LASER BASED METALLIZATION OF MATERIALS WITH LOW WETTABILITY FOR JOINING OF HYBRID MATERIAL COMBINATIONS

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1. Introduction

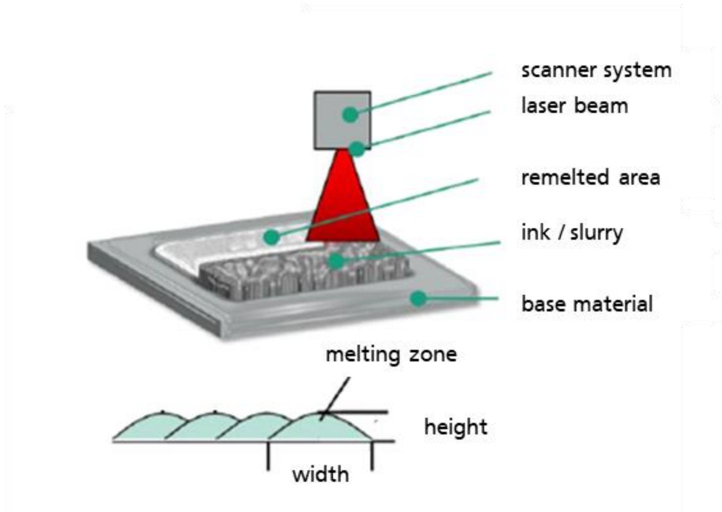
In the field of high-performance components, different materials are increasingly being combined. The use of different materials allows an optimal local adjustment of the required component properties. Often, different materials such as ceramics (e.g. SiC, SiSiC, Si3N4, Al2O3, BN, WC, Zr02) and metals (e.g. Al, Cu, Ti) are combined. The bonding of such different materials, which are difficult to wet, is often carried out in a vacuum furnace using special active solders at temperatures of 850 °C and higher. However, heating the whole samples to such high temperatures often leads to high stresses and consequently to the formation of cracks both in the base material and in the coating. In addition, a furnace process is always associated with high energy costs and is a batch process, which means that it cannot be integrated into a production process chain.

This paper reports about a laser-based process for metallization materials that are difficult to wet. The aim is to achieve complete wetting of the surface, low-porosity and crack-free coatings, as well as sufficient adhesion of the coatings to the base material. The requirement for the subsequent soldering process is a minimum layer thickness of 20 µm. By using metallic micro or nano particles, the inks or slurries should be adapted to the laser process, especially the short temperature-time cycles. The metallization temperature can thus be reduced up to 50%. A reduction in the metallization temperature goes hand in hand with lower stresses in the components and thus a reduced risk of crack formation. Furthermore, in contrast to a furnace process, the laser-based metallization can be integrated in a process chain. Applications can be found where material combinations are used, e.g. batteries, fuel cells, heat exchangers, LED or tools.

2. Process principle and experimental setup

The inks and slurries are applied to the components using a scraper or screen printing and then functionalized with laser radiation. In addition to metallic particles, the inks or slurries contain agents for adjusting the desired viscosity and wetting. The outgassing of the additives occurs by drying in air at room temperature. In figure 1 the experimental setup as well as the range of the investigated process parameters are shown. For laser processing a scanner system was used. The beam diameter was d_s = 0.06 mm. The laser power was varied between P_L = 5 W and P_L = 100 W. The scanning speed was between v_v = 10 mm / s to v_v = 100 mm / s and the track offset was $\Delta x = \Delta y$ = 0.15 mm. The samples were irradiated one to five times. For an irradiation of four times the best results are achieved. The best method proved to be a four times irradiation of the surfaces, whereby the direction of movement of the laser beam for traverses 2 and 4 is rotated by 90° relative to traverses 1 and 3. The positioning of traverse 3 is offset by half the track offset with respect to traverse 1, and traverse 4 is shifted by half the track offset with respect to area 2. This ensures that the laser beam lies exactly in the space of the previous irradiation, with the aim of achieving a homogeneous processing result (regarding layer thickness, structure, porosity). A protective gas atmosphere was necessary for oxidation-prone materials since the solder oxidized rapidly in air. For this reason, the irradiation was conducted in a shielding gas chamber.

Figure 1: Principle of laser functionalization



Process parameters for laser functionalization:

- Beam Diameter d_s = 0,06 mm
- Laserpower P_L = 5 W bis P_L = 100 W
- Scanning Speed v_v = 10 mm / s bis v_v = 100 mm / s
- Track Offset $\Delta x = \Delta y$ = 0,15 mm
- Number of irradiations n = 1 bis n = 5
- Direction and position of the laser scan paths

The results were evaluated using adhesion tests, light microscopy, scanning electron microscopy and EDX. The decisive criteria were the wetting of the surface, the porosity, the formation of cracks, the adhesive strength of the layers and the layer thickness.

3. Results

3.1 Ag-nano ink

Figure 2 shows the surface of a functionalized Ag-nano ink on WC and the measured chemical composition. The scanning speed was v_v = 50 mm / s and the laser power P_L = 25 W. The laser functionalized Ag- nano ink has formed into small balls. The formation of the balls is possibly a consequence of low wetting. An EDX mapping on the surface showed 64 wt,.-% which proofs that the layer is not dense (incomplete coating in between the balls).

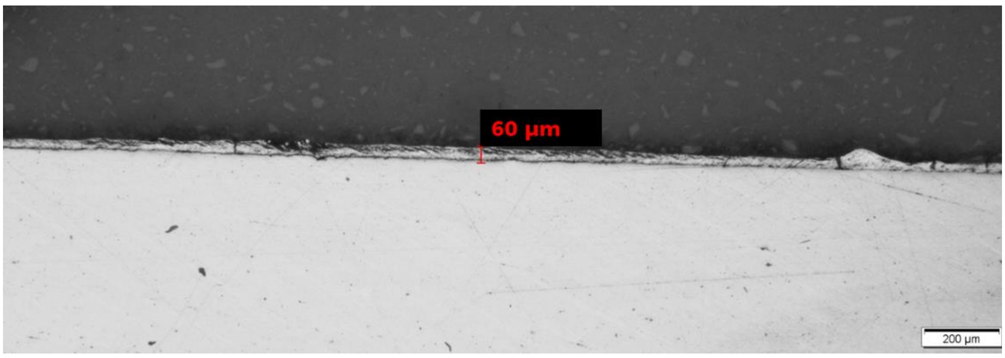
Figure 2: Surface of functionalized Ag-nano ink on WC and chemical composition (P_L = 25 W, v_v = 50 mm / s, $\Delta x = \Delta y$ = 0,15 mm, n = 4)

Spectrum	In statistics	C	O	Mg	Cr	Co	Ag	W	Total
s1	Ja	6.12	2.33			6.68	20.58	64.29	100.00
s2	Ja	1.43		0.40			98.17		100.00
s3	Ja					0.65	98.60	0.74	100.00
s4	Ja	1.39		0.40		1.22	93.47	3.52	100.00
s5	Ja	1.28		0.48			97.57	0.67	100.00
s6	Ja	4.18	4.81		0.51	8.12	18.33	64.05	100.00
s7	Ja	2.10		0.44			97.46		100.00
s8	Ja	4.07					93.48	2.45	100.00
s9	Ja	1.61		0.48			97.90		100.00
s10	Ja	2.54		0.41			97.05		100.00
s11	Ja	2.60		0.39			97.00		100.00
s12	Ja	1.58	1.68	0.51		1.33	94.90		100.00
Maximum		6.12	4.81	0.51	0.51	8.12	98.60	64.29	
Minimum		1.28	1.68	0.39	0.51	0.65	18.33	0.67	

3.2 Ag-nano slurry

In figure 3 and 4 the cross section of a functionalized Ag-nano slurry on copper and aluminum is shown. The scanning speed was v_v = 50 mm / s and the laser power P_L = 5 W and P_L = 10 W. A dense, adherent and crack-free layer is achieved. The thickness of the the layers was measured at eight points on five copper samples coated with Ag nano paste. The average layer thickness of all samples is 28 µm. The deviation in layer thickness from sample to sample, as well as the deviation in layer thickness within a layer, is still up to 40%. However, the thickness of the layers examined here is still minimum 20 µm, which is required for the soldering process.

Figure 3: Cross section of functionalized Ag-nano-slurry on copper as base material (P_L = 5 W, v_v = 50 mm / s $\Delta x = \Delta y$ = 0,15 mm n = 4)



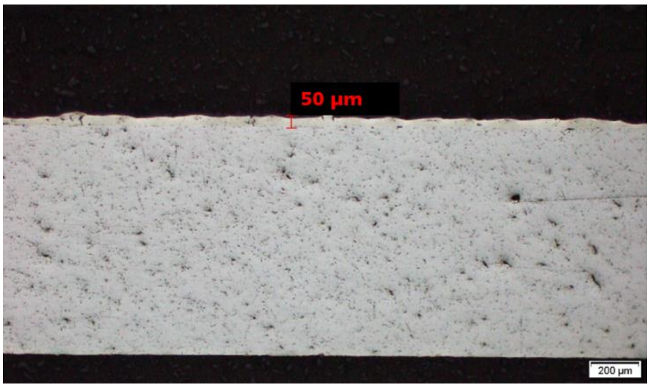


Figure 4: Cross section of functionalized Ag-nano-slurry on Alu as base material (P_L = 5 W 1 and 2 crossing, P_L = 10 W 3 and 4 crossing, v_v = 50 mm / s, $\Delta x = \Delta y$ = 0,15 mm. n = 4)

In figure 5 the surface of a functionalized Ag-nano slurry on WC is shown. The scanning speed was v_v = 50 mm/s and the power P_L = 5 W. An adherent and dense coating without cracks is achieved.

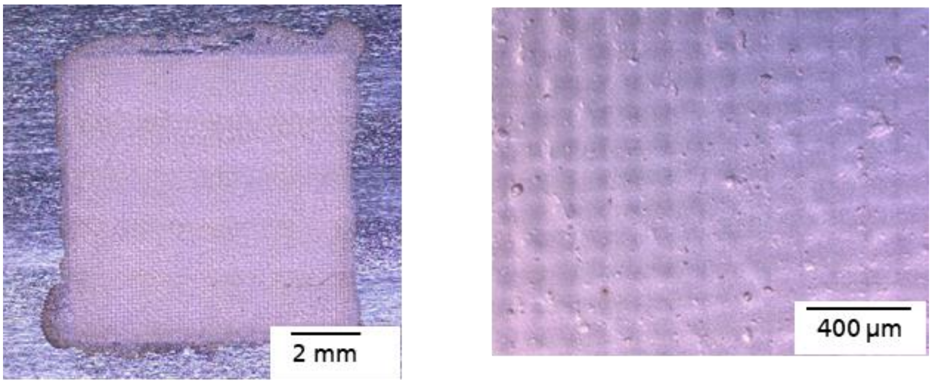
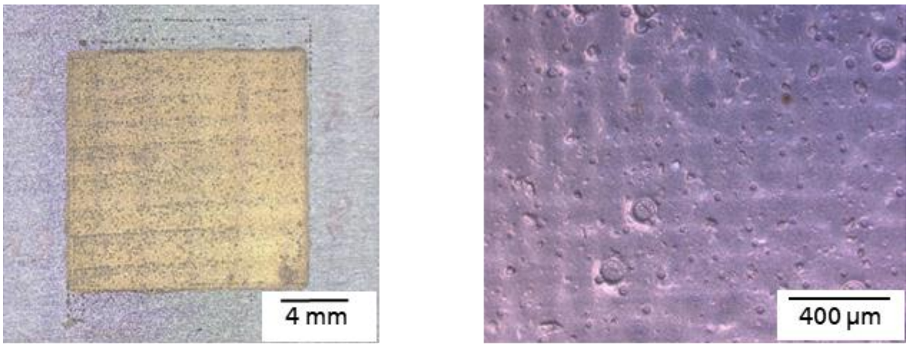


Figure 5: Surface of a functionalized Ag-nano slurry on WC (P_L = 10 5, v_v = 50 mm / s, $\Delta x = \Delta y$ = 0,15 mm, n = 4)

Figure 6 shows an example of the surface of a laser functionalized Ag-nano slurry on SiSiC. The scanning speed was v_v = 50 mm / s and a laser power of P_L = 10 W. An adherent and dense coating without cracks is achieved. The samples were used to produce the demonstrators (chapter 3.3).

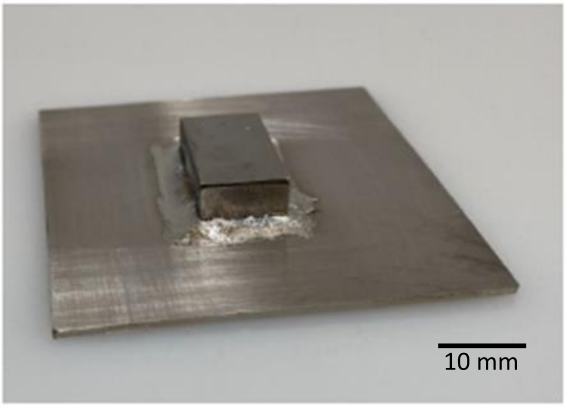
Figure 6:
Surface of a functionalized Ag-nano slurry on SiSiC (P_L = 10 W, v_v = 50 mm / s, $\Delta x = \Delta y$ = 0,15 mm, n = 4)



3.3 Demonstrators

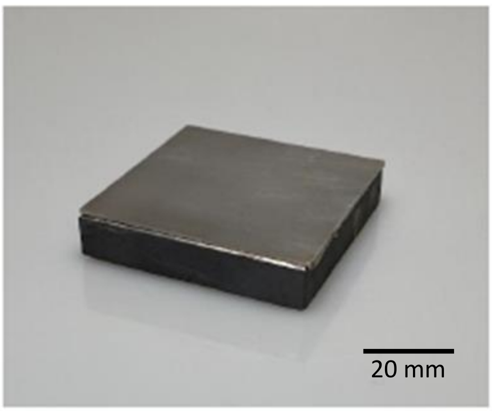
Figure 7 shows a WC block which was ultrasonically brazed to a steel plate. The bonding layer is the Ag-nano slurry functionalized by the laser process.

Figure 7:
Demonstrator – successful soldering WC with a laser-functionalized intermediate layer (Ag-nano) onto a steel plate



In figure 8 a thin stainless-steel plate was successfully soldered to a SiSiC sample coated with Ag-Nano also using an ultrasonic soldering process.

Figure 8:
Demonstrator – successful soldering a steel plate onto a SiSiC substrate with a laser-functionalized intermediate layer (Ag-nano)



4. Summery and outlook

The feasibility of local laser metallization of materials with low wettability for joining of hybrid materials combination was demonstrated. Dense and adherent layers of Ag-nano could be deposited on WC, SiSIC, Cu and Al by use of the laser process. Due to the low heat input required, no cracks occur even on the brittle ceramics. In contrast to the furnace process, which includes long temperature cycles, laser functionalization is a short time process and thus strongly influenced by the layer thickness of the pre-coated solders; here, only small tolerances in the range of 5-10 µm are permitted to achieve a homogeneous layer and good adhesion. The application process must be improved in this respect. However, it was possible to reliably achieve layer thicknesses larger than 20 µm, which is a prerequisite for the soldering process. This was shown with two demonstrators in which steel was joined to WC and SiSiC using ultrasonic soldering.

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