Reliability of SnAgCu composite solder joints in a corrosive environment

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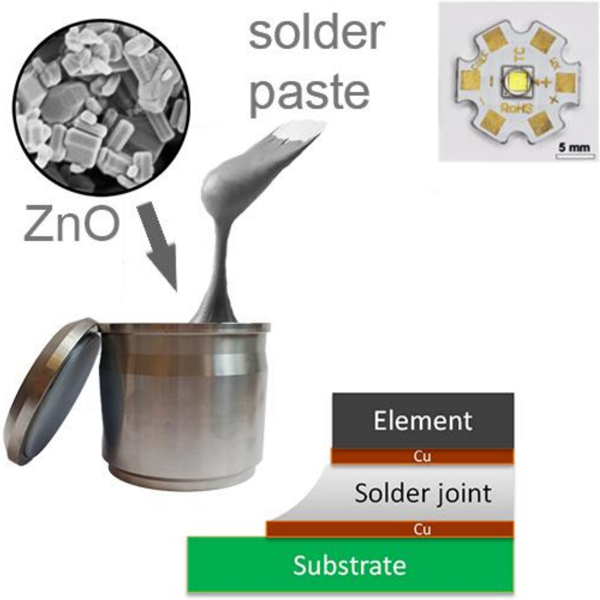
Outline/Agenda

- *Introduction composite soldering*
- *Materials and methods*
- *Results of TiO_2*
- *Results of ZnO*
- *Results of SiC*
- *Results of CuO*
- *Results of ZrO_2*
- *Results of Al_2O_2*
- *Conclusions*
- *Q & A*

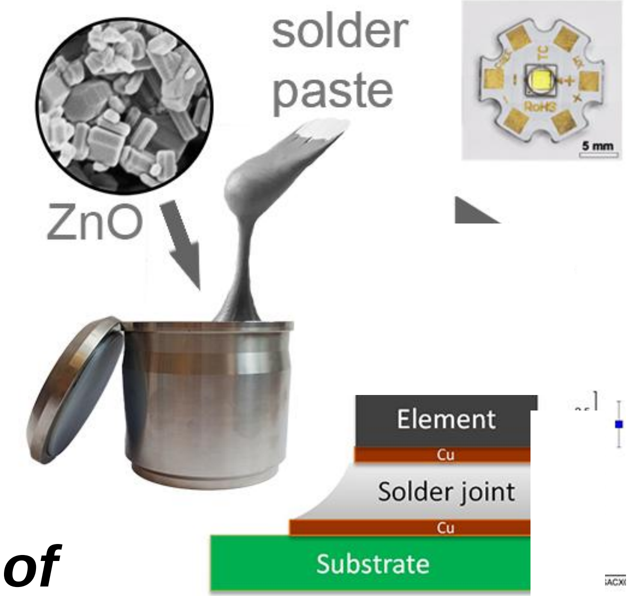
Composite soldering

- ***Composite solder paste:*** adding reinforcement particles – ceramics, IMCs, graphene, etc. – into the solder paste in 0.05-2 wt%.
- Particles are usually nano-sized, <100nm.
- ***State of the art***: most of the researches investigated bulk the solder alloy and not solder joints.



Composite soldering

- **Why composite soldering? ->** NPs improve the solder joints’ mechanical properties.
- It is caused by dispersion-strengthening mechanisms. The NPs refine the grain structure of the solder matrix.
- Aim: investigate the ***quality and reliability of SAC0307-(SiC/ZrO$_2$/CuO/ZnO/Al$_2$O$_3$/TiO$_2$)*** composite solder joints.



Materials and methods

Solder paste:

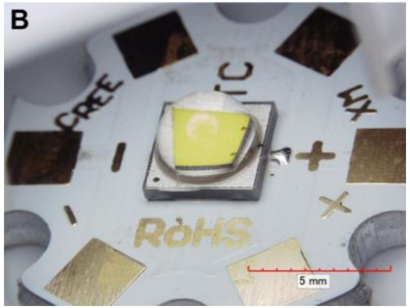
- Sn99Ag0.3Cu0.7 (SAC0307)

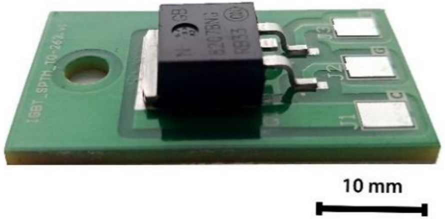
Nano-particles (NPs)

- Weight fraction 0.1-1wt%:
- Primary particle size <100nm
- Form: nano-powder and fiber

NPs were mixed into the solder paste by a solder paste mixer (10mins and 400rpm)

Materials and methods





Wetting test:

- Standard spread test (IPC-650)

Mechanical test:

- Shear strenght measurements (IPC-650),
- 0603 SMD chip resistors soldered on PCB.

Thermal and optical test:

- Thermal resistance (on LEDs and FETs.) and luminous efficiency (on LEDs) measurements.

Materials and methods

Wetting test:

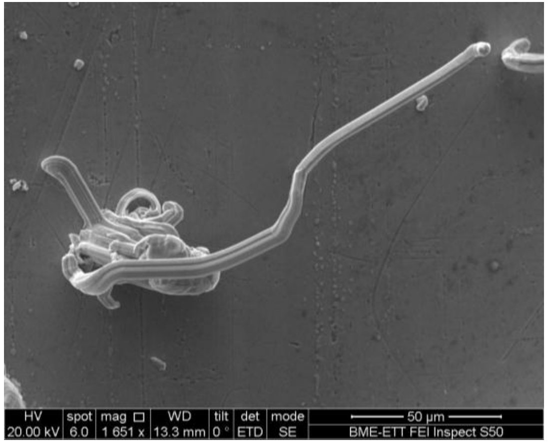
- Standard spread test (IPC-650)

Mechanical test:

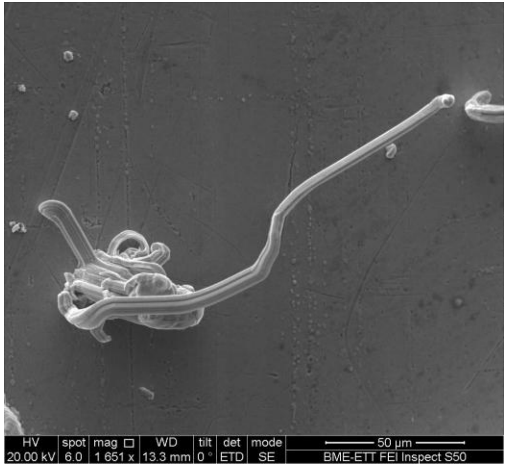
- Shear strenght measurements (IPC-650)
- on 0603 SMD chip resistors soldered on PCB.

Reliability test:

- TH test 85ºC/85RH% for 3000h: corrosion resistance and ***Sn whisker growth***

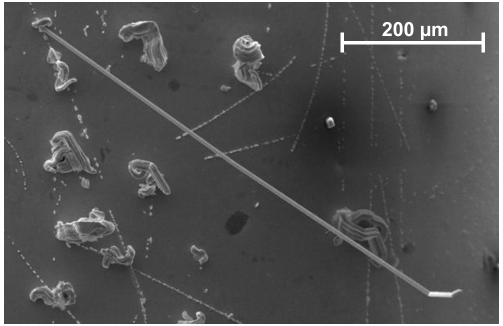


Materials and methods – Sn whiskers



Reliability test:

- TH test 85ºC/85RH% for 4000h: corrosion resistance and ***Sn whisker growth*** *(reliability issue)*
- Conductive whiskers „spontaneously” grow from Sn surfaces

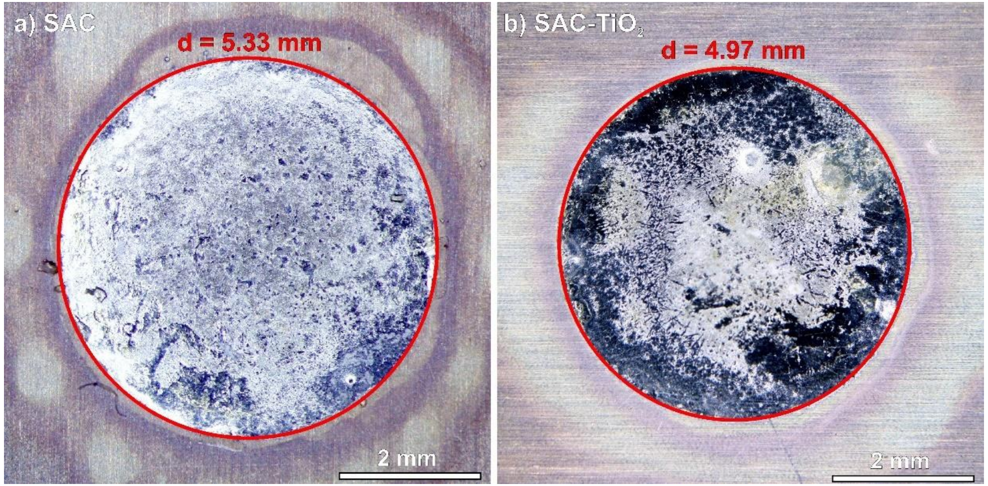


Mechanical stresses cause whiskering:

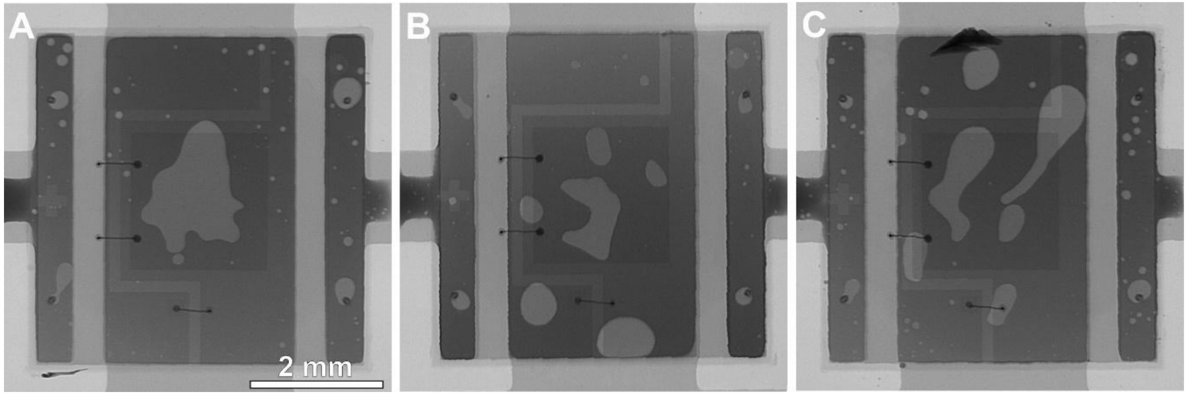
- residual stress in the Sn layer, direct external mechanical load,
- volumetric expansion (by intermetallic or ***oxide growth***), thermomechanical effects.

TiO_2 - Quality

- *Minor decrease (~1%) of wetting in the case of TiO_2.*
- ***No change in voiding.***



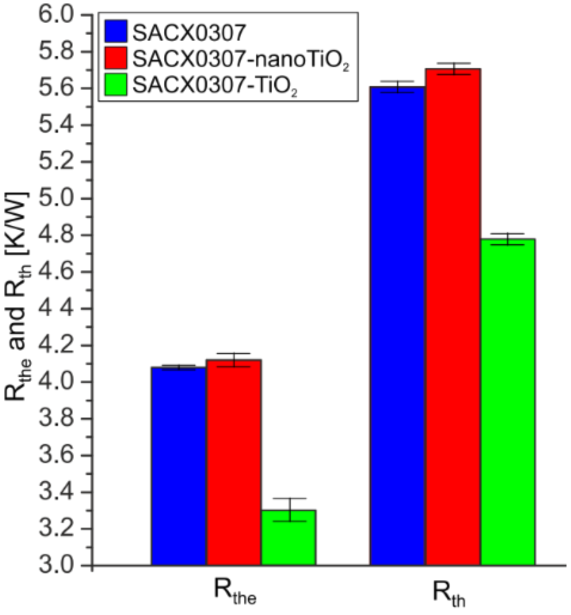
*B. Illés et al. Comparing the solderability of different SAC0307 composite solder pastes, Proc. of 23rd EMPC conference, Cambridge, England, 2023, pp. 1-4.
**A. Skwarek et al., Microstructure Influence of SACX0307-TiO2 Composite Solder Joints on Thermal Properties of Power LED Assemblies, Materials 13 (2020) 1563.



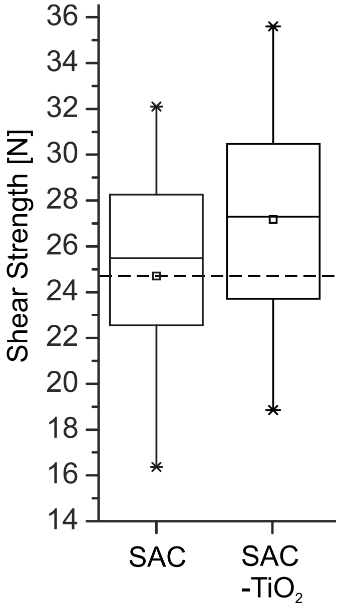
X-ray images of the solder joints under the LED component: (A) SACX0307 sample; (B) SACX0307-nanoTiO_2; (C) SACX0307-TiO_2.

TiO_2 - Quality

- ***TiO_2 NPs increased the shear strength (as reflowed) with 10%,***
- TiO_2 NPs decrease R_{th} and R_{the} of the LEDs by 20% and 16%, and it slightly increases the luminous efficiency.



Thermal resistance (R_{th}), electric thermal resistance (R_{the}), of the LEDs.



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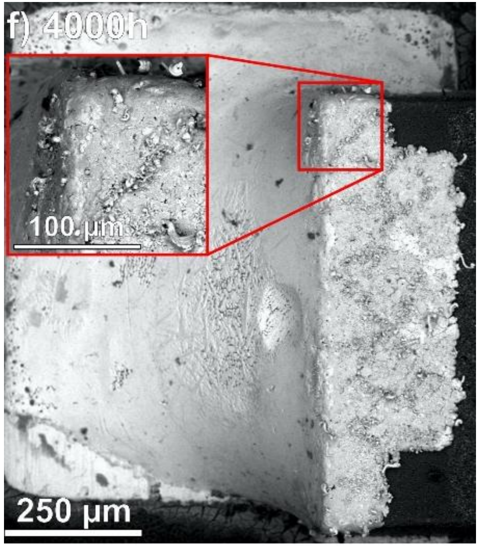
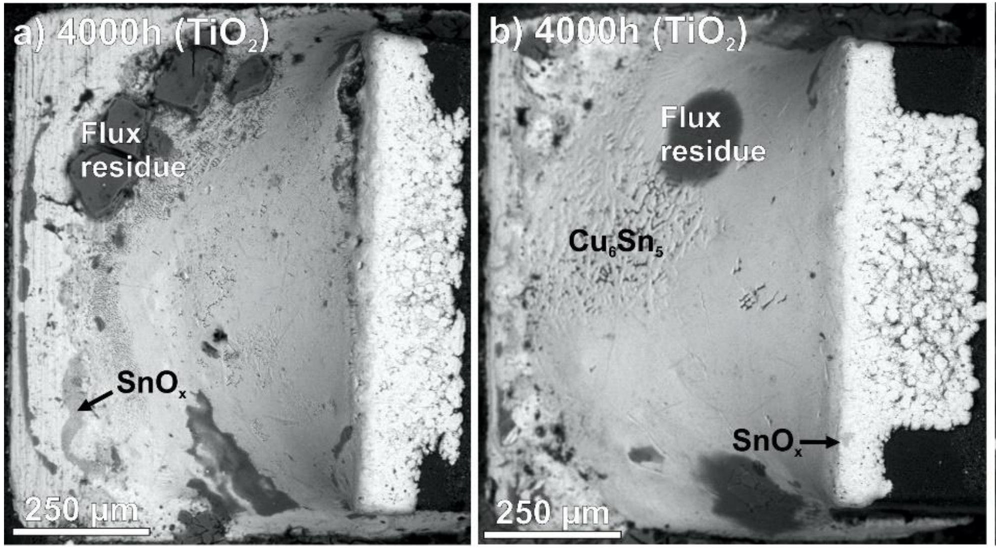
TiO_2 - Reliability

SAC0307-TiO2 after 4000h: TiO_2 NPs can improve the corrosion resistance of SAC alloys and suppress Sn whisker growth.

*B. Illés et al. Suppression of Sn whisker growth from SnAgCu solder alloy with TiO_2 and ZnO reinforcement nano-particles by increasing the corrosion resistance of the composite alloy, J. Mater. Res. Tech. 20 (2022) 4231-4240**.**



Ref. SAC0307

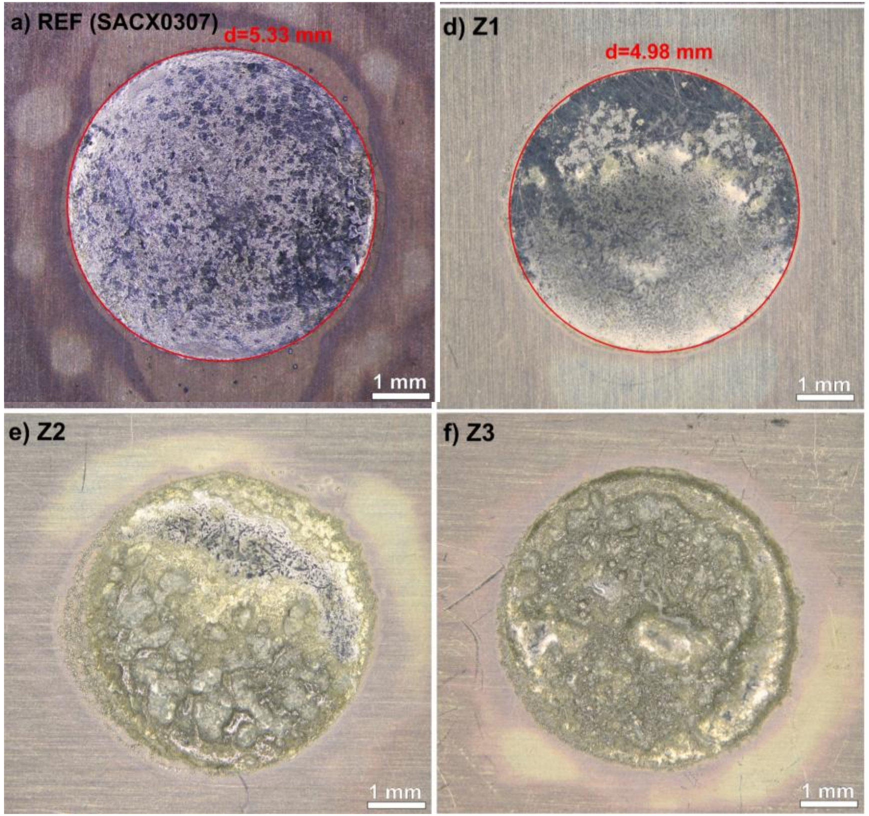


SAC0307-TiO_2

ZnO - Quality

- ***Over 0.5wt%*** and under ***100nm primary*** particle size, ZnO NPs can decrease the wetting and the shear force and increase the voiding of the composite solder joints.

*B. Illés et al. Comparing the solderability of different SAC0307 composite solder pastes, Proc. of 23rd EMPC conference, Cambridge, England, 2023, pp. 1-4.



Spreading test: (a) SACX0307; (d) SACX0307-1ZnO(200nm); (e) SACX0307-1ZnO(100nm); (f) SACX0307-1ZnO(50nm);

ZnO - Reliability

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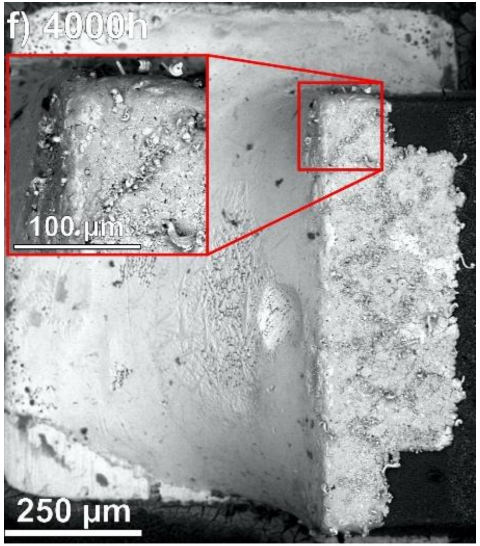

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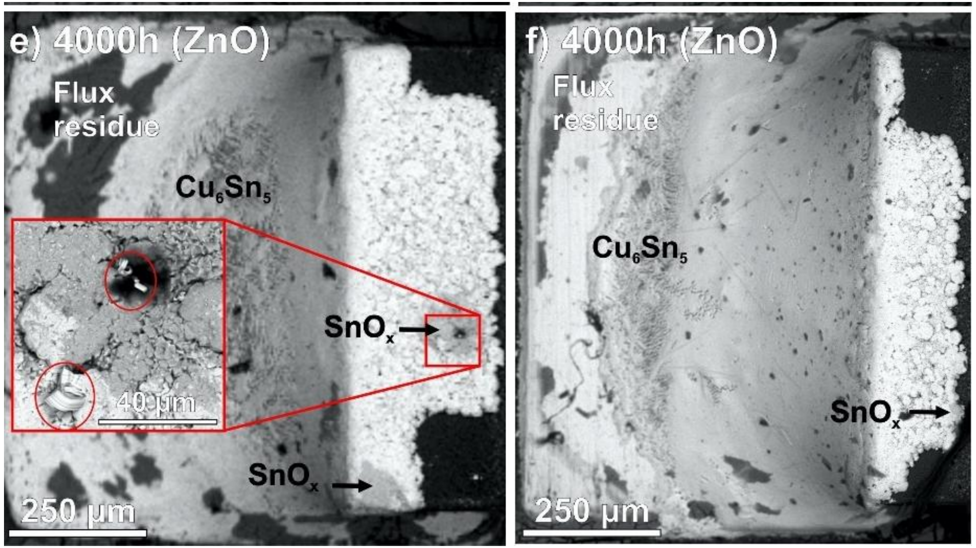
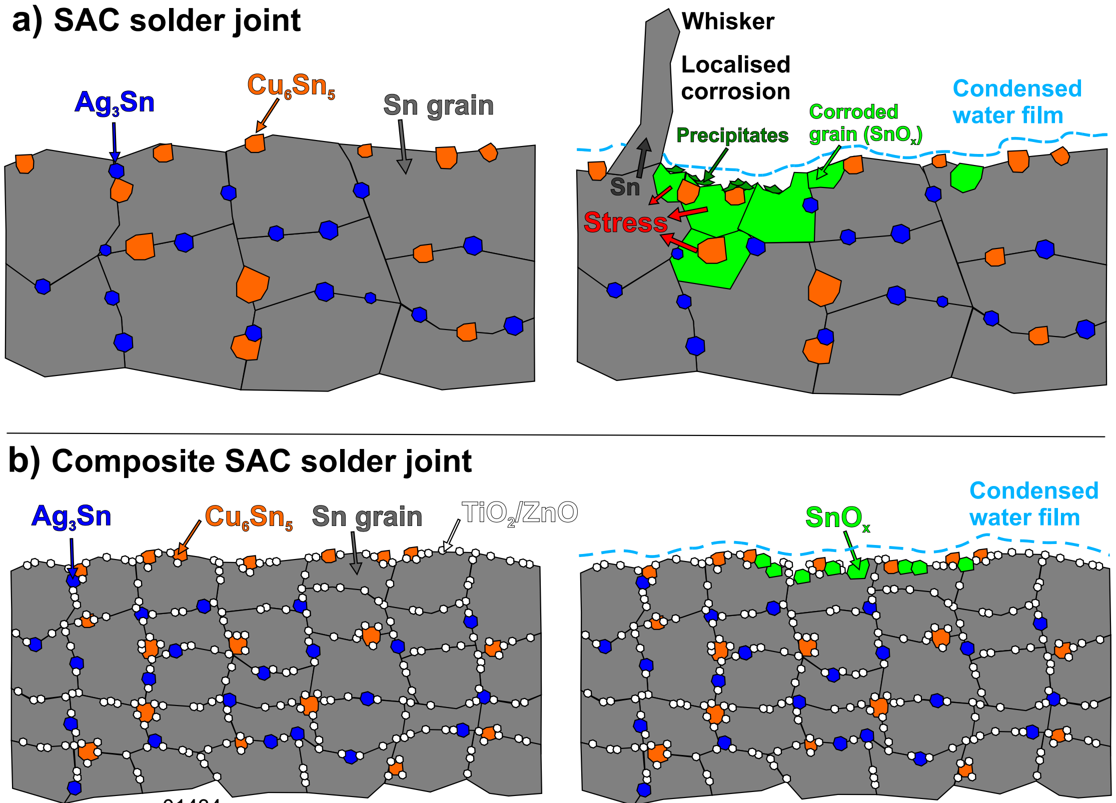


SAC0307-ZnO

Corrosion protection of TiO_2 and ZnO

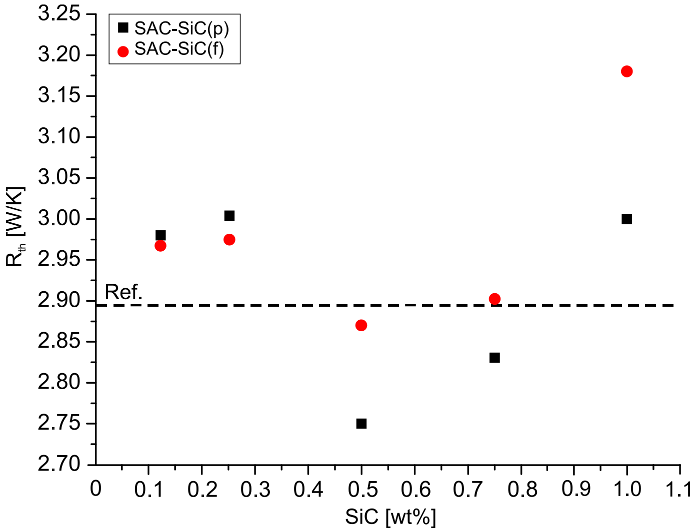
- TiO_2/ZnO NPs form a uniform and compact ***protective oxide layer*** at Sn grain boundaries.
- Contains stable ZnO/TiO_2-Sn bonds

*B. Illés et al. Suppression of Sn whisker growth from SnAgCu solder alloy with TiO_2 and ZnO reinforcement nano-particles by increasing the corrosion resistance of the composite alloy, J. Mater. Res. Tech. 20 (2022) 4231-4240**.**

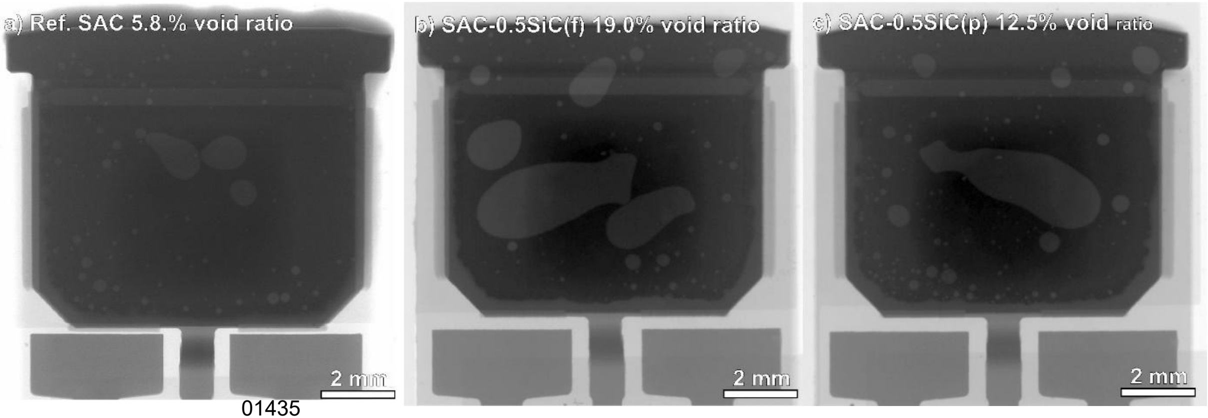


SiC - Quality

- *In appropriate amount (~0.5-0.75 wt%), SiC NPs can decrease the Rth of the solder joints of power MOSFETs.*
- *SiC NPs increased the voiding.*



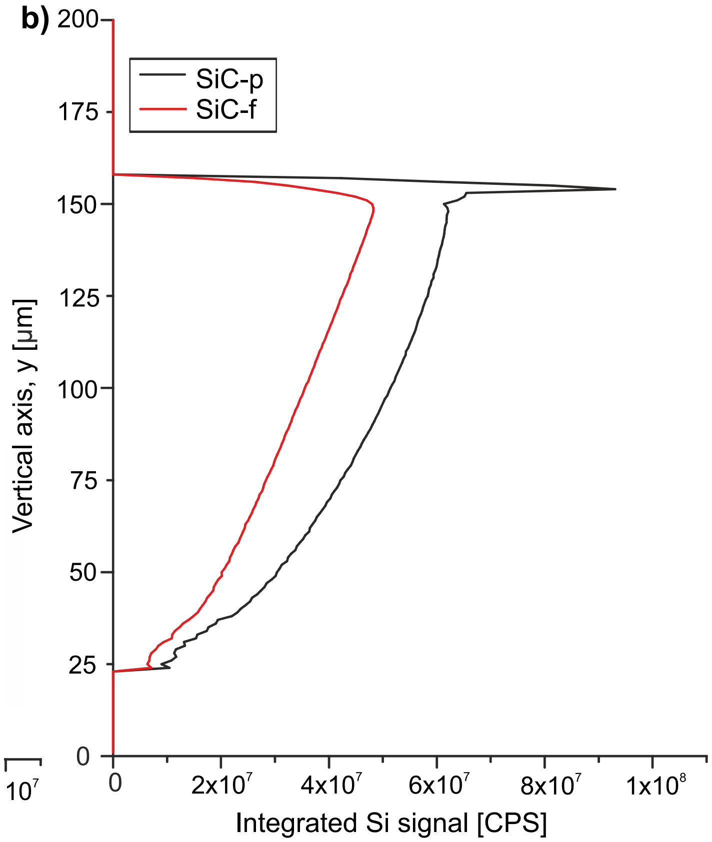
*A. Skwarek et al. Influence of SiC reinforcement on microstructural and thermal properties of SAC0307 solder joints, J. Mater Res. Tech. *22* (2023) 403-412.



SiC - Quality

- The distribution of SiC NPs was measured by SIMS on cross-sectioned SiC composite solder joints
- ***The distribution of the NPs is far from homogeneous in composite solder joints.***
- The distribution depends on the form of the NPs.

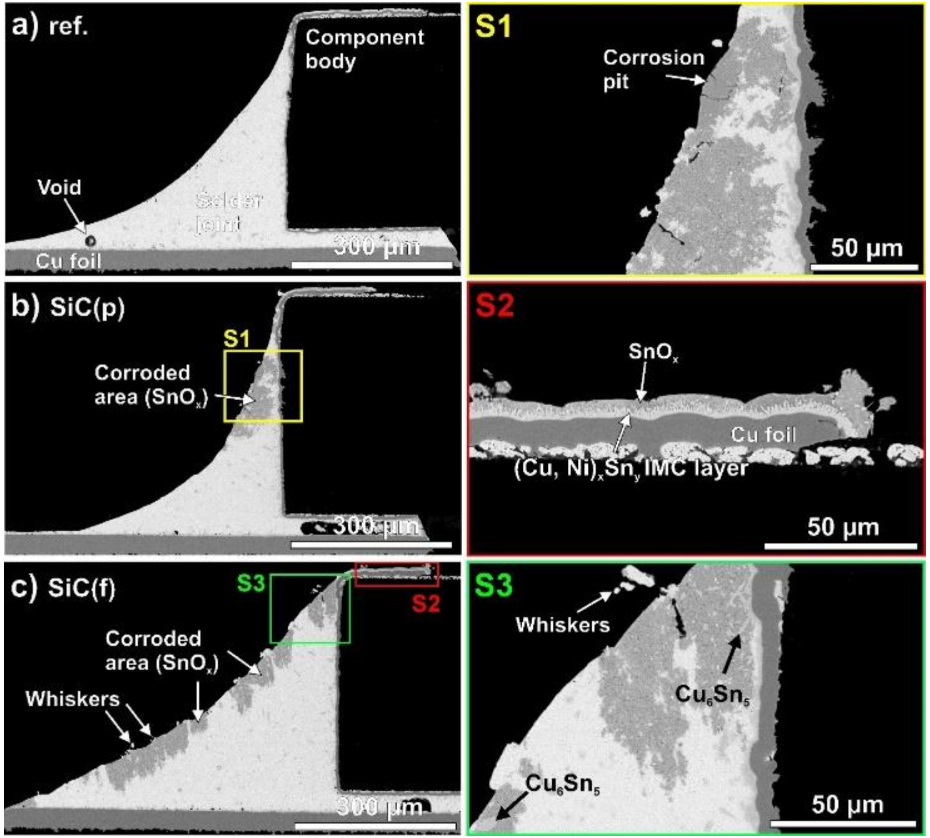
*B. Illés et al., Dispersion and incorporation of TiO2 and SiC nano-particles in SAC alloy: SIMS and DFT study, Scripta Mater. 243 (2024) 115987.



Integrated SIMS signal along the cross-sections of SiC composite solder joints in the case of nano-powder (p) and nano-fiber (f) forms.

SiC - Reliability

- **SAC0307-SiC after 4000h:** SiC NPs significantly decreased their corrosion resistance and enhanced the Sn whisker formation
- DFT proved that SiC can bond to Sn, but they are prone to corrosion.
- ***SiC NPs acting as corrosion incubation points*** in the solder matrix.



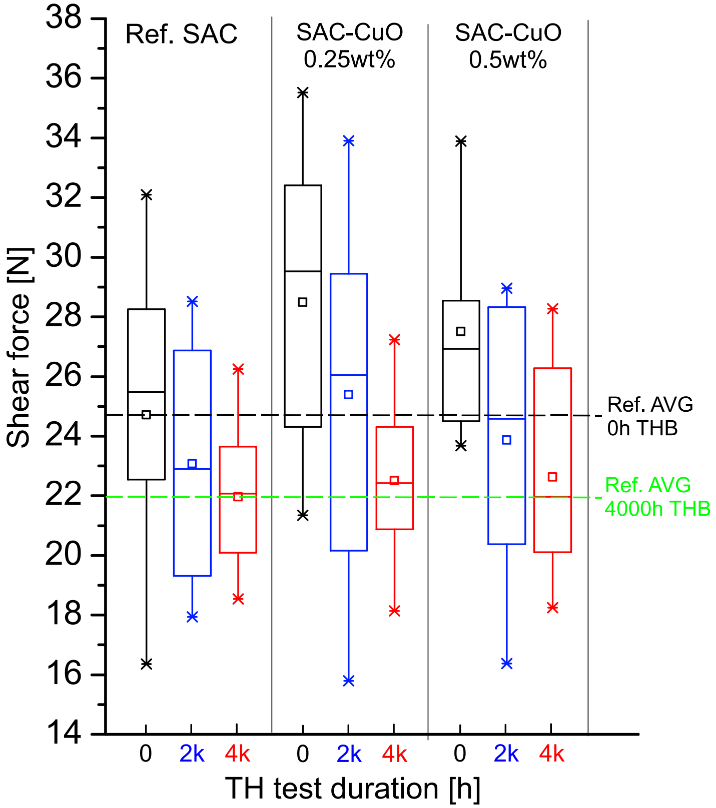
SEM-BSE micrographs of the cross-sectioned solder joints: a) ref. SAC; b) SAC-SiC(p)owder; c) SAC-SiC(f)iber.

*H. Choi et al. Corrosion problems of SAC-SiC composite solder alloys”, Corr. Sci. 224 (2023) 111488.

CuO - Quality

- CuO NPs does not influence the wetting performance
- ***CuO NPs can increase the shear force by ~20% in "as reflowed" state*.**
- This increase was consumed during a 4000 hour 85° C/85 %RH test

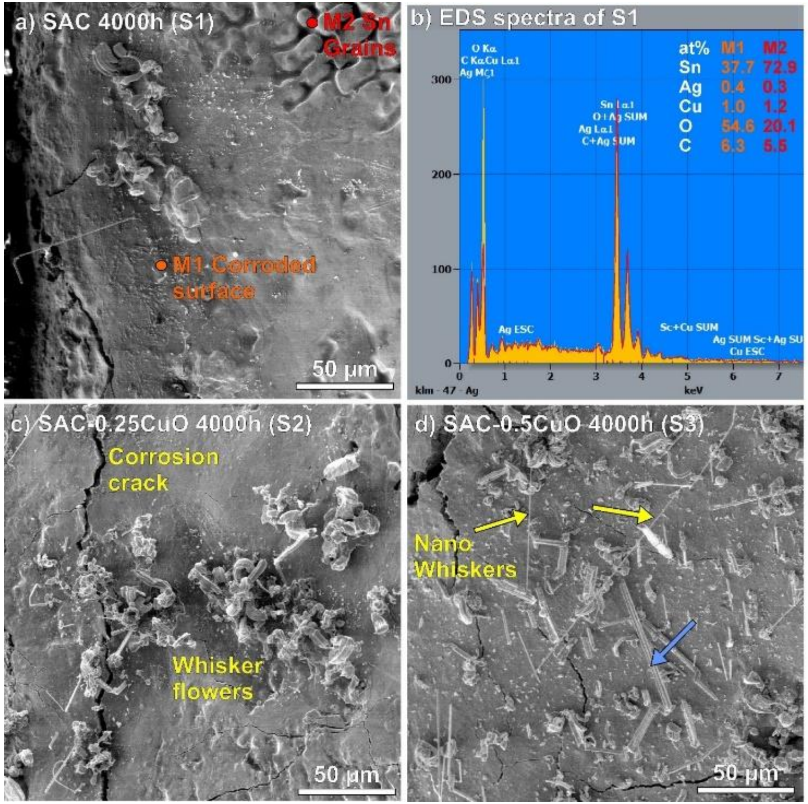
*B. Illés et al., Effects of CuO nanoparticles on SAC composite solder joints: Microstructural and DFT study, J. Mater Res. Technol. 32 (2024) 609-620.



Shear force statistics of SAC0307-CuO solder joints before and after a 4000 hours 85° C/85 %RH test.

CuO - Reliability

- Considerable shear force drop of the CuO composite joints was caused by their more ***serious corrosion***.
- Corrosion produced numerous ***Sn whiskers.***
- CuO can bond to Sn, but it prone to react with the Cu_6Sn_5 IMCs in the solder bulk, which results in the formation of SnO2 inside the solder bulk

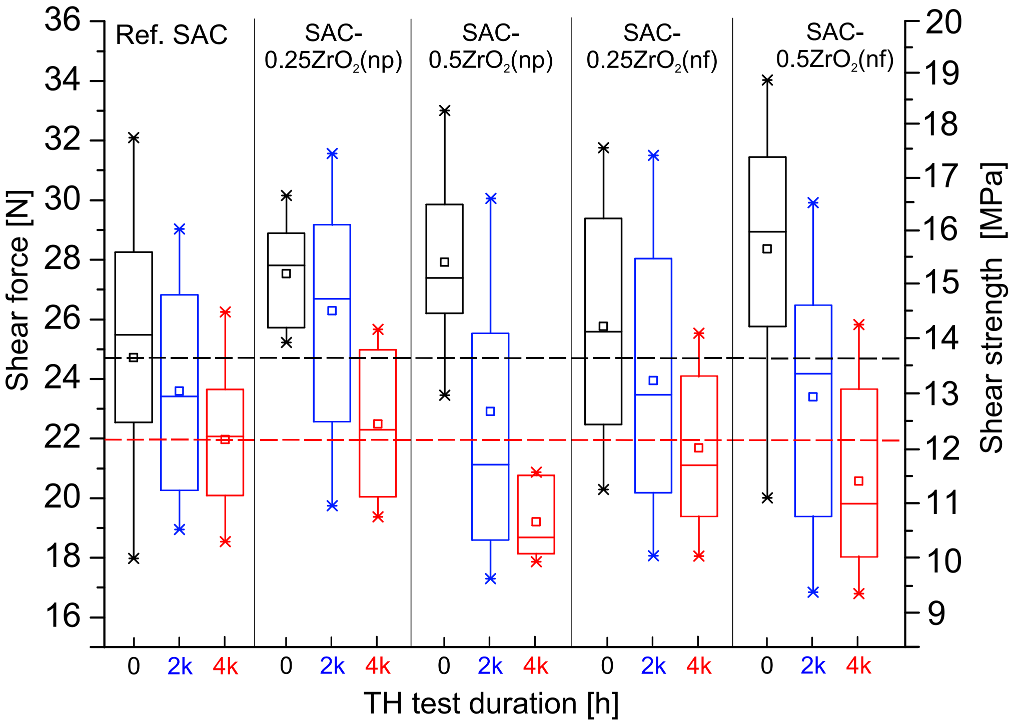


SEM micrograph of the Sn whiskers on the surface of the solder joints: a) SAC; b) EDS spectra of S1; c) SAC-0.25CuO; d) SAC-0.5CuO

*B. Illés et al., Effects of CuO nanoparticles on SAC composite solder joints: Microstructural and DFT study, J. Mater Res. Technol. 32 (2024) 609-620.

ZrO_2 - Quality

- Same behaviour as CuO
- No wetting effect
- ***Considerable shear force increase in “as reflowed” state***.
- This increase was consumed during a 4000 hour 85° C/85 %RH test

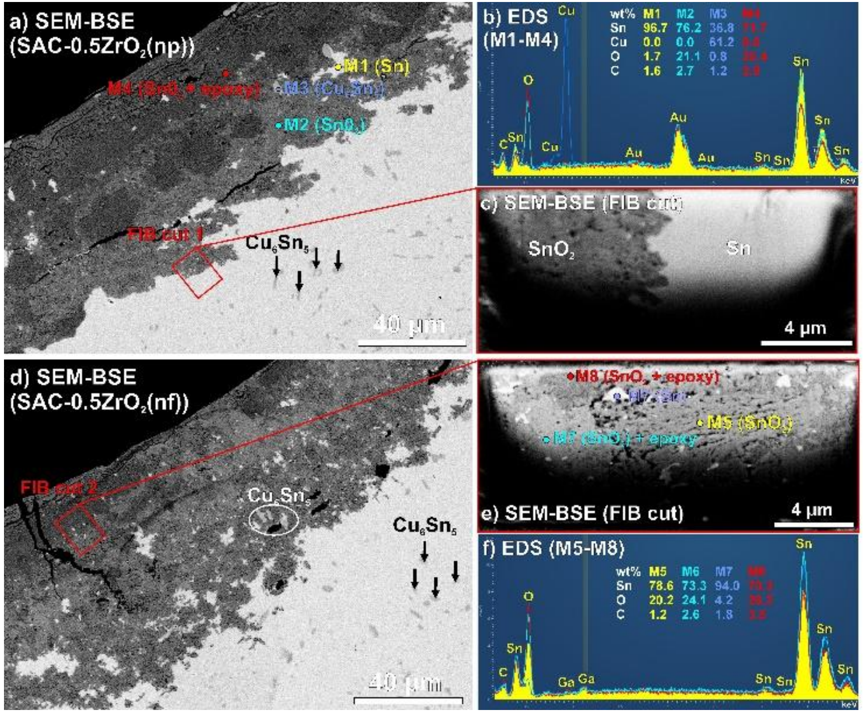


Shear force statistics of SAC0307-ZrO_2 solder joints before and after a 4000 hours 85° C/85 %RH test.

*A. Skwarek et al., Effects of ZrO2 Nano-Particles’ Incorporation into SnAgCu Solder Alloys: An Experimental and Theoretical Study, Nanomater. 14 (2024) 1636.

ZrO_2 - Reliability

- Considerable shear force drop of the CuO composite joints was caused by their more ***serious corrosion***.
- Corrosion produced numerous ***Sn whiskers.***
- The porose structure of SnO_2 can conduct the water into the solder bulk, which can enhance the penetration of the corrosion even more.

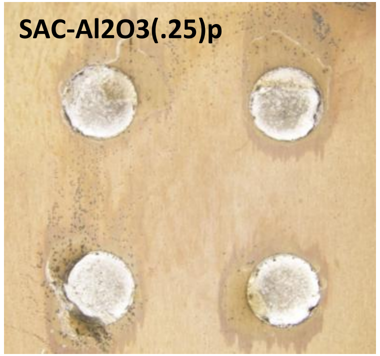


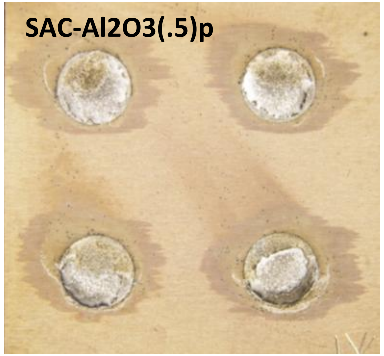
Localized corrosion in a SAC-ZrO_2 solder joint: a) SEM-BSE of SAC-0.5ZrO_2; b) EDS spectra (M1-M4); c) SEM-BSE of FIB cut 1; d) SEM-BSE of SAC-0.5ZrO_2; e) SEM-BSE of FIB cut 2; f) EDS spectra (M5-M8).

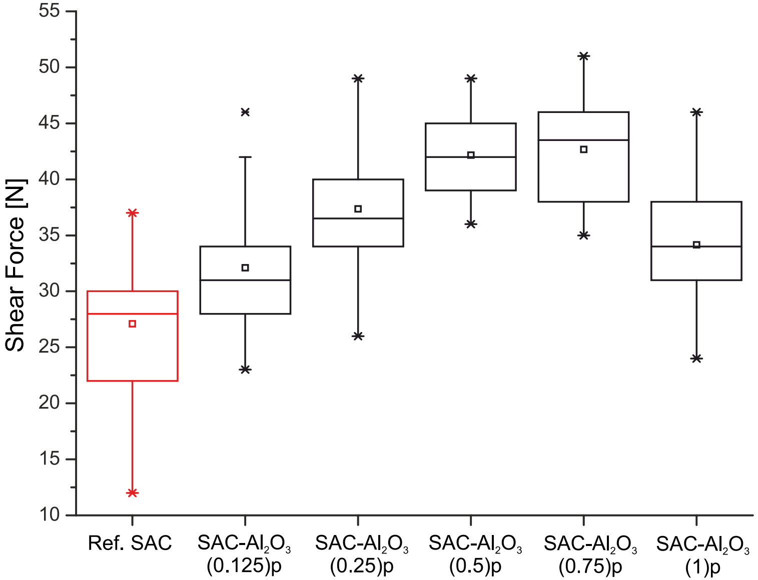
*A. Skwarek et al., Effects of ZrO2 Nano-Particles' Incorporation into SnAgCu Solder Alloys: An Experimental and Theoretical Study, Nanomater. 14 (2024) 1636.

Al_2O_3 - Quality

- ***Al_2O_3 nano-powder (0.25-0.5wt%) improved the wetting.***
- Al_2O_3 nano-fiber the did not have a effect on the wetting.
- ***Considerable shear force increase in "as reflowed" state.***

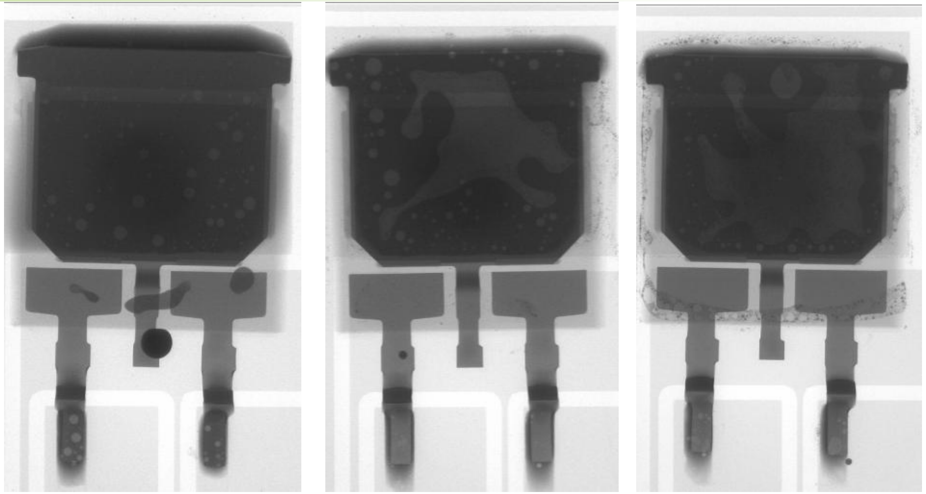






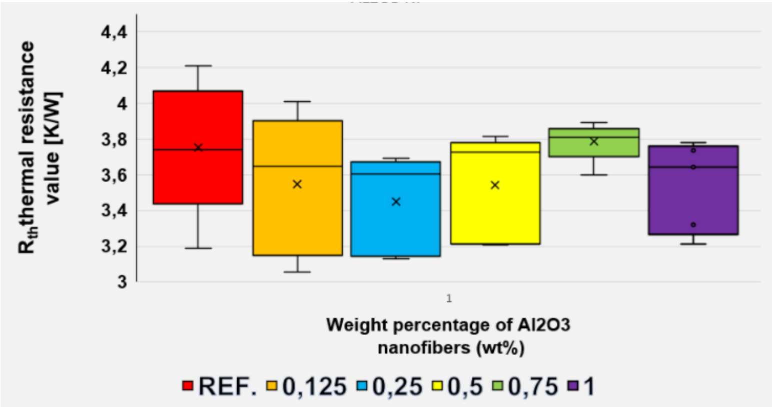
Al_2O_3 - Quality

- Al_2O_3 nano-powder increased the voiding, nano-fiber did not chang it.
- ***Al_2O_3 nano-particles decreased the thermal resistance*** of the composite solder joints of power MOSFETs



Ref. SAC

SAC-Al_2O_3 (0.5 /1)p



Conclusions

- Any kind of NP ***improved the mechanical parameters*** of the composite solder joints due to the microstructural refinement.
- The NPs could ***decrease the wettability and increase the void formation*** in the case of higher weight fractions***, typically over 0.5 wt%.***
- The NPs could improve the thermal resistance of the composite solder joints.
- ***TiO_2 and ZnO*** considerably ***increase the corrosion resistance*** of the composite solder joints.

Conclusions

- ***CuO, ZrO_2, and SiC*** considerably ***decrease the corrosion resistance*** of the composite solder joints. The enhanced corrosion resulted in the growth of plenty ***Sn whiskers***.
- ***Lower weight fractions***, between 0.1-0.5wt%, and the nano-powder form are the most beneficial in the composite soldering.
- Only an ***appropriate ceramics*** and their appropriate amount can ensure the ***further reliability development of automotive electronics***.

THANK YOU!

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- Acknowledgement: This work was supported by the National Science Center Poland (NCN) project no. 2022/47/B/ST5/00997.