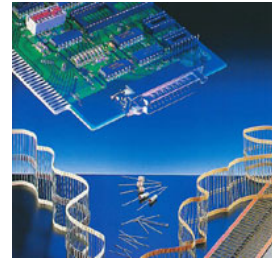


Continuous Product Improvements

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LEAD WIRES - WELDING PROCESS AND NEW MATERIALS

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1. SUMMARY

Within the passive electronic components industry, both, SMD-components and components with lead wires are subject of further developments.

Basing on presently used materials the paper gives recommendations to modified low-cost orientated materials for lead wires. Resistor applications as well as capacitor applications are concerned.

Special attention is given to the soldering / welding process of lead wires to the component itself. A number of examples concerning proper and improper welds / soldering-joints are shown, parameters of the soldering / welding process are described.

This paper is a further approach to support producers of leaded components

- to review existing specifications
- to have a look for appropriate lead wire materials
- to have a focus on material cost issues
- to adapt material properties and welding / soldering process parameters to get components, which grant high reliability and good performance.

2. INTRODUCTION

Electronic Circuits are the combination of various different single components. Only a proper function of every single element and it's proper adaption to the other ones allows a functioning of the total circuit.

Depending on the tolerances of single components the reliability of the total circuit is influenced. Too high tolerances can result in improper functioning of the circuit, too high tolerances can lead to unnecessary high production costs. Appropriate quality and reliability of passive components are

therefore a permanent issue in circuit design.

Also lead wires have their impact on component's quality, reliability and price, as there are:

- different materials of lead wires
- with it's different physical properties
- it's different material costs and
- different technologies for connecting the component (by welding/soldering) to the leads.

3. PHYSICAL DEMANDS ON LEAD WIRES

Lead wires for passive components have to fulfill various requirements:

- conducting the current from the circuit to the component
- fixing and stabilizing the component on the board
- granting thermal protection against thermal stress.

Therefore lead materials are selected in regard to:

- Physical properties

- Electrical resistance
- Thermal conductivity
- Thermal expansion coefficient
- Tensile strength
- Elongation
- Surface hardness

- Process properties

- Soldering / welding properties
- Dimensional properties - diameter and length
- Bending/placing properties
- Abrasion strength
- Ageing characteristics

Further informations to some of those selection criteria has already been given in previous CARTS papers [1] and [2].

4. LEAD WIRE MATERIALS

There are different materials for lead wires and appropriate coatings. Materials are:

- Copper
- Bronze
- Nickel - Silver
- Brass
- Nickel
- Nickel - Iron
- CCS 30 , CCS 40
- Steel

Short sections of these coated wires are connected to the component itself by welding or soldering. In the following chapters specific attention is given to specific materials and specific parameters of the connecting process.

5. MODIFIED STEEL WIRES AS REPLACEMENT FOR CCS WIRES

CCS wires are specified in many applications whenever:

- high tensile strength (350 N/mm² - 700 N/mm²)
- appropriate electrical and thermal resistance and
- high stability on the PCB

are needed.

Compared to copper CCS materials have a higher tensile strength and can better balance thermal requirements during

- placing the component onto the board or
- during operation.

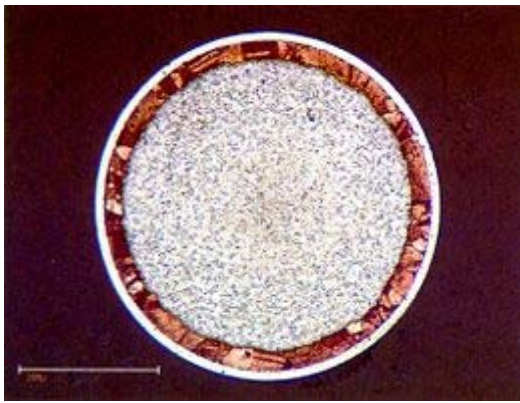


Fig. 1: CCS 30 Wire

The lower thermal coefficient of CCS 30 - 134 W/mK - or CCS 40 - 172 W/mK- compared to copper -380 W/mK - gives protection against thermal stress coming from the the soldering process during board-placement.

During operation - specifically some resistor types are concerned - a certain percentage of copper is needed to let the heat disappear from the component via the leads.

Due to its sophisticated production process the use of CCS material is rather cost intensive. Fig 2 shows steps of the production process.

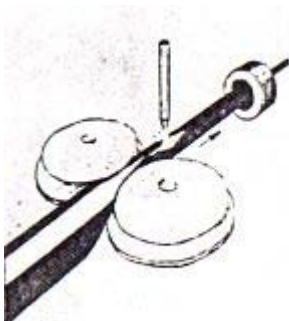


Fig. 2: Production Process of CCS Wire

As shown there are single steps like:

- Feeding the iron core
- Feeding the copper strip
- Forming the copper strip around the iron core

- Welding the copper strip
- Cladding the material to finer diameters
- Unnealing process

Due to cost reasons EDELHOFF introduced a modified material FeNiCu for specific applications instead of CCS [3], which can as well balance electrical, thermal and mechanical properties of the leads and which can be less expensive. Special types of such materials has been tested successfully as leads for film capacitors, such as FeNiCu06Sn.

For specific applications the copper layer can be reduced to zero. The FeNi material, which is coated to FeNiSn doesn't need a cladding process and is therefore less cost intensive.

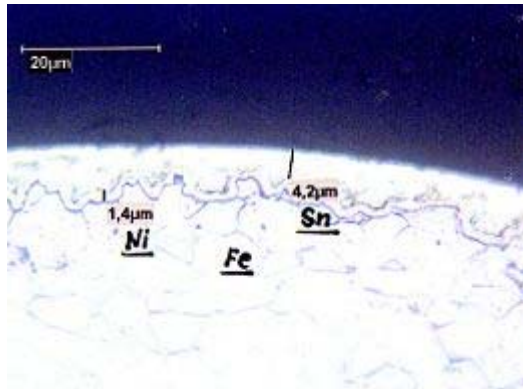


Fig. 3: FeNiSn Wire

Steps of the production process of FeNi wires are:

- Drawing of the iron wire to a finer diameter
- Unnealing process
- Coating process with Ni

The final coating is done with Sn/Pb alloy or - future orientated - with pure tin. FeNiSn materials are existing lead materials being used for specific resistor applications. Fig. 4 shows some technical data.

Material	Ø [mm]	Layer Thickness [µm]		Electrical Conductivity $\frac{m}{\Omega \cdot mm^2}$	Electrical Resistance $\frac{\Omega \cdot mm^2}{m}$	Thermal Conductivity $\frac{W}{m \cdot K}$
		Ni	Cu			
FeNi02	0,5	2	-	8,5	0,117	57
CCS 30	0,5	-	32,5- 36,3	20,408	0,049	134
CCS 40	0,5	-	50- 65	26,315	0,038	172
Steel	0,5	-	-	8,3	0,120	50

Fig. 4: Technical Data
FeNi02 compared to CCS and Steel

FeNi02Sn has a relatively low thermal conductivity - 57 W/mK . This low conductivity gives protection against thermal stress. Therefore:

- **FeNiCuSn** as soldered radial lead of film capacitors and

- **FeNiSn** as welded lead wires for specific resistors

can be cost reducing materials instead of some CCS types. Anyway, all significant physical, mechanical and electrical factors / properties have to be considered to find the appropriate material / coating - combination.

As EDELHOFF worked out a lot of combinations, further informations should be given to the welding / soldering process of lead wires to components.

6. WELDING PROCESS OF LEADS TO FILM CAP

Fig. 5 shows the welding process of leads to a film capacitor.

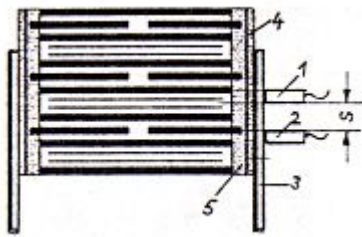


Fig. 5: Lead Wire Welding

In most cases a resistance welding process is used set up a connection between leads and film capacitors. Two conducting electrodes (1) and (2) let heat up the tinned lead (3), which is pressed against the conducting sputtered conducting layer of the film capacitor (4). This sprayed layer mostly consists of two different layers, one is Zn or Al (5) , the other Sn/Zn/Cu or Sn/Cu (4).

The residual resistance R of the specific welding zone comes from the combination of the single resistances:

- R1 Resistance of the metal electrode
- R2 Contact resistance between electrode and wire
- R3 Resistance of the lead wire
- R4 Contact resistance between lead wire and sputtered layer on the film capacitor
- R5 Resistance of the sputtered layer

The produced heat-energie Q in a certain time t is calculated from

$$Q = I^2 \cdot R \cdot t$$

The heat leads to a melting of the coating of the lead wire and a melting of the sputtered/sprayed layer as well. Both molten alloys set up the connection between lead wire and capacitor.

The soldering / welding process is influenced by a number of various factors:

- Material of the electrodes
- Contour of the electrodes
- Force, with which the eletrodes press the leads
- Distance of the electrodes
- Curve of the voltage
- Soldering time
- Solder current

- Thickness of the Sn coatings
- Thermal conductivity of the lead wire and the contacted cap

The following figures 6 and 7 are showing the impact of soldering time and electrode-distance on fixing force between lead wire and capacitor.

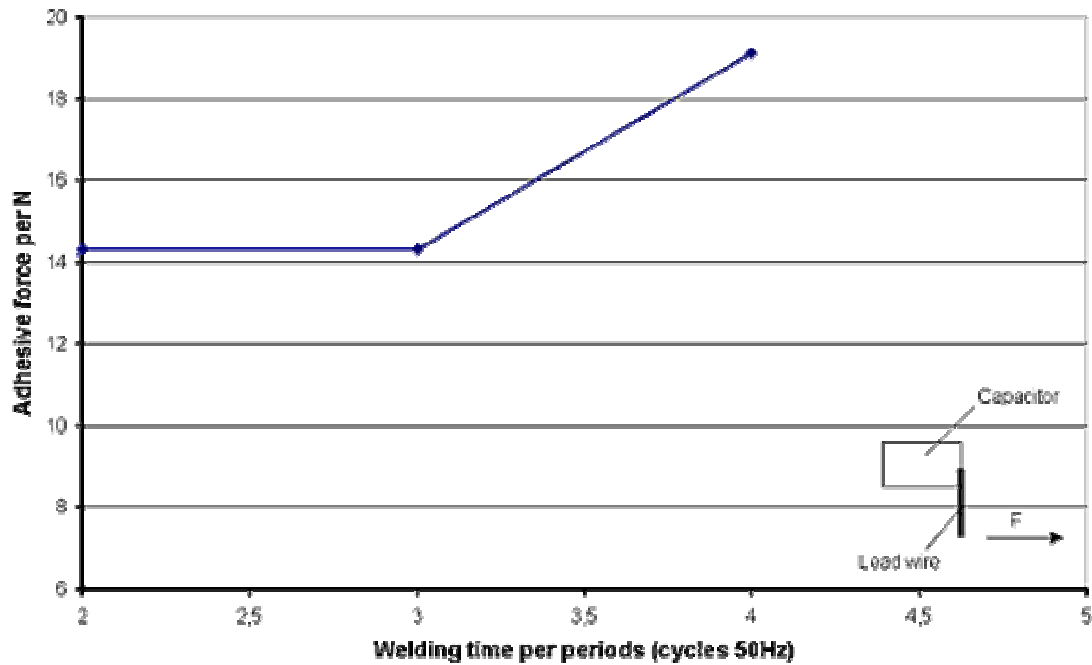


Fig. 6: Impact of Soldering Time on Fixing Force of the Wire

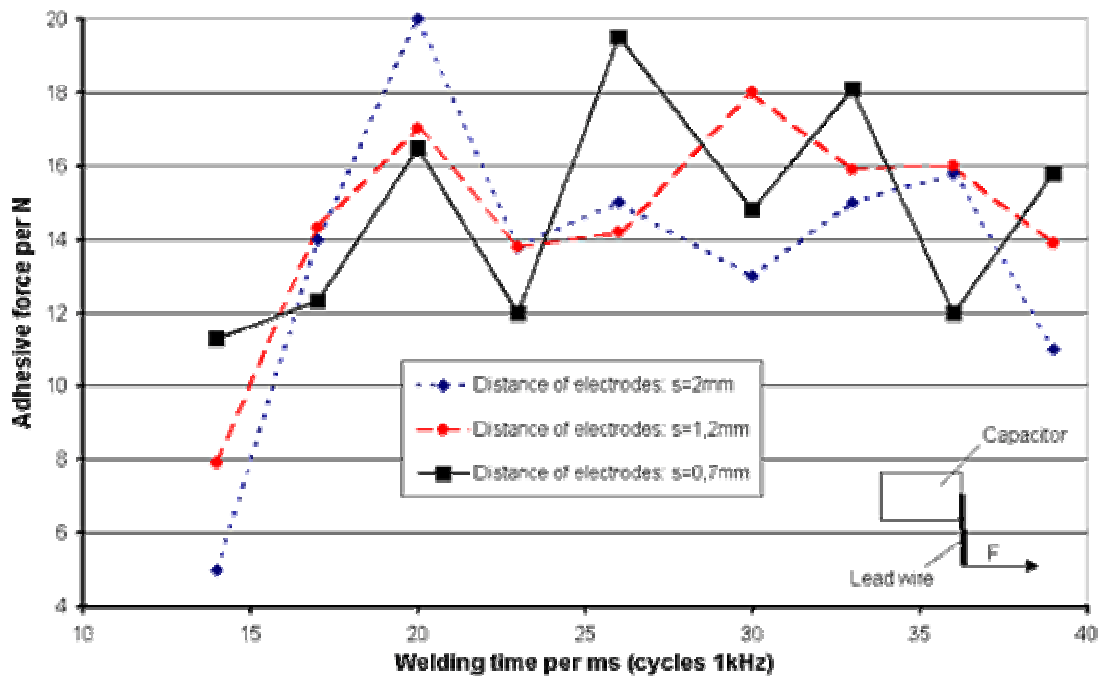


Fig. 7: Impact of Soldering Time and Electrode Distance on Fixing Force of the Wire

Due to the number of factors, which influence the quality of the soldering-joint, examples of proper and insufficient solderings should be shown in the following figures 8 to 13. Lead wires are always connected to film capacitors.

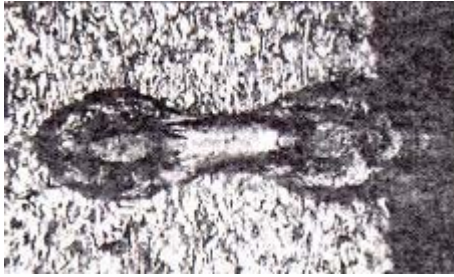


Fig. 8: Soldering ok

Parameters: $t=21\text{ms}$; $I=271\text{A}$; $s=2\text{mm}$; $F_e=15\text{N}$; $\varnothing 0.5\text{mm}$; $F=16.3\text{N}$

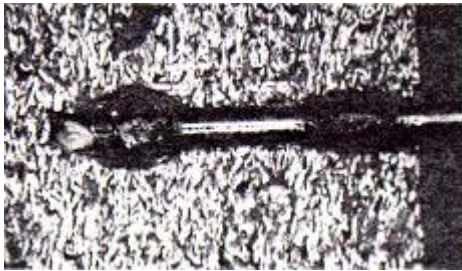


Fig. 9: Soldering not ok;

Welding Time too short

Parameters: $t=14\text{ms}$; $I=250\text{A}$; $s=2\text{mm}$; $F_e=15\text{N}$; $\varnothing 0.5\text{mm}$; $F=11\text{N}$

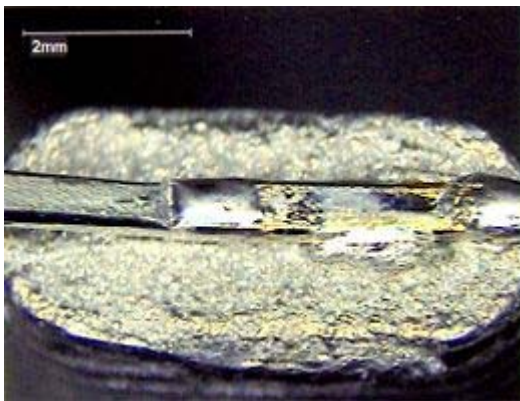


Fig. 10: Soldering ok

Parameters: $t=60\text{ms}$ 3 periods; $U=97\text{V}$; $s=2\text{mm}$; $F_e=7\text{N}$; $\varnothing 0.6\text{mm}$; $F=14\text{N}$



Fig. 11: Soldering not ok

Parameters: $t=60\text{ms}$ 3 periods; $U=97\text{V}$; $s=2\text{mm}$; $F_e=6\text{N}$; $\varnothing 0.6\text{mm}$; $F=11\text{N}$

Fig. 11 shows a constellation, where the force F_e , which presses the electrodes onto the leads, is too low. Therefore the lead doesn't connect the capacitor properly, the resistance R becomes too high and the heat energy Q becomes too high as well. As a result the coating on the leads burns off,

pure copper (oxide) can be seen; the component has an electrical defect.

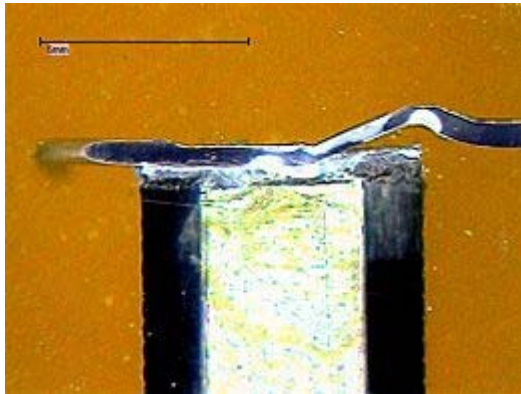


Fig. 12: Soldering ok
Parameters: $t=60\text{ms}$ 3 periods; $U=92\text{V}$; $s=2\text{mm}$; $F_e=8\text{N}$; $\varnothing 0.6\text{mm}$; $F=12\text{N}$

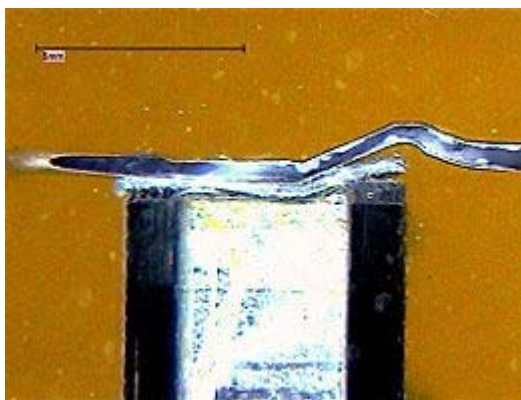


Fig. 13: Soldering not ok
Parameters: $t=60\text{ms}$ 3 periods; $U=97\text{V}$; $s=2\text{mm}$; $F_e=6\text{N}$; $\varnothing 0.6\text{mm}$; $F=11\text{N}$.

Force F_e is too high. The sputtered layer becomes brittle and separates from the capacitor. There is an electrical defect.

7. WELDING PROCESS OF LEADS TO RESISTORS

Fig. 14 shows a typical leaded resistor.

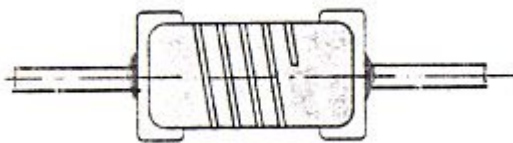


Fig. 14: Leaded Resistor

Resistance welding technology is needed to connect the axial lead wires to the metal caps on side of every resistor component. Mostly the caps are consisting of nickel-plated steel. In comparison to the soldering process on film capacitors the welding on resistors is done by melting the core wire to the caps itself. This means that significantly higher temperatures - up to at least 1535°C - occur (melting point Fe).

The produced heat-energie Q in a certain time t is again calculated from

$$Q = I^2 \cdot R \cdot t$$

The molten core sets up a connection with the molten surface of the nickel-plated steel cap.

Influence factors to proper connections are similar to the previous case, where capacitors were concerned:

- Material of the electrodes
- Contour of the electrodes
- Force, with which the electrodes press the lead wire
- Distance of the electrodes
- Curve of the voltage
- Soldering time
- Solder current
- Thickness of the Sn coatings
- Thermal conductivity of the lead wire and the contacted cap

The following figures show proper and improper weldings on leaded resistors. The reliability of a weld is tested by bending the wire at the cap for several times by 90°. The more bendings are possible, the better is the weld. In the very end there should be a breakage of the wire instead of the weld. A breakage of the weld itself is basing on a poor welding, a breakage about 0.5mm to 1mm away from the welding zone shows a good weld.

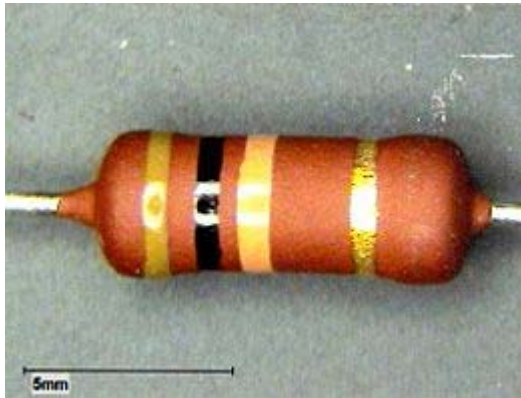


Fig. 15: Leaded Resistor

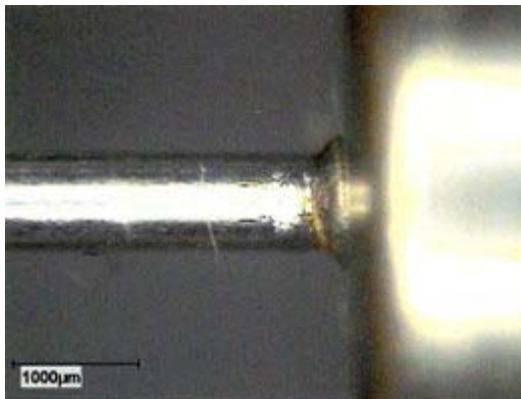


Fig. 16: Lead Wire $\varnothing 0.8\text{mm}$, CCS 40, Welding ok, 9 Bending Cycles

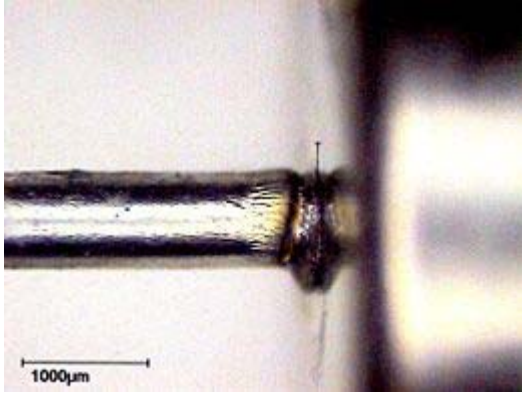


Fig. 17: Lead Wire Ø0.8mm, CCS 40, Welding not ok, 4 Bending Cycles; Force Fe is too low, Resistance R becomes too high, Materials get burned

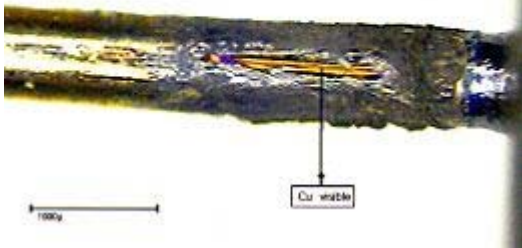


Fig. 18: Lead Wire Ø0.8mm, FeNiCuSn, Welding not ok, Welding Temperature too high, Thermal Conductivity of the Lead too low, Sn Coating gets burned, Copper Core visible

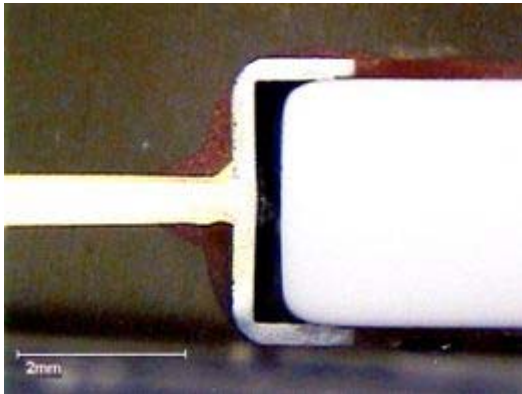


Fig. 19: Cross Section of a Resistor with Cap and Lead Wire

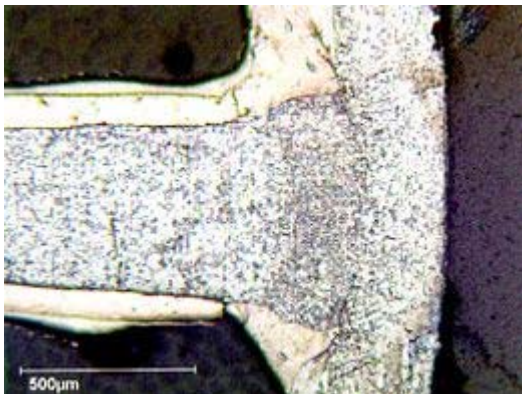


Fig. 20: Cross Section, CCS 40, Ø0.8mm

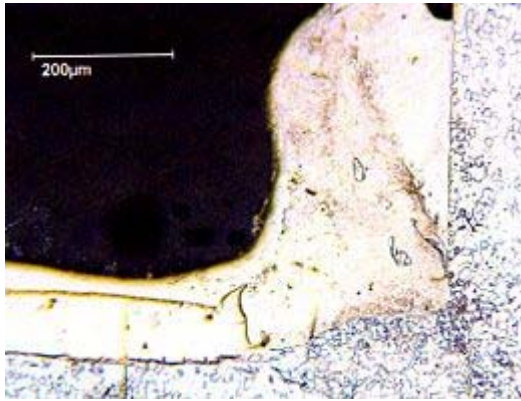


Fig. 21: Detailed Section of Fig. 20 near the Welding Zone

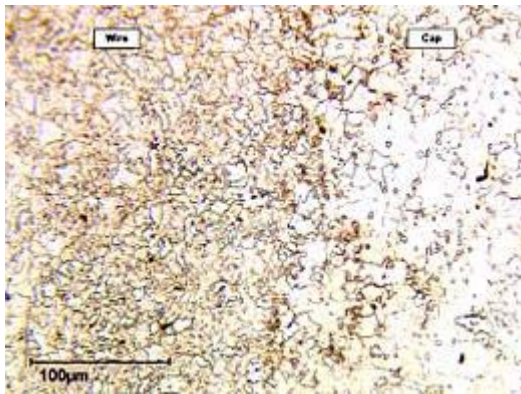


Fig. 22: Detailed Section of Fig. 20 - Welding of Lead with Cap

Figures 20 to 22 demonstrate an excellent welding. As shown in Fig. 21 the welding process created an alloy Cu/Sn/Fe, which increased the strength of the weld. Fig. 22 shows the grain structure of the lead at the welded cap. As there is no visible zone, where different materials are apparent, a proper welding between lead and cap can be shown.

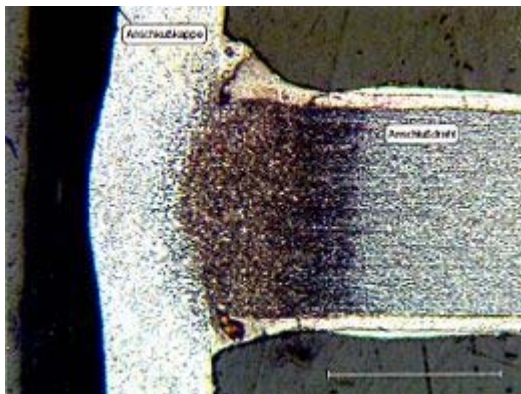


Fig. 23: Cross Section CCS 30, Ø0.8mm; excellent Weld between Lead and Cap, Alloyed Material

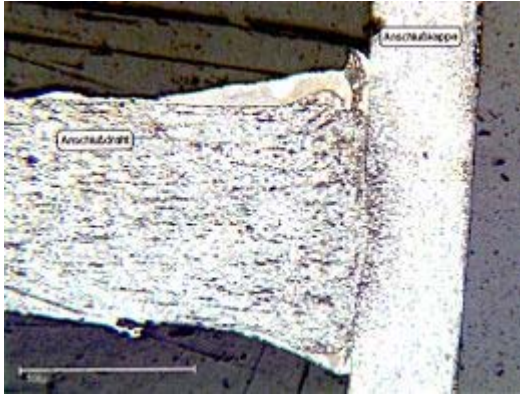


Fig. 24: Cross Section FeNiCuSn 30, \varnothing 0.8mm; Poor Weld between Lead and Cap, Force Fe is too low, Welding Temperature too low, Separated Material Zone between Lead and Cap visible

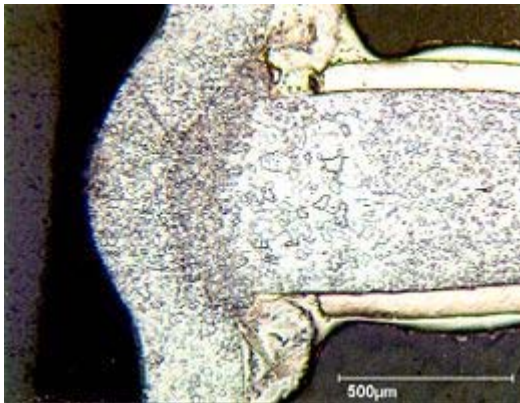


Fig. 25: Cross Section CCS 40, \varnothing 0.8mm

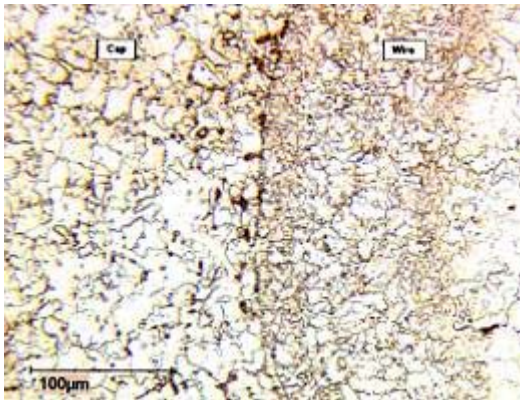


Fig. 26: Detailed Section of Fig. 25 - Welding of Lead to Cap

The welds shown in Fig. 25 and 26 are sufficient, but not excellent. The partially visible zone with different materials shows that there was no melting to an alloy in every section of the welding zone. There was a breakage after 6 bending cycles.

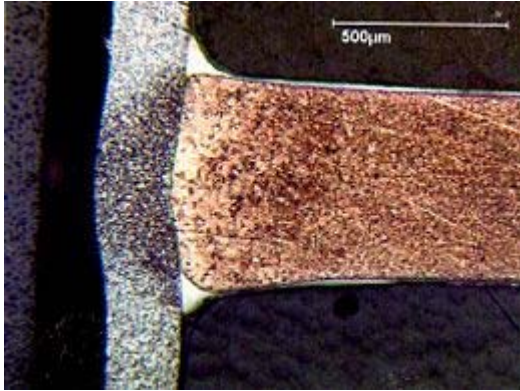


Fig. 27: Cross Section, Cu, Ø 0.6mm

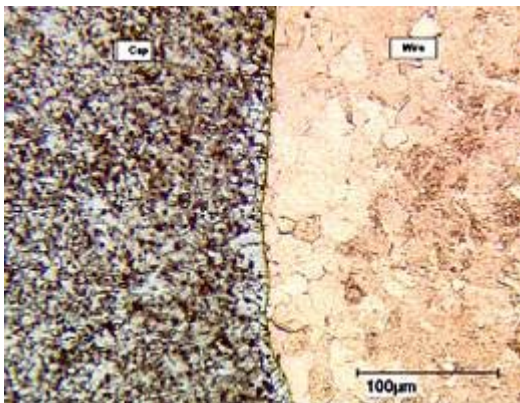


Fig. 28: Detailed Section of Fig. 27 - Welding of Lead to Cap

Figures 27 and 28 show a very good welding of a copper wire with a nickel plated cap (9 cycles to breakage). In the melting zone (Cu wire / cap) there is a modified CuFe alloy consisting of about 4% Fe [4]. The surrounding weld is set up properly, the tin coating is still existing without being burnt, as the copper wire was able to balance the heat during the welding process.

8. CONCLUSIONS

As shown in the previous chapters there are the following conclusions:

- Physical properties of materials being used as lead wire have a significant impact on the reliability and function of a passive component.
- In regard to the physical properties and specific input factors there are low cost alternatives to CCS wires, such as

FeNiSn for resistors and
FeNiCuSn for capacitors.

- A major focus has to be given to a proper welding / soldering between lead wire and resistor / capacitor.

Examples concerning proper and improper welds were shown. Input factors to the welding/soldering process has been described. Material properties and parameters within the welding / soldering process has to be adapted to get a proper connection between lead wire and component itself.

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