Influence of Corrosive Gases on Reliability of Conductive Joints

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***Abstract*—This paper deals with the reliability under the flowing mixed gases corrosion test of interconnection techniques for the mounting surface mounted device (SMD) component. In the experiment, three types of substrates (conductive stretchable textile ribbon, knitted fabric, and flexible kapton substrate) and three contacting techniques (low-temperature soldering, isotropic electrically conductive adhesive bonding, and non-conductive adhesive bonding) were used. The experiment provided proof that soldered or non-conductive adhesive bonded samples are applicable even in a contaminated or industrial corrosive atmosphere, and the electrical resistance of joints on these samples remains acceptable. It follows e-textiles with soldered or non-conductive adhesive bonded components can also be used in a contaminated or industrial atmosphere.**

***Keywords*—Flowing mixed gas corrosion test, conductive ribbon, knitted fabric, kapton, non-conductive adhesive, wearable electronics, e-textiles.**

I. Introduction

Nowadays, there has been a growing interest in smart and wearable electronics. Especially electronic textiles (e-textiles) are growing as a class of smart textiles. These textiles have a wide range of applications such as aerospace, automotive, telecommunications, fashion, fitness, sports, and healthcare [1], [2]. The e-textiles can be realized by a combination of standard textiles with integrated standard electronics like sensors, passive components, LED components, etc. The second option is electronics fully printed onto the textile. In the case of integration of standard electronic components, the connection of these components is one of the key parts of the solution. This conductive connection of SMD components onto the flexible or textile substrates is complicated, and this connection's reliability has to be solved. The consumers expect e-textiles to retain the features of normal clothes, such as elasticity, breathability, wearing comfort, washability, and the use of hypoallergic materials that are non-irritating for skin, while providing added value functions such as heating, active illumination, and environmental or body parameter monitoring [3]–[6]. The use of soldering or adhesive bonding technique seems to be a promising solution, but the reliability of these standard techniques is different for using on the flexible or textile substrates, and each technique has some pros and cons.

In the standard soldering process, the soldering alloy with a melting point above 219°C is used, and the process temperature is around 250°C which is too high for some substrates, so the standard soldering of components onto these temperature-sensitive substrates is not possible [7]. It follows that only low-temperature soldering or adhesive bonding can be applied. The tin-bismuth solder alloy with a melting point of 139°C is the best choice due to the temperature of soldering, which is around 160°C [8]. These temperatures are limiting for some types of substrates, like stretchable textile ribbons of PET substrates, but can be used in the short term. The adhesive bonding technique is another option. It is possible to use electrically conductive adhesive, but these adhesives are primarily designed for rigid substrates, and the stretching is challenging for them. The third option is the use of non-conductive adhesive to make a conductive connection. In this case, the conductive joint is made by the direct contact of a component with a substrate. This technology, with using of UV curable non-conductive adhesive to make conductive and reliable joints, is able to make the connection very fast (in a few seconds) and without sample overheating. This technology was researched in our previous experiments [9], [10], but the reliability of joints under the effect of contaminated or industrial corrosive atmosphere during the real-life samples was not researched.

In the experiment, the comparison of a few contacting methods onto flexible polyimide substrate and stretchable e-textile substrate was realized. The electrical resistance of these joints was measured before, periodically during, and after the flowing mixed gas corrosion test with H_2S and SO_2 gases according to the IEC standard. This standard simulates the effect of a contaminated or industrial corrosive atmosphere during the real life of the expected devices.

II. Materials and Procedures

For the experiment, three types of substrates were used. The first type was the conductive stretchable textile ribbons with ten SMD chip resistors mounted by soldering / conductive bonding / non-conductive bonding technique and encapsulated after the connection by non-conductive adhesive. The second type was the knitted fabrics with integrated electrically conductive lines with ten SMD chip resistors mounted by soldering / conductive bonding / non-conductive bonding technique and encapsulated after the connection by non-conductive adhesive.

TABLE I. Table of used sample types.

	Substrate type	Connection material	Encapsulation
1	Textile ribbon	SnBi solder	with encapsulation
		ECA ME902	
		ECA 8331S	
		NCA AA3926	
2	Knitted fabric	SnBi solder	with encapsulation
		ECA ME902	
		NCA AA3926	
3	Kapton substrate	ECA ME902	without encapsulation
		ECA ME902	with encapsulation

The third type was flexible kapton substrates with copper pads with nine SMD chip resistors mounted by conductive

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bonding technique. Half of them were also encapsulated after the connection by non-conductive adhesive. The details of the sample types can be seen in Table 1.

A. Substrates

The first substrate type was specially developed electrically conductive textile stretchable ribbon. This ribbon, protected by patent No. 308614, consists of polyester threads in a warp and weft to ensure the durability and strength of the ribbon, rubber threads in a warp to ensure the stretchability of the ribbon, and special hybrid conductive threads in a warp to ensure electrical conductivity along with the ribbon. These hybrid threads consist of continuous PES monofilaments, and 8 Ag plated Cu conductive microwires for each thread. The details of this ribbon can be seen in Figure 1.

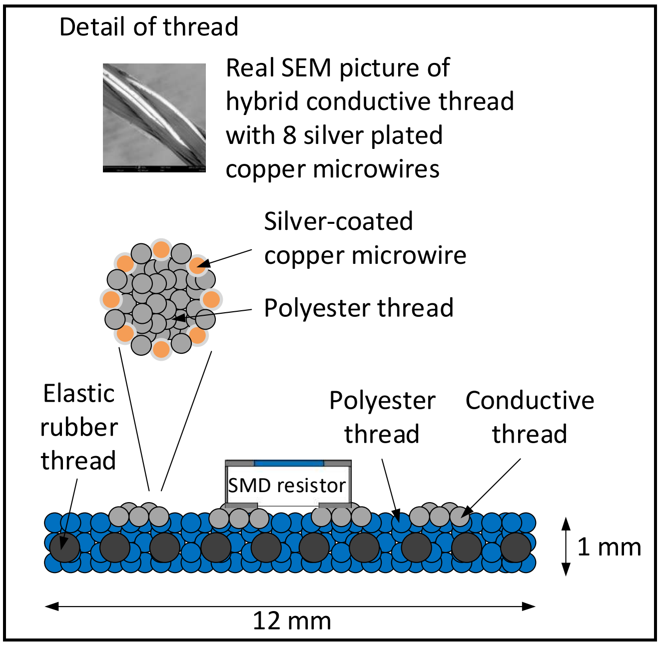

Fig. 1. Schematic cross-section of electrically conductive textile stretchable ribbons.

The second substrate type was knitted fabric, which consisted of modal thread (i.e., based on regenerated cellulose with basic material from beech wood) to ensure the strength and durability of the fabric, and special hybrid conductive threads to ensure the electrical conductivity of conductive lines. Each line consists of 4 conductive threads. Each conductive thread consists of PESh and eight brass microwires with a diameter of 30 µm.

The third substrate type was a flexible printed circuit board DuPont Pyralux with an 18 µm thick copper conductive pattern.

B. Components

The SMD chip resistors with a 1206 case size were used for the preparation of all samples. The theoretical resistance of these resistors is 0 Ω. From our previous experiments, the real median resistance of these resistors was measured at 8.2 mΩ.

C. Contacting technique

The first contacting technique was low-temperature soldering. For the ribbon substrate, the resistors were soldered perpendicular to the ribbon traces. For fabric substrate, the trace was interrupted by electric discharge, and the resistor was soldered onto the one trace with the interruption in the middle of the resistor. The tin-bismuth solder paste with a melting point of 139°C was used. During the sample preparation, this paste was applied onto the conductive lines in the ribbon by dispensing. In the next step, the SMD chip resistor was mounted into the paste with tweezers and soldered by hot air. At the final step, the soldered chip resistor was encapsulated by adhesive.

The second contacting technique was a connection by isotropic electrically conductive adhesive. The two types of adhesive were used. The first type was DuPont ME902 (one component) with a curing temperature of 120°C / 20 min, and the second type was MG Chemicals 8331S (two-component) with a curing temperature of 130°C / 30 min. Both types are adhesives with silver conductive particles. During the preparation, the adhesive was applied to the conductive places on the substrate by stencil printing. In the next step, the SMD chip resistor was mounted into the adhesive by tweezers, and the adhesive was cured in the oven. At the final step, the soldered chip resistor was encapsulated by adhesive.

The third contacting technique was using non-conductive adhesive. The UV-curable, acrylic, electrically non-conductive adhesive Loctite AA3926 was used. During the preparation, the adhesive was applied onto the substrate between two conductive traces by dispensing. In the next step, the SMD chip resistor was mounted to the adhesive and mechanically pushed by a thorn into the conductive traces in the substrate with downforce of 30 N. The pressure caused adhesive extrusion from the space between the resistor pads and conductive traces on the substrate. The adhesive reached a pointwise zero thickness, allowing intimate contact between the metal parts. The resistor pads were also pressed into the conductive traces, and direct mechanical-electrical contact was made. Under pressure, the adhesive was cured by UV light, and mechanical fixation of connection was realized. At the final step, the adhesive bonded chip resistor was encapsulated with the same adhesive.

D. Electrical resistance measurement

The electrical resistance of each SMD chip resistor with two joints was measured by the 4-point probe method. The measurement was realized by Keithley 2701 device.

E. Corrosive gases aging

In the experiment, the accelerated aging of samples by flowing mixed gas corrosion test with H2S and SO2 gases according to the standard IEC 60068-2-60 method 1. This standard simulates the effect of a contaminated or industrial corrosive atmosphere during the real life of the expected devices. The prepared samples were added to the plastic box inside the corrosive climatic chamber. According to the standard, the temperature was set to 25°C and relative humidity 75%. The number of atmosphere changes in the box was set to 6 times per hour. The concentration of hydrogen sulfide (H_2S) was maintained at 100 ppb. The concentration of sulfur dioxide (SO_2) was maintained at 500 ppb. The length of the test was chosen to be 21 days, with regular testing of samples' electrical resistance every seven days.

III. Results and Discussion

The values of electrical resistance were statistically analyzed, and the boxplot diagrams for all samples were prepared (see Figures 2, 3, and 4). The results show that the electrical resistance of all soldered samples is low and stable during the aging. The results also show that the electrical resistance of samples adhesive bonded by NCA AA3926 is low and stable during the aging for both substrate types. The results of isotropic electrically conductive adhesive are worse but for adhesive ME902 are still relatively low and stable during the aging. The samples without encapsulation on the kapton substrates have a higher variance of values against the same samples with encapsulation. It follows that encapsulation is important even in the case of kapton substrates. The results show that the electrical resistance of adhesive 8331S is higher with a high variance of values. It follows that the adhesive 8331S is not suitable for the connection of components onto the textile substrate.

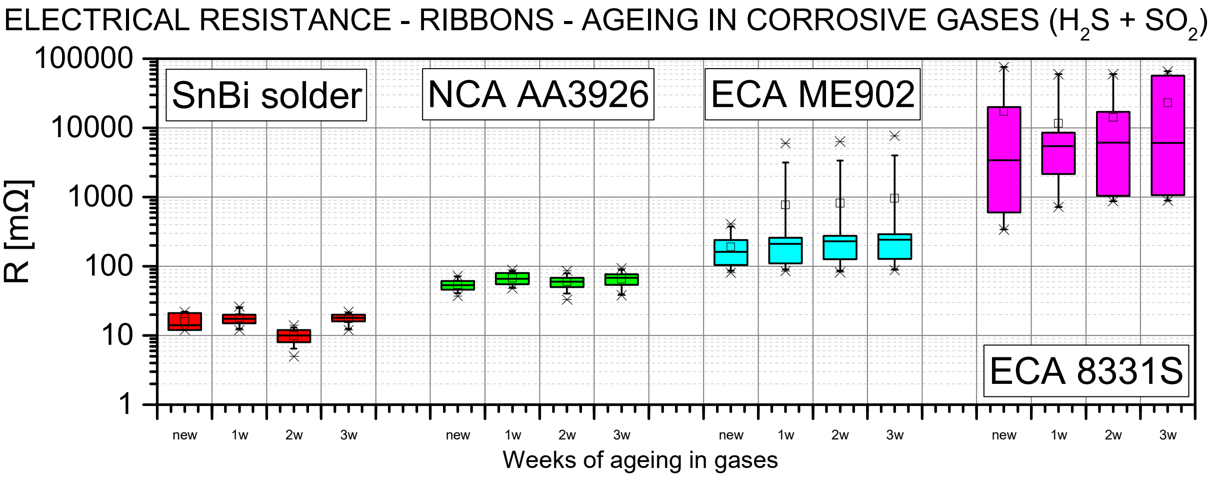

Fig. 2. The electrical resistance of ribbon samples – boxplot diagram.

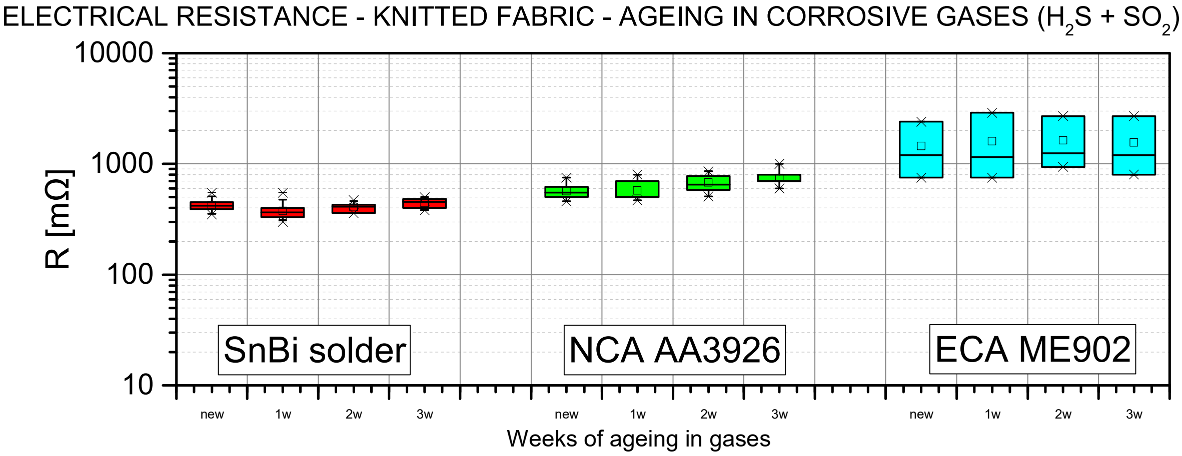

Fig. 3. The electrical resistance of knitted fabric samples – boxplot diagram.

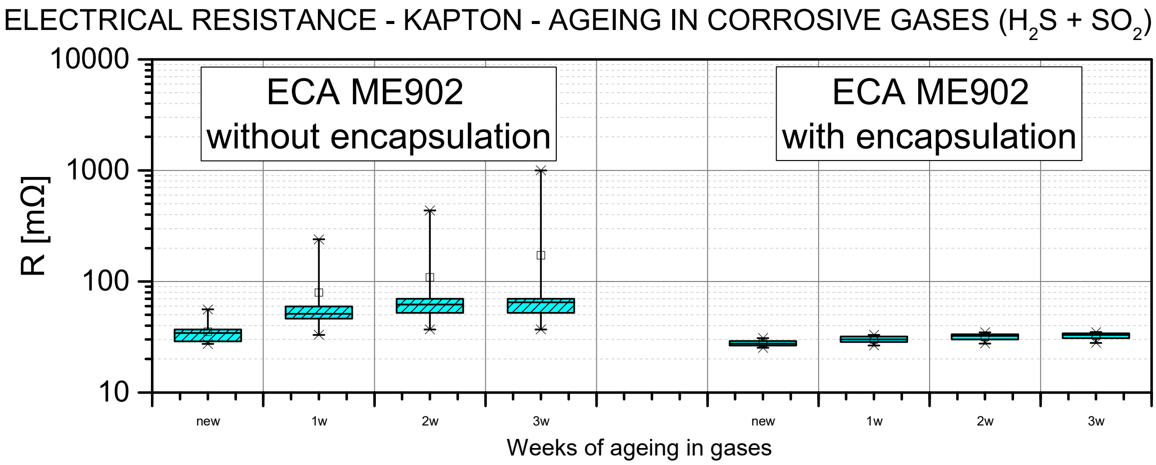

Fig. 4. The electrical resistance of kapton samples – boxplot diagram.

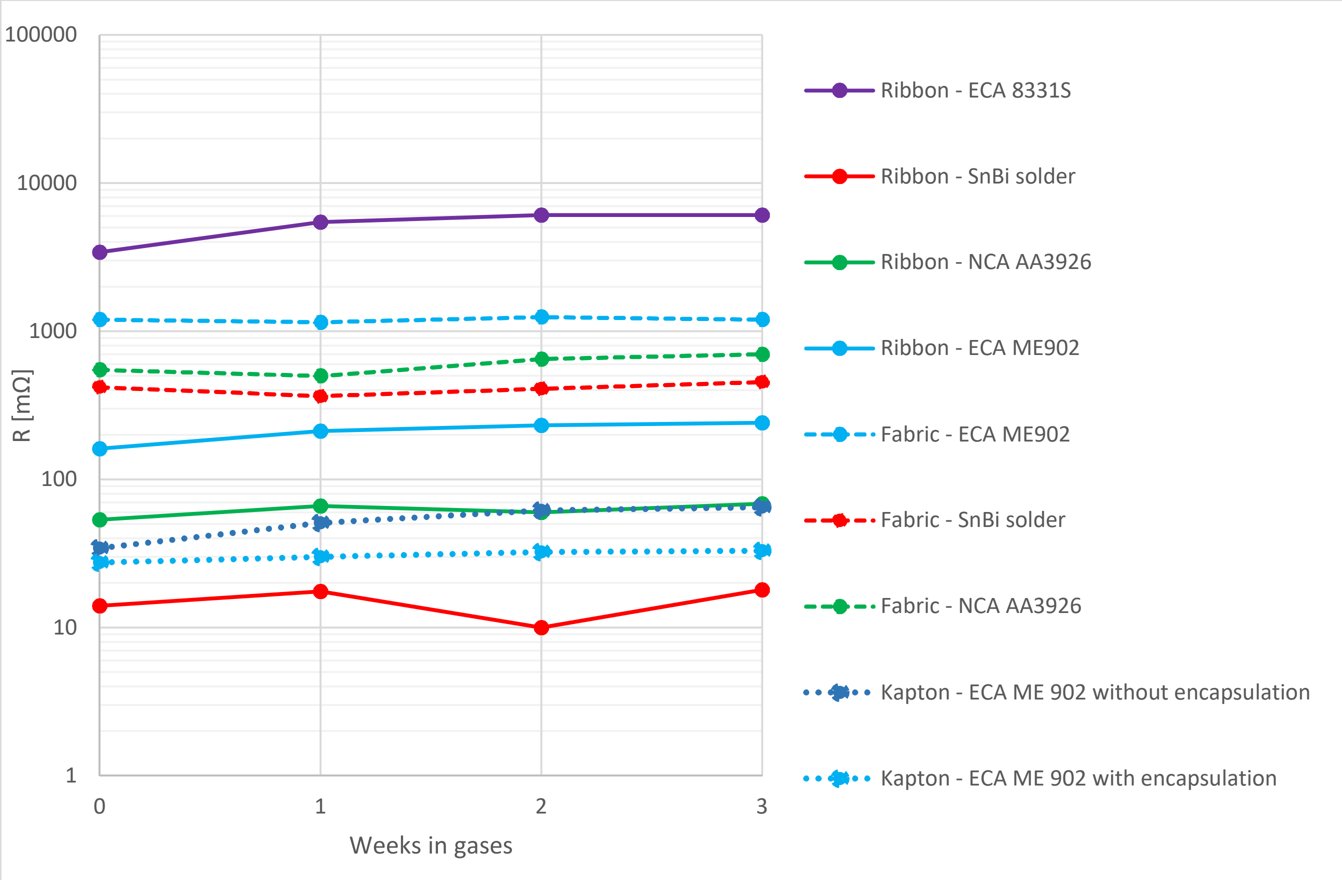

Fig. 5. Medians of electrical resistance for all samples.

IV. Conclusion

The results of samples tested by the flowing mixed gas corrosion test with H_2S and SO_2 gases show that the prepared samples are also applicable in the contaminated or industrial corrosive atmosphere, and the electrical resistance of joints on these samples remains acceptable. The results also show that soldered samples have lower resistance, non-conductively adhesive bonded samples have still low resistance and isotropic electrically conductive adhesive bonded samples using ME902 adhesive have still acceptable resistance values during the whole accelerated aging test. The best results in terms of electrical resistance of joints were obtained for soldered samples. However, this method can damage the textile due to the high temperature during soldering and significantly reduce the mechanical properties and flexibility of the textile, which can lead to a limited service life of samples. On the other hand, the non-conductive adhesive bonding technique is a very interesting alternative, where the above-mentioned properties are preserved, but the electrical resistance is a little higher.

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