is shown in Figure 2.

Using the hybrid equivalent circuit of the BJT, the ratio of the output to the input signals of this circuit known as the voltage gain factor, is obtained from Equation (9) [19].

$$A_v = \frac{-h_{fe}R_C}{h_{ie} + (1 + h_{fe})R_E} \tag{9}$$

where h_{fe} is the AC form of the β and it can be referred to as β_{ac}, and h_{ie} is the input resistance of the hybrid equivalent circuit of the BJT. The value of h_{fe} has ranged

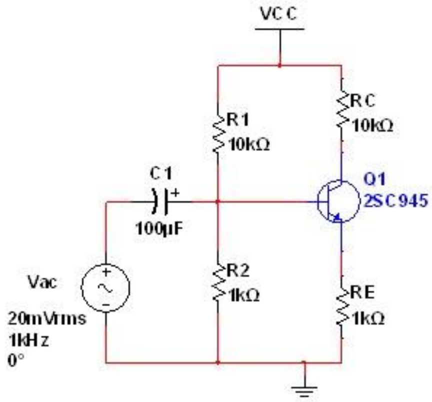

Figure 2. Schematic of the common–emitter amplifier circuit used to evaluate the AC performance of CA7530 adhesive

from about 50 to over 400. The practical value of the h_{fe} was 270 for 2SC945 transistor at room temperature. The value of h_{ie} is calculated using Equation (10) [19].

$$h_{ie} = \frac{\eta V_T \beta}{I_C} \tag{10}$$

where η is an internal value of BJT (1.05 at this work), and the V_T is the thermal voltage with the value of about 26mV at room temperature. Equation (11) can be used to calculate the voltage gain factor from an oscilloscope using observed signals.

$$A_V = \frac{v_O}{v_i} = \frac{peak\text{−}peak\ of\ the\ output\ voltage\ signal}{peak\text{−}peak\ of\ the\ input\ voltage\ signal} \tag{11}$$

A real illustration of a circuit made with conductive adhesive, the devices used, and the components connected to the circuit are shown in Figure 3.

The input and output signals of the three circuits based on conductive adhesive and the reference circuit are shown in Figure 4. As shown in Figure 4, the voltage gain can be obtained from the amplitude of the input and

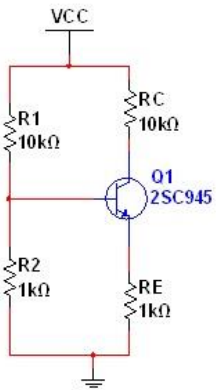

Figure 1. Schematic of the self–biased common-emitter circuit used for the DC performance test of CA7530 adhesive

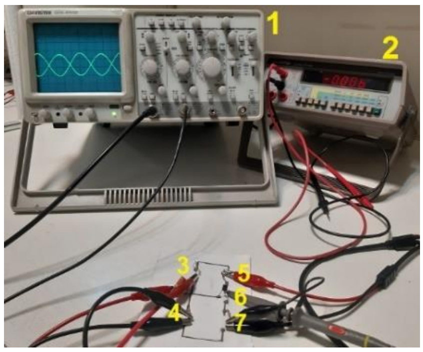

Figure 3. Implemented circuit with CA7530 adhesive and equipments used to assess its performance. 1-Oscilloscope, 2-Multimeter, 3- Oscilloscope channel 1, 4- Input from signal generator, 5-Positive terminal of Vcc, 6-Oscilloscopre Channel 2, 7-Negative terminal of Vcc

output voltage signals. To this end, the amplitude of each signal was measured based on the cells and sub-cells of the screen and then multiplied by the value indicated by the voltage divider volume (volt \ div). The values of this volume are shown in Figure 4 (a-d) with green arrows. In all pictures of Figure 4, channel 1 and 2 represents the input and output signals, respectively. Comparing the pictures of Figure 4 shows that the amplitude of the input and output voltage signals are very close to each other. This is while the ratio of the volume volt \ div of channel 2 (output) to the volume volt \ div of channel 1 (input) is 10. This means that the voltage gain is approximately 10. It should be noted that the difference in the amplitude of the signals in pictures Figure 4 (a to d) is due to the different inputs applied to each of the four different circuits. The exact amount of voltage gain can be calculated with the stated method (Equation (11)). These values are given in Table 3.

3. RESULTS AND DISCUSSION

3. 1. Morphology of Conductive Adhesives

Figure 5 illustrates SEM images of the cross-section of CA7520, CA7530 and CA7540 adhesives. In these images, Cu@Ag particles have surrounded by black epoxy phase. As can be seen, with increasing silver amount from 20 to 30 and 40 wt%, the average thickness of silver coating around copper particles increases. Consequently, electrical resistivity of the adhesive is reduced due to the decrease in contact resistance between particles [24].

3. 2. Thermal Stability of Adhesives

Figures 6 and 7 show the TG/DSC results of conductive adhesives. According to the TG curves in Figure 6, which indicate

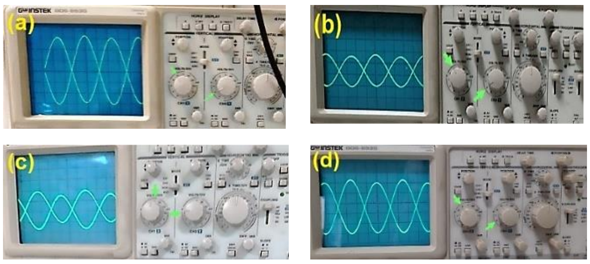

Figure 4. Oscilloscope graphs obtained after connecting circuits made of (a) copper board and CA7530 adhesive with a thickness of 0.5 mm and a width of (b) 1 mm, (c) 1.5 mm and (d) 2 mm under AC current

TABLE 3. Voltage gain of various circuits

Circuit type	Copper board	1 mm	1.5 mm	2 mm
Voltage gain	9.5	9.6	9.7	9.4

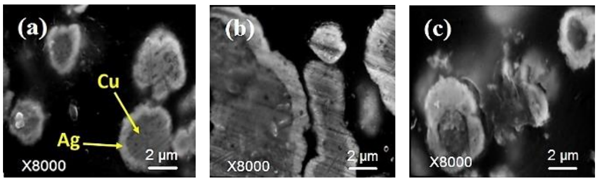

Figure 5. SEM images of conductive adhesives: a) CA7520, b) CA7530, c) CA7540

the effect of filler amount on the thermal stability of the conductive adhesive, temperature rising has reduced weight of both samples. The corresponding weigth loss of CA7030 sample (15.48 wt%) is more than that of CA8530 sample (11.35 wt%) at 350 ºC. Reason is that the CA7030 sample has more epoxy that decomposes with temperature rising. Two exothermic peaks at 210 and 330 °C are clearly evident in DSC curves of Figure 6. The first peak is related to residual cure and the second peak is related to the epoxy degredation [25].

According to TG curves in Figure 7, it is evident that the CA7540 sample (40 wt% Ag) showed greater thermal stability than CA7520 sample (20 wt% Ag. Therefore, increasing the silver amount from 20 to 40% improves the thermal stability of the conductive adhesives.

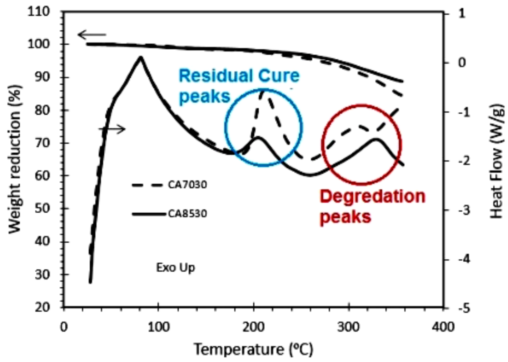

Figure 6. TG and DSC curves of CA7030 and CA8530 conductive adhesives

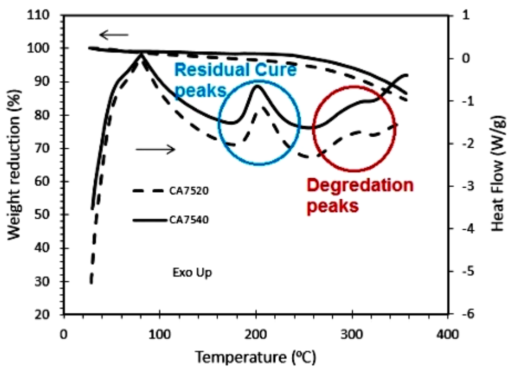

Figure 7. TG and DSC curves of CA7520 and CA7540 conductive adhesives

According to the DSC curves in Figure 7, it is clear that the samples have almost the same behavior in terms of exothermic peak position and area (calorific value). The reason for the similar behavior of the samples is that both samples have the same amount of epoxy/filler and the same amount of Cu@Ag particles.

3. 3. Performance of the Conductive Adhesive as a Transistor Circuit under DC and AC Currents

3. 3. 1. DC Current The performance results of the circuits with copper board and CA7530 adhesive with a width of 1, 1.5, and 2 mm (Figure 1) for CA7530 dhesive under DC supply are listed in Tables 4-7 and plotted in Figures 8a-8d, respectively. As can be seen, as the supply voltage increases, the current (Ic) increases, and all three curves follow a linear pattern with almost similar positive slopes. This observation indicates the similar V-I characteristic of the circuits according to Ohm's law (V = RI). This means that changing the width of the circuits has no significant impact on the obtained results. Comparing Figure 8a with Figures 8b-8d showed that the same results were obtained from circuits made of conductive adhesives. As a result, it can be said that the performance of these adhesives is the same as that of the copper board.

3. 3. 2. AC Current AC sinusoidal signal was used as the input voltage signal to calculate the voltage gain. Since the high amplitude of the input signal may lead to output signal distortion, then the amplitude of the input signal is set within the range of 1 mV to 100 mV. Voltage gain was calculated using Equations (4) and (5). The voltage gain for all three circuits prepared from adhesive was approximately the same as 9.5. Consequently, the circuit width did not affect the voltage gain significantly. Then, to compare the circuit made of conductive adhesives with the copper board, the voltage gain from the graph in Figure 4a was recalculated for the copper board and the same results were obtained.

TABLE 4. Circuit Data related to the copper board

V_{CC}(V)	10	20	30
V_B(V)	0.888	1.776	2.283
V_E(V)	0.288	1.143	2.041
Ic (mA)	0.292	1.159	2.070
V_{RC}(V)	3.011	11.667	20.74
V_{CE}(V)	6.725	7.120	7.220

TABLE 5. Circuit data for a width of 1 mm

V_{CC}(V)	8	10	15	20	25	30
V_B(V)	0.709	0.892	1.334	1.774	2.220	2.666
V_E(V)	0.126	0.329	0.701	1.208	1.654	2.103
Ic (mA)	0.127	0.334	0.711	1.225	1.677	2.133
V_{RC}(V)	1.646	3.353	7.893	12.263	16.789	21.35
V_{CE}(V)	6.161	6.350	6.382	6.480	6.146	6.568

TABLE 6. Circuit data for a width of 1.5 mm

V_{CC}(V)	8	10	15	20	25	30
V_B(V)	0.720	0.896	1.334	1.768	2.235	2.268
V_E(V)	0.122	0.305	0.697	1.129	1.567	1.989
Ic (mA)	0.124	0.309	0.707	1.145	1.589	2.017
V_{RC}(V)	1.398	2.960	7.064	11.442	15855	20.029
V_{CE}(V)	6.537	6.750	7.040	7.214	7.445	7.572

TABLE 7. Circuit data for a width of 2 mm

V_{CC}(V)	8	10	15	20	25	30
V_B(V)	0.634	0.904	1.345	1.795	2.249	2.695
V_E(V)	0.078	0.301	0.721	1.159	1.602	2.043
Ic (mA)	0.079	0.305	0.731	1.175	1.625	2.072
V_{RC}(V)	0.749	3.032	7.283	11.695	16.165	20.61
V_{CE}(V)	6.247	6.730	7.020	7.168	7.268	7.350

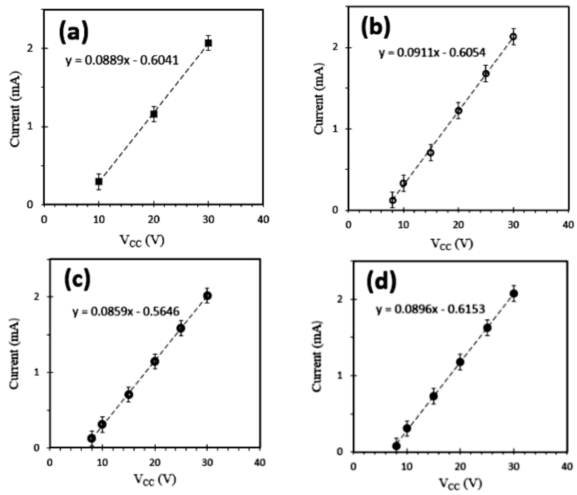

Figure 8. The V–I characteristic of the implemented circuits (Operating frequency of 1 kHz). a) copper board, b) CA7530 adhesive with a thickness of 1 mm, c) CA7530 adhesive with a thickness of 1.5 mm, d) CA7530 adhesive with a thickness of 2 mm

4. CONCLUSIONS

The most important results of this research are as follows:

1. SEM images showed that changing the silver amount from 20 to 30 and to 40 wt% increases the average thickness of the silver coating on copper particles from 0.5 to 1 and to 1.5 µm, respectively.
2. TG and DSC analyses showed that when the filler amount increases from 70 to 85 wt%, the adhesive weight loss reduces from 15.48 to 11.35 wt%.
3. Adhesive prepared from Cu@Ag particles containing 40 wt% silver had more thermal stability than adhesive prepared from Cu@Ag particles containing 20 wt% silver.
4. Performance evaluation of circuit made of conductive adhesives under DC and AC currents showed that changing the circuit width (1, 1.5, and 2 mm) has no significant effect on the V–I characteristic and also on the voltage gain of the circuit. The voltage gain of all three circuits was 9.5.
5. It was found that the circuit made from conductive adhesive indicates the behavior quite similar to the behavior of the circuit made on the copper board.

5. ACKNOWLEDGMENTS

The authors are thankful to Mr. Ahmad Nasri and Mr. Ehsan Zamanian for their assistance during the experiments. This work was supported by Hamedan University of Technology under grant No. 18-94-1-361.

6. REFERENCES

1. Trinidad, E., "Evaluation of hybrid electrically conductive adhesives", University of Waterloo, (2016),
2. Massoumi, B., Hosseinzadeh, M. and Jaymand, M., "Electrically conductive nanocomposite adhesives based on epoxy or chloroprene containing polyaniline, and carbon nanotubes", ***Journal of Materials Science: Materials in Electronics***, Vol. 26, No. 8, (2015), 6057-6067, doi: 10.1007/s10854-018-9284-9.
3. Licari, J.J. and Swanson, D.W., "Adhesives technology for electronic applications: Materials, processing, reliability, William Andrew, (2011).
4. Zhang, R. and Wong, C., "Low cost copper-based electrically conductive adhesives", in 2010 12th Electronics Packaging Technology Conference, IEEE. (2010), 715-720.
5. Yim, M.J. and Paik, K.W., "Review of electrically conductive adhesive technologies for electronic packaging", ***Electron Mater Lett***, Vol. 2, No. 3, (2006), 183-194, doi.
6. Aradhana, R., Mohanty, S. and Nayak, S.K., "A review on epoxy-based electrically conductive adhesives", ***International Journal of Adhesion and Adhesives***, Vol. 99, (2020), 102596, doi: 10.1016/j.ijadhadh.2020.102596.
7. Ji, X., Jin, X., Hou, C., Xiao, G., Fan, X. and Shu, X., "Loading rate response on shear mechanical properties of conductive adhesive with different silver contents", ***Journal of Adhesion Science and Technology***, Vol. 34, No. 18, (2020), 1935-1946, doi: 10.1080/01694243.2020.1749405.
8. Ali, A., Baheti, V., Khan, M.Z., Ashraf, M. and Militky, J., "Development of electrically conductive composites based on recycled resources", ***The Journal of The Textile Institute***, Vol. 111, No. 1, (2020), 16-25, doi: 10.1080/00405000.2019.1644121.
9. Szeluga, U., Pusz, S., Kumanek, B., Olszowska, K., Kobyliukh, A. and Trzebicka, B., "Effect of graphene filler structure on electrical, thermal, mechanical, and fire retardant properties of epoxy-graphene nanocomposites-a review", ***Critical Reviews in Solid State and Materials Sciences***, Vol. 46, No. 2, (2021), 152-187, doi: 10.1080/10408436.2019.1708702.
10. Meng, Q., Han, S., Araby, S., Zhao, Y., Liu, Z. and Lu, S., "Mechanically robust, electrically and thermally conductive graphene-based epoxy adhesives", ***Journal of Adhesion Science and Technology***, Vol. 33, No. 12, (2019), 1337-1356, doi: 10.1080/01694243.2019.1595890.
11. de Oliveira, C.S., Quispe, L.T., Pla Cid, C.C., Sierra, J.A., de Barros, S., Mello, A. and Pasa, A.A., "Dtt functionalization of ag particles for conducting adhesives", ***The Journal of Adhesion***, Vol. 94, No. 6, (2018), 473-485, doi: 10.1080/00218464.2017.1288113.
12. Zhang, X.M., Yang, X.-L. and Wang, B., "Electrical properties of electrically conductive adhesives from epoxy and silver-coated copper powders after sintering and thermal aging", ***International Journal of Adhesion and Adhesives***, Vol. 105, (2021), 102785, doi: 10.1016/j.ijadhadh.2020.102785.
13. Wang, Q., Zhang, S., Liu, G., Lin, T. and He, P., "The mixture of silver nanowires and nanosilver-coated copper micronflakes for electrically conductive adhesives to achieve high electrical conductivity with low percolation threshold", ***Journal of Alloys and Compounds***, Vol. 820, (2020), 153184, doi: 10.1016/j.jallcom.2019.153184.
14. Aradhana, R., Mohanty, S. and Nayak, S.K., "Novel electrically conductive epoxy/reduced graphite oxide/silica hollow microspheres adhesives with enhanced lap shear strength and thermal conductivity", ***Composites Science and Technology***, Vol. 169, (2019), 86-94, doi: 10.1016/j.compscitech.2018.11.008.
15. Chen, Y., Li, Q., Li, C., Dai, Z., Yan, H., Zhu, M., Zhang, Y., Yao, Y. and Li, Q., "Regulation of multidimensional silver nanostructures for high-performance composite conductive adhesives", ***Composites Part A: Applied Science and Manufacturing***, Vol. 137, (2020), 106025, doi: 10.1016/j.compositesa.2020.106025.
16. Dou, J., Tang, L., Mou, L., Zhang, R. and Jiang, X., "Stretchable conductive adhesives for connection of electronics in wearable devices based on metal-polymer conductors and carbon nanotubes", ***Composites Science and Technology***, Vol. 197, (2020), 108237, doi: 10.1016/j.compscitech.2020.108237.
17. Lin, W., Xi, X. and Yu, C., "Research of silver plating nano-graphite filled conductive adhesive", ***Synthetic Metals***, Vol. 159, No. 7-8, (2009), 619-624, doi: 10.1016/j.synthmet.2008.12.003.
18. Zhang, Y., Qi, S., Wu, X. and Duan, G., "Electrically conductive adhesive based on acrylate resin filled with silver plating graphite nanosheet", ***Synthetic Metals***, Vol. 161, No. 5-6, (2011), 516-522, doi: 10.1016/j.synthmet.2011.01.004.
19. Boylestad, R.L. and Nashelsky, L., "Electronic devices and circuit theory 11th ed", (2018).
20. Fathi, A., Azizian, S. and Sharifan, N., Sensors and amplifiers: Sensor output signal amplification systems, in Handbook of research on nanoelectronic sensor modeling and applications. 2017, IGI Global.423-504.
21. Rashtian, M. and Vafapour, M., "Gain boosted folded cascode op-amp with capacitor coupled auxiliary amplifiers", ***International Journal of Engineering, Trnsactions B: Applications***, Vol. 34, No. 5, (2021), 1233-1238, doi: 10.5829/ije.2021.34.05b.16.
22. Chauhan, D.S., Tomar, R. and Singh, S., "A new trans-admittance-mode biquad filter suitable for low voltage operation", ***International Journal of Engineering, Trnsactions C: Aspects***,

Vol. 28, No. 12, (2015), 1738-1745, doi: 10.5829/idosi.ije.2015.28.12c.06.

23. Dehghanian, R. and Salimi, A., "A hysteretic two-phase supply modulator for envelope tracking rf power amplifiers", ***International Journal of Engineering, Trnsactions C: Aspects***, Vol. 27, No. 12, (2014), 1832-1840, doi: 10.5829/idosi.ije.2014.27.12c.05.

24. Zhao, J. and Zhang, D., "Epoxy-based adhesives filled with flakes ag-coated copper as conductive fillers", ***Polymer Composites***, Vol. 38, No. 5, (2017), 846-851, doi: 10.1002/pc.23645.

25. Abenojar, J., Enciso, B., Pantoja, M., Velasco, F. and Martínez, M.-A., "Thermal characterization and diffusivity of two mono-component epoxies for transformer insulation", ***International Journal of Adhesion and Adhesives***, Vol. 103, (2020), 102726, doi: 10.1016/j.ijadhadh.2020.102726.

Persian Abstract

چکیده

چسب های کامپوزیت رسانای الکتریکی از ۷۰، ۷۵ و ۸۵ درصد وزنی ذرات پر کننده (پودر مس پوشش داده شده با نقره) و ماتریس پلیمری تهیه شدند. پایداری حرارتی و مورفولوژی چسب های تهیه شده با استفاده از روشهای ترموگراویمتری (TG)، کالریمتری روبشی تفاضلی (DSC) و میکروسکوپ الکترونی روبشی (SEM) بررسی شدند. در مرحله بعدی، یک مدار الکترونیکی مبتنی بر ترانزیستور (مدار امیتر- مشترک خود بایاس) از چسب رسانا و نیز به طور جداگانه از یک بورد مسی ساخته شد. جهت بررسی عملکرد مدارهای ساخته شده، همه آنها تحت جریان DC (۳۰–۸ ولت) و جریان AC (یک کیلو هرتز) قرار گرفتند. برای این مدارها، پارامترهایی مانند نقطه کار ترانزیستور و بهره ولتاژ اندازه گیری شدند. نتایج آنالیزهای TG و DSC نشان داد که افزایش مقدار پرکننده از ۷۰ تا ۸۵ درصد وزنی، اتلاف وزنی چسب ها را از ۱۵/۴۸ به ۱۱/۳۵ درصد وزنی کاهش می دهد. همچنین، بررسی اثر افزایش مقدار نقره در ذرات پرکننده روی پایداری حرارتی چسب ها در دماهای زیر ۳۵۰ درجه سانتیگراد، نشان داد که افزایش مقدار نقره از ۲۰ به ۴۰ درصد وزنی تاثیر کمی روی تغییر وزن چسب ها (در حدود ۲ درصد وزنی در دمای ۲۵۰ درجه سانتیگراد) دارد و هر دو نمونه در دمای ۳۵۰ درجه سانتیگراد اتلاف وزنی تقریبا یکسانی از خود نشان دادند. ارزیابی عملکرد مدارها نشان داد که تغییر در عرض مدار (۱، ۱/۵ و ۲ میلیمتر) تاثیری قابل توجهی روی مشخصه V-I و بهره ولتاژ ندارد. مقدار این دو پارامتر برای هر سه نوع مدار و نیز مدار تهیه شده از بورد مسی یکسان بودند که نشان دهنده هدایت بالای چسب های رسانا است.