Improved Silver / Tin Oxide Contact Material for Automotive Applications

Oliver Lutz, Volker Behrens, Werner Wasserbäch, Susanne Franz, Thomas Honig, Dietmar Späth
AMI DODUCO GmbH, D-75181 Pforzheim, Email: olutz@amidoduco.com
Jens Heinrich
Tyco Electronics AMP GmbH, D-13629 Berlin, Email: jens.heinrich@tycoelectronics.com

Abstract
The requirements pertaining to the electrical load and service life of relays and switches used for automotive applications are becoming more and more stringent.
In order to meet these requirements, the existing silver / tin oxide (Ag/SnO_2) material with indium oxide (In_2O_3), produced by the melting metallurgy method and subsequent internal oxidation, was developed further. By optimizing manufacturing equipment and the stages of the process, an improved Ag/SnO_2 (with In_2O_3) with a very fine microstructure was developed.
Electrical test results show very low and regular material transfer and low erosion during service life tests, even with inductive loads. In addition, no sticking or welding occurred with capacitive loads.

Key words:
Automotive relays, silver / tin oxide with indium oxide.

1. Introduction

The requirements pertaining to the electrical load and service life of relays and switches used for automotive applications are becoming more and more stringent. The reasons for this are to be found in the greater use of electrical functions for safety, economy and comfort features in cars [1]. For example, flasher relays were previously required to switch a maximum of two flasher lights simultaneously. Nowadays, the car's flasher relay has to switch four or more lights simultaneously every time the doors are locked or unlocked. The relay for the windshield wiper did not previously have to switch very often in manual mode but more often in intermittent mode. Because of the use of modern technology such as rain sensors, the relay now has to switch much more frequently throughout its entire service life.
In order to meet these more demanding requirements, the existing silver / tin oxide (Ag/SnO_2) material with indium oxide (In_2O_3) produced by the melting metallurgy method and subsequent internal oxidation, was developed further.
Ag/SnO_2 with In_2O_3 is a common contact material in the Asian market [3], [4], [5]. Currently, the demand for these materials for inductive DC and some special AC applications is also increasing in Europe. It is known that the amount of In_2O_3 has an influence on switching behaviour [6]. The addition of In_2O_3 to Ag/SnO_2, produced by the melting metallurgy method performs two functions – firstly, it is necessary for the internal oxidation manufacturing process and secondly, it has a positive effect on switching behaviour.
By optimizing the manufacturing equipment and the stages of the process it was possible to produce an improved Ag/SnO_2 with In_2O_3 with a very fine microstructure and consequently with improved switching behaviour.
This paper focuses on the switching behaviour of Ag/SnO_2 contact materials with different additives and made by different manufacturing processes in a model switch and in a relay applying various electrical loads.

2. Experiment

2.1 Contact materials

The contact materials investigated in this paper are listed in table 1.
The internally oxidized (i.o.) contact materials Ag/SnO_2 12 and Ag/SnO_2 14 were produced by melting different Ag-Sn-In alloys in a protective atmosphere and subsequent casting and oxidation. The alloy compositions were designed to yield a total oxide content of 12 wt% and 14 wt%, respectively. By improving the oxidation process, it was possible to obtain a very fine microstructure. The microstructures of the standard contact material Ag/SnO_2 12 TOS is shown in figure 1 and Ag/SnO_2 12 TOS F is shown in figure 2. The comparison shows a very fine and uniform distribution of the oxides in the case of the internally oxidized TOS 12 F material.
All other contact materials (p.m.) with a total oxide content of 12 wt% were produced by blending powders, pressing a billet, extrusion and subsequent drawing. Ag/SnO_2 12P has no further additive besides the respective oxide component. The Ag/SnO_2 12PE has bismuth oxide (Bi_2O_3) and copper oxide (CuO) and Ag/SnO_2 12PW has tungsten oxide (WO_3) as additives besides the respective oxide component. For a comparison of the typical micro section of the p.m. contact materials see figure 3.
In order to study the mechanical behavior of the contact materials, tensile samples were deformed using an Instron testing machine operating at a constant cross head velocity of 3 mm / min (nominal axial strain rate 5 x 10^{-4} sec^{-1}).

Table 1: Contact materials

No.	Material	Silver content / wt%	Additives	Electrical conductivity / $m/\Omega mm^2$	Vickers hardness / HV5	Remarks
1	Ag/SnO_2 12P	88	-	45 – 47	63	p. m.
2	Ag/SnO_2 12PW	88	WO_3	45 – 46	64	p. m.
3	Ag/SnO_2 12PE	88	Bi_2O_3, CuO	45 – 46	65	p. m.
4	Ag/SnO_2 12TOS	88	In_2O_3	44 - 46	96	internal oxidation
5	Ag/SnO_2 12TOSF	88	In_2O_3	44 - 46	95	internal oxidation
6	Ag/SnO_2 14TOSF	86	In_2O_3	42 - 44	98	internal oxidation

The physical properties of the contact materials are given in table 1. For all samples the typical parabolic stress strain curves are seen to be normal for particle reinforced materials as shown in figure 4. However, the tensile strengths of the internally oxidized materials are at least 40 to 80 MPa greater when compared to the p.m. materials. Furthermore, all i.o. materials have a higher ductility than the p.m. materials.
The contact materials were made into composite rivets with a head diameter of 2.8 mm.

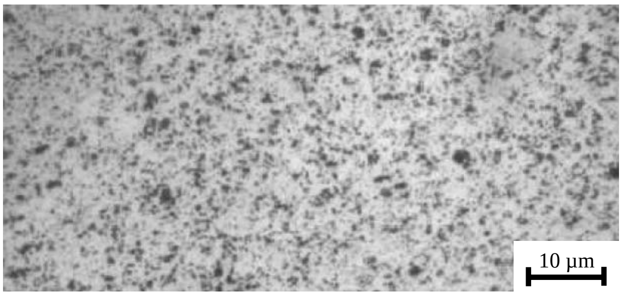

Figure 1: *Micro section of Ag/SnO_2 12 TOS*

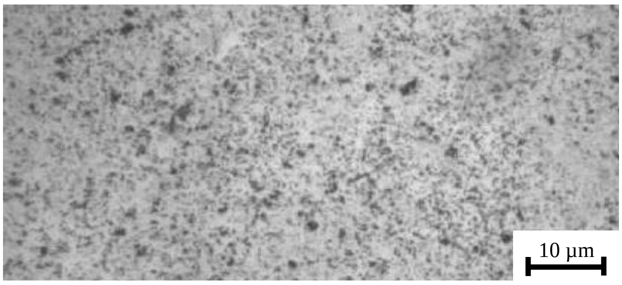

Figure 2: *Micro section of Ag/SnO_2 12 TOS F*

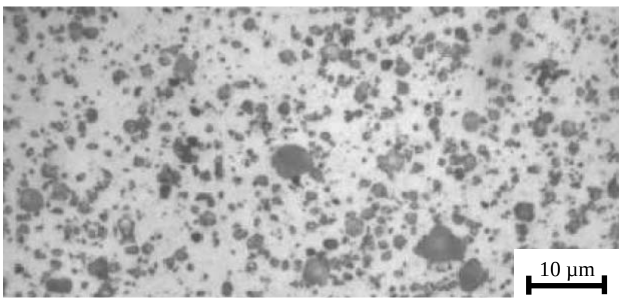

Figure 3: *Micro section of Ag/SnO_2 12 P*

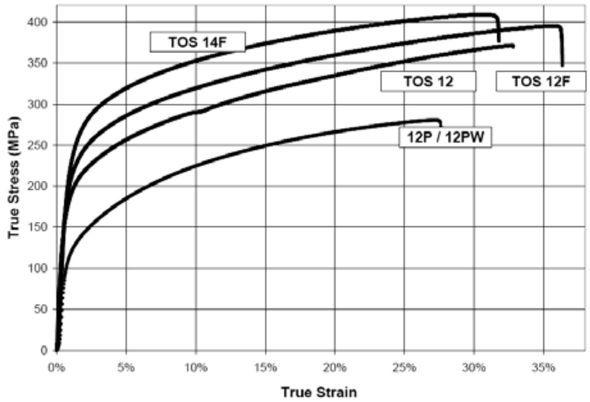

Figure 4: *Stress/strain curves of p.m. and i.o. materials*

3. Electrical tests

3.1 Model switch tests

3.1.1 Setup of the model switch

The equipment (i.e. model switch control and evaluation software and hardware) is designed to meet the requirements of the typical automotive 14 V DC power net [1].
The movable contact (anode) is driven by a linear actuator. Depending on the length of the contact gap, an opening velocity of max 0.5 m/s was obtained. The parameters used are as follows:

- Contact force: approximately 1 N;
- Contact gap: 0.5 mm;
- Opening velocity: 0.1 m/s.

The movement of the linear drive was controlled by a personal computer. By means of a spring/damper system with a fixed contact (cathode), a reproducible contact bounce at make (t_{bounce} = 450 – 500 µs) was achieved.

3.1.2 Electrical tests with model switch

For the electrical tests a power supply with a maximum rating of 70 A at 60 V DC was used. The electrical tests were carried out with artificial load circuits (e.g. adjustable resistors and air-core coils) given in table 2.
In order to characterize the switching behavior of the contact materials, the following electrical tests were

performed. Electrical service life tests were run with two different inductive loads. The electrical service life test sequence (i.e. linear motor control and data acquisition and evaluation) was controlled by a personal computer and run automatically.

While make parameters and therefore make bouncing were kept constant for all tests, the make bouncing and the break arc were monitored by means of a transient measurement PCI card. With every load cycle, the voltage U(t) and current I(t) curves by current probe, contact travel a(t) and contact force F(t) were measured by the transient measurement card. The program includes the evaluation and storage of the number of contact bounces, the bouncing time, bouncing energy, arc duration, arc energy, opening and closing velocity, contact resistance, contact force and contact welding force.

After 50,000 make and break operations the test was stopped and the mass changes at the anode and cathode were determined gravimetrically.

Table 2: *Electrical loads used (model switch)*

Load	I a	I b
Load voltage U / V	14	14
Load current I_{on} / A	25	25
Load current I_{off} / A	25	25
Inductance L / mH	0.5	1
t_{on} / t_{off} / sec	0.3 / 1.7	0.3 / 1.7
Ambient temperature	room temperature	

3.2 Automotive relay tests

3.2.1 Relay description

The service life tests were performed with the commercial plug-in type relay "Power F4" [7] for automotive applications. The joining of the contact rivets as well as the assembly of the relays was carried out under normal factory mass-production conditions. Rivets used for the stationary and movable contact were composites as described in 2.1.
The typical relay parameters (all values refer to the contact level) are as follows:

- Contact arrangement: make contact (1 Form A);
- Contact force: approximately 200 cN;
- Contact gap: 0.5 mm;
- Release force (normally open contact opens): 50 cN;
- Polarity: movable contact: anode / fixed contact: cathode.

3.2.2 Electrical tests with the relay

To evaluate the new contact materials, both inductive and capacitive loads were tested.
Capacitive load types for automotive applications, such as front and rear beams, flasher and filter capacitors in electronic modules mainly stress the contact material during switch-on. Capacitive loads (current profile show in figure 5) have a high current inrush combined with a remarkable arc during bouncing and a low steady current. The electrical life tests were run with a current inrush of 200 A and a current break of 20 A.

Inductive load types for automotive applications, such as heater blower, cooling fan and window lifter particularly stress the contact material. Inductive loads (current profile shown in figure 6) are characterized by a relatively slow current increase at make and a remarkable switch-off arc at break, induced by the demagnetization of the magnetic circuit of the load. The electrical life tests were run with three typical load types, shown in table 3.

All tests were performed with an electric life endurance tester; each switching operation was monitored for reliable closing and opening of the contacts. The load characteristic was simulated by electronic load simulation. The first failure was monitored.

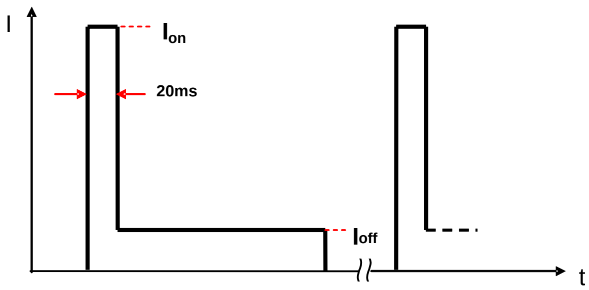

Figure 5: *Current profile of capacitive DC load tested*

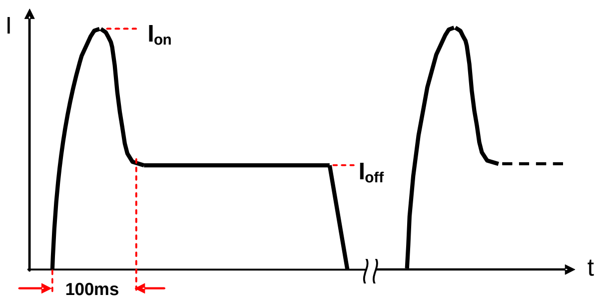

Figure 6: *Current profile of inductive DC loads tested*

Table 3: *Inductive loads used (relay)*

Load	II a	II b	II c
Load voltage U / V	13.5	13.5	13.5
Load current I_{on} / A	80	90	140
Load current I_{off} / A	33	30	50
Inductance L / mH	0.25	0.125	0.1
t_{on} / t_{off} / sec	1 / 3	1 / 1	1 / 3
Ambient temperature / °C	-40 to +85 (2 h)		

4. Test results

4.1 Model switch

The test results under load I b with tests as described above are summarized in figures 7 and 8. The test results under load I a are similar to the results of load I b, the differences are not so distinctive.
Contact erosion, either loss or transfer of contact material for 1,000 make and break operations is shown in figure 7. The 5 %, 50 % and 95 % quantile values of contact resistance recorded during electrical service life tests are charted in figure 8.

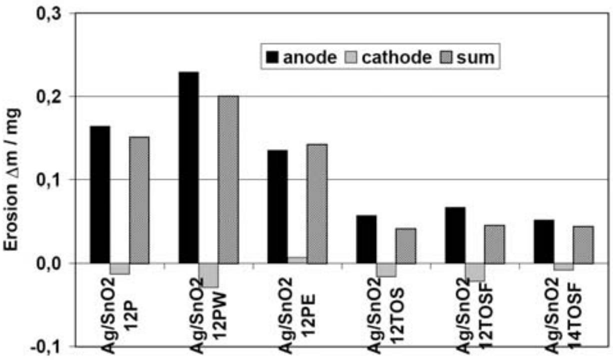

Figure 7: *Contact erosion and material transfer with test Ib for 1,000 operations (25 A, 1 mH, 50,000 operations)*

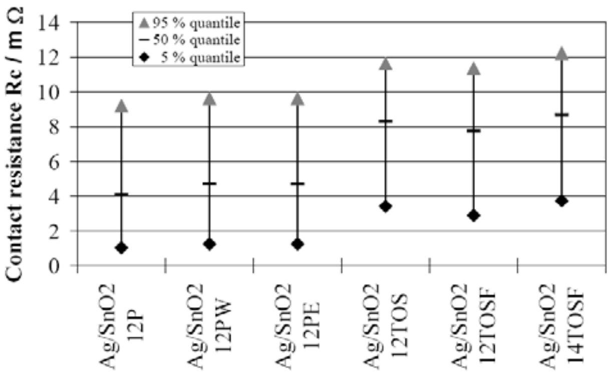

Figure 8: *Contact resistance during service life at test Ib (25 A, 1 mH, 0 to 50,000 operations)*

4.2 Automotive relay

4.2.1 Capacitive load

All tests were terminated at the required service life without failures and revealed no differences between the contact materials. Therefore the data base does not allow a definitive statement concerning the differences between the tested contact materials. Additional tests will be carried out.

4.2.2 Inductive load

The results of the first failure are summarized under load IIa (80A / 33A / 0.25mH) in figure 9, under load IIb (90A / 30A / 0.125mH) in figure 10 and under load IIc (140A / 50A / 0.1mH) in figure 11.

All three figures show the Weibull distribution of failure probability through the first failure during the service life test. For a direct comparison between the materials tested the switching cycles in the diagram were scaled to the first missing operation of all relays (relative factor = no. of operations of the first failure / min. no. of operations in this test).

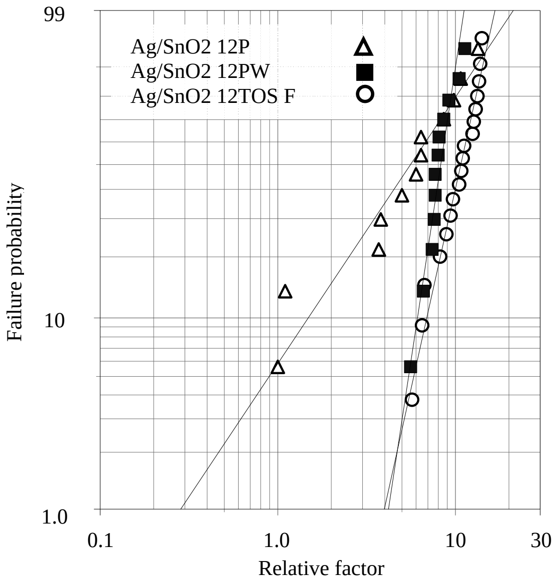

Figure 9: *Weibull distribution of failure probability through the first failure under load IIa (80 A / 33 A / 0.25 mH)*

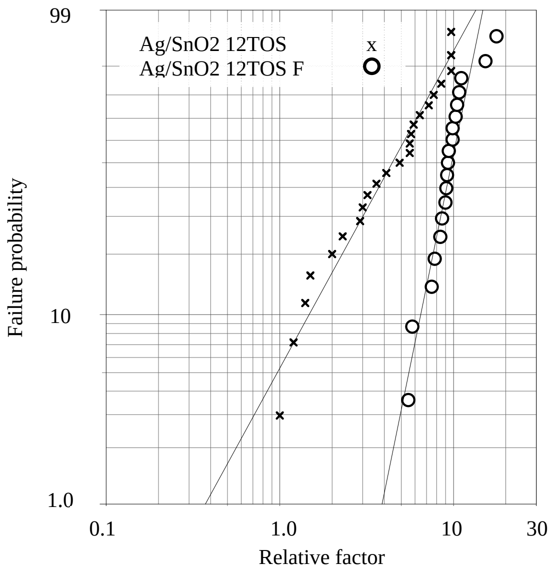

Figure 10: *Weibull distribution of failure probability through the first failure under load IIb (90 A / 30 A / 0.125 mH)*

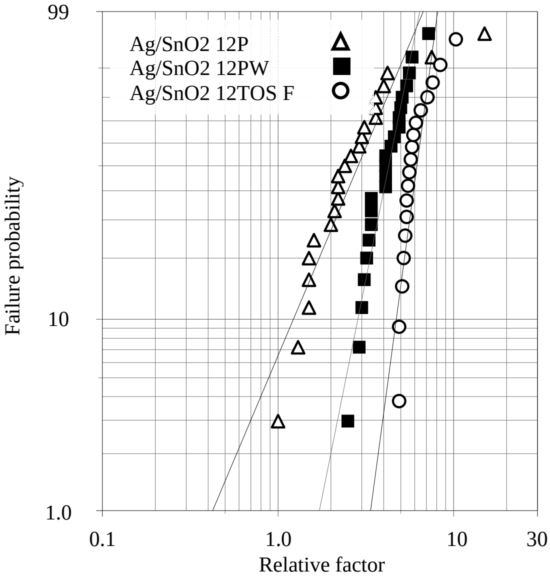

Figure 11: *Weibull distribution of failure probability through the first failure under load* IIc (140 A / 50 A / 0.1 mH)

5. Discussion

5.1 Contact erosion / Material transfer

Figures 12 and 13 show micro sections of Ag/SnO_2 12 TOS and TOSF after service life, load II b. The contact erosion is due to the high arc energy at break. A material transfer is observed from the anode to the cathode.
Under inductive load IIb, Ag/SnO_2 12TOSF shows less contact erosion than Ag/SnO_2 12TOS even after twice service life (see figure 10). In addition Ag/SnO_2 12TOSF shows erosion of very low tendency to crater/pip-formation. So obviously the fine oxide particle distribution has a positive effect on the erosion of Ag/SnO_2 12TOSF.

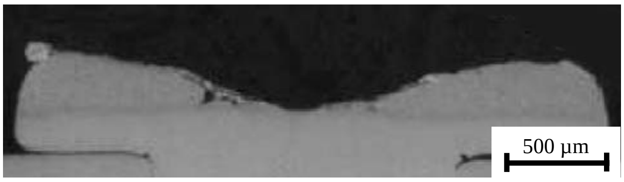

Figure 12: *Micro section of Ag/SnO_2 12TOS (movable contact: anode) under load IIb (90 A / 30 A / 0.125 mH) first failure after 5.6 (relative factor)*

Figure 13: *Micro section of Ag/SnO_2 12TOSF (movable contact: anode) under load IIb (90 A / 30 A / 0.125 mH) first failure after 10.5 (relative factor)*

Under load IIc Ag/SnO_2 12PW shows a higher tendency to material transfer than Ag/SnO_2 12TOSF (see figures 14 and 15).
Also with load II c Ag/SnO_2 12TOSF (see figure 14) shows low material transfer and no crater/pip-formation. Comparing Ag/SnO_2 12P and 12PW (see figure 15) the additive WO_3 improves the switching behavior in respect of anti-welding behavior but does not improve properties such as contact erosion or material transfer with special inductive loads as shown in figure 7.

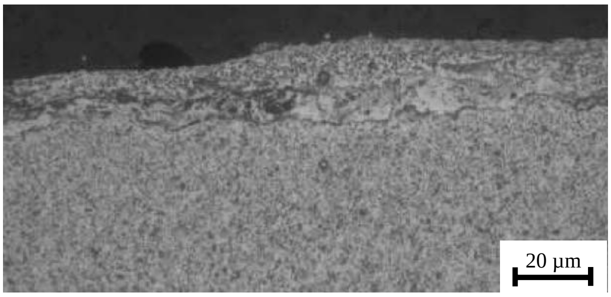

Figure 14: *Micro section of Ag/SnO_2 12TOSF (fixed contact: cathode) under load IIc (140 A / 50 A / 0.1 mH) first failure after 5.9 (relative factor)*

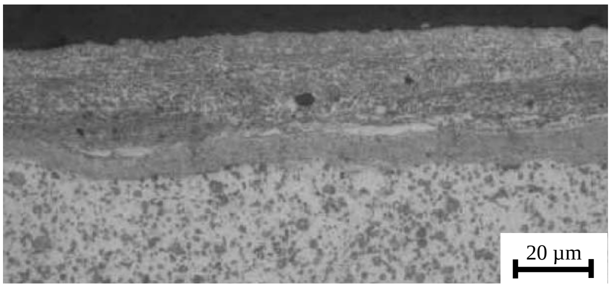

Figure 15: *Micro section of Ag/SnO_2 12PW (fixed contact: cathode) under load IIc (140 A / 50 A / 0.1 mH) first failure after 2.5 (relative factor)*

5.2 Anti-welding properties / first failure

Typical first failures are generated by a sticking of the contacts. The contacts no longer open within a specific time. This is influenced by separation of silver and tin oxide forming tin oxide layers as shown in figures 16 and 17 at the contact surface due to the action of the arc.

Ag/SnO_2 12PW (see figure 16) shows a no great tendency towards the separation of silver and tin oxide or to the formation of tin oxide layers. The lower area (1) shows the original microstructure obtained by extrusion. The upper area (2) close to the contact surface shows fine tin oxide particles dispersed in Ag even after the melting and re-solidification of the Ag.

After a very long service life under load II b, Ag/SnO_2 12TOSF (see figure 17) starts to show the formation of silver-rich layers (1) and tin oxide lines (2) in the contact material on its surface. The tin oxide lines can elevate high contact resistance and the silver layers can cause the first failure. The lower area (3) shows the original microstructure.

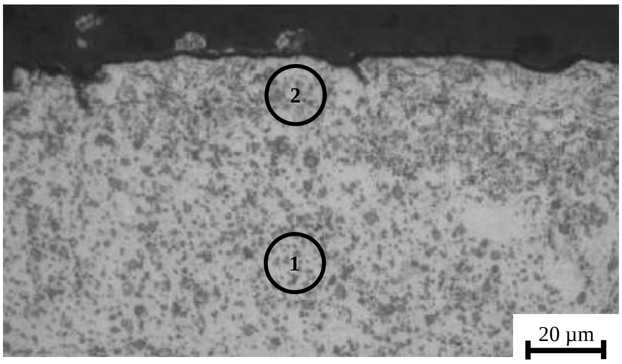

Figure 16: *Micro section of Ag/SnO_2 12PW (movable contact: anode) under load IIa (80 A / 33 A / 0.25 mH) first failure after 5.6 (relative factor)*

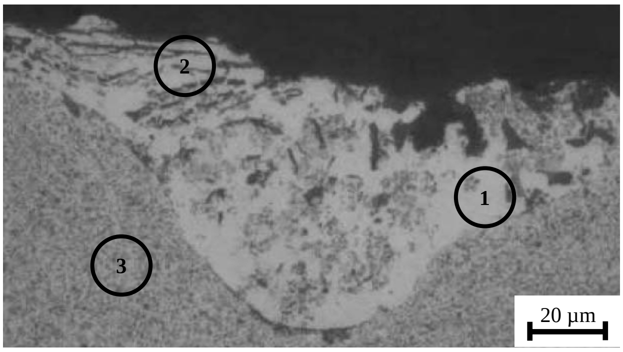

Figure 17: *Micro section of Ag/SnO_2 12TOS F (movable contact: anode) under load IIb (90 A / 30 A / 0.125 mH) first failure after 10.5 (relative factor)*

6. Summary

The results are summarized in table 4.

Table 4: *Summary*

Contact materials	Material erosion / transfer		Contact resistance		First failure (relay)		
Load (table 2 & 3)	**Ia**	**Ib**	**Ia**	**Ib**	**IIa**	**IIb**	**IIc**
Ag/SnO_2 12P	+	+	+	+	0	*	0
Ag/SnO_2 12PW	+	0	+	+	+	*	+
Ag/SnO_2 12PE	+	+	+	+	*	*	*
Ag/SnO_2 12TOS	++	++	+	+	*	0	*
Ag/SnO_2 12TOSF	++	++	+	+	++	++	+
Ag/SnO_2 14TOSF	++	++	+	+	*	*	*

Loads: see table 2 & 3
++ = very good; + = good; 0 = average
** not tested*

According to table 4 Ag/SnO_2 12 P without any additive demonstrates a tendency to material transfer and erosion. Additives such as Bi_2O_3 and CuO in Ag/SnO_2 12 PE and WO_3 in Ag/SnO_2 12 PW noticeably improve the anti-welding behavior. These two materials are recommended for normal inductive loads where Ag/SnO2 12 P is not sufficient.

Ag/SnO_2 12 TOS F and Ag/SnO_2 14 TOS F show the best overall performance for high inductive DC loads, where a low and regular contact erosion and low material transfer over a high service life is required (14 TOS F: preliminary failure results in a model switch). In addition, no sticking or welding with capacitive loads occurs. Furthermore they have a higher ductility than materials produced by powder metallurgy methods.

Outlook

After proving that a reduction in oxide particle size leads to improved switching behavior, the effect of the total oxide content is to be evaluated. Internally oxidized Ag/SnO_2 materials with oxide contents ranging from 8 wt% to 14 wt% will therefore be subject of future work.

References

[1] O. Lutz, V. Behrens, T. Honig, A. Kraus: ”Switching Behavior of Silver Based Contact Materials in 42 V DC Applications”, Proceedings of the 51st International Relay Conference, Lake Buena Vista 2003, pp. 15-1 – 15-7.

[2] C. Leung, E. Streicher, D. Fitzgerald, J. Cook: ”High Current Erosion of Ag/snO2 Contacts and Evaluation of Indium Effects in Oxide Properties”, Proceedings of the 52nd IEEE Holm Conference on Electrical Contacts, Montreal 2006, pp. 143 – 150.

[3] G. Horn, C. Ming: “Achievements in the Research and Development of Silver-based Alloys for the Electrical Contact Materials”, Proceedings of the 5th China International Conference, Panya 2006.

[4] A. Shibata, “Silver-Metal Oxide Contact Material by Internal Oxidation Process,” Proceedings 7th ICEC, Paris, 1974, p214-220.

[5] M. Kume and S. Kabayama, “Evaluation of Contact Welding Characteristics in high Current Regions,” Proceeding 7th ICEC, Paris, 1974, p132-137.

[6] P. Braumann, A. Koffler: “Einfluss von Herstell-verfahren, Metalloxidgehalt und Wirkzusätzen auf das Schaltverhalten von Ag/SnO2 in Relais (2)”, VDE-Fachbericht 61, VDE Verlag GmbH, Berlin, Offenbach 2005, pp. 149 – 154.

[7] Tyco Electronics, Catalogue for Automotive Relays and Switching Modules, #1308028-2, issued 3-2008.