Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 23 (2014) 13 – 18

www.elsevier.com/locate/procedia

Conference on Assembly Technologies and Systems

Automation Concepts and Gripping Solutions for Bonding with Reactive Multilayer Systems

J. Heyn[a]*, P. Blumenthal[a], G. Hemken[b], S. Fiedler[a], C. Walz[b], A. Raatz[c], K. Dröder[a]

[a]TU Braunschweig, Institute of Machine Tools and ProductionTechnology (IWF), 38106 Braunschweig, Germany
[b]InnoJoin GmbH & Co. KG, 28259 Bremen, Germany
[c]Leibniz Universität Hannover, Institut für Montagetechnik, 30823 Garbsen, Germany

* Corresponding author. Tel.: +49-531-3917605; fax: +49-531-3915842. *E-mail address:* j.heyn@iwf.tu-braunschweig.de

Abstract

Reactive multilayer systems (RMS) represent an innovative heat source for the establishment of solder joints. They offer fast bonding processes that introduce very little thermal input and internal stress on the bonded parts. The current application process of RMS is predominantly manual labor. There are a couple of challenges to be overcome to automate this process, a requirement for its introduction into industrial production.
In this paper we evaluate the requirements for an automated joining process with RMS and devise a concept of a modular assembly system for different product structures. Furthermore we show our results in gently and reliably gripping and handling of RMS.

Selection and peer-review under responsibility of the International Scientific Committee of 5th CATS 2014 in the person of the Conference Chair Prof. Dr. Matthias Putz matthias.putz@iwu.fraunhofer.de

Keywords: Automated Bonding; Reactive multilayer systems; Automated Assembly; Process Automation; Handling; Gripping;

1. Introduction

As a consequence of continuous progress in the field of system integration, microsystems are packed ever-more tightly. Due to a particularly high number of diverse materials, as well as sensitive components and substrate surfaces, component damage during joining and bonding is becoming more frequent. Joining techniques used for joining microelectronic and micromechanical components generally cause high levels of heat to develop in the joining zone and adjacent areas. This can lead to reduced stability of the material structure and/or to internal stress due to variation in the degree of thermal expansion among the components to be joined.

1.1. Reactive Multilayer Systems

So-called reactive multilayer systems (RMS) enable a new approach, in which the heat necessary for joining is introduced into the joining zone in a temporary and localized way only. These are multi-layer foil materials consisting of nanoscale nickel and aluminum layers that create mechanically stable joints during the joining process, even at low component temperatures ("cold joining,"). Other Material systems exhibit the same behavior, e.g. aluminium/titanium, nickel/silicon or niobium/silicon. The joining process is enabled by an exothermal chemical reaction of the different layers of the foil and starts when the necessary activation energy is provided (see figure 1). The reaction is fast, progressing at 6-10 m/s which leads to a duration of the bonding process in the order of milliseconds.

Selection and peer-review under responsibility of the International Scientific Committee of 5th CATS 2014 in the person of the Conference Chair Prof. Dr. Matthias Putz matthias.putz@iwu.fraunhofer.de
doi:10.1016/j.procir.2014.03.198

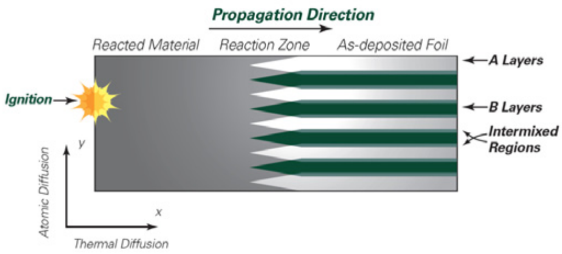


Fig. 1: schematic overview of RMS reaction

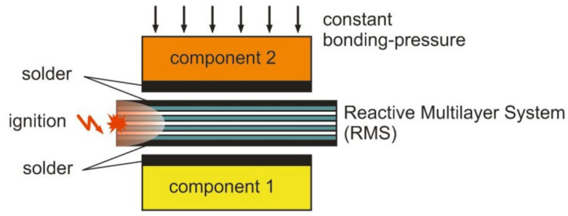


Fig. 2 Bonding package of component 1, RMS and component 2.

Not only materials made of pure metal can be joined reproducibly and extremely rapidly in this way, but also materials with significantly divergent thermal expansion coefficients, such as ceramics, carbon-fibre-reinforced plastics (CFRP) and even glass. Localized heating of components – which means that heat produced by the exothermically reacting foil is targeted exclusively on the joining zone – is a highly effective joining technique, ensuring reliable joining at low component temperatures. The short-time application of heat allows soldering materials, for example, to melt without the need for significant heating of the base materials. The solder or metallization – applied either directly to the RMS or to the components to be joined – melts, and a mechanically stable joint is created. The process can be ignited at room temperature by a short spark (produced by a 9 V battery or a laser beam, for example). As far as ignition is concerned, the aim is to disrupt the instable states of both reactive materials locally, thus initiating the mutual diffusion of both materials into one another, a process that takes place as an exothermic reaction.

1.2. Applications

The unique properties of RMS enable a multitude of applications. There are applications that just use their ability to produce heat, e.g. as heating elements in thermal batteries [1]. However, the scope of this work focuses on bonding applications.

One important current application is the bonding of sputter targets to their backing plates [2, 3, 4]. In this application the localized heat produced by RMS produces large-area solder-joints while introducing much lower thermal stresses in the bond compared to traditional soldering techniques.

A similar application, albeit with smaller bonding areas, is the assembly of integrated circuits and micro-electro-mechanical systems (MEMS) [5]. The low thermal stresses and controlled heat input make RMS an interesting option in this application.

Akin to the assembly of MEMS, but with slightly different constraints, is the packaging of sensors. The sensors might actually be MEMS, but the main concern in this application is the tightness of the seal and the possibility of bonding dissimilar materials, as well as the low thermal stresses [6, 7].

A traditional use of soldering is the assembly of electronic systems. For most small solder bonds in those applications RMS do not offer benefits over current techniques. For larger bonds, which are mostly used as thermal joints, the low heat input and good thermal conductivity of the finished bond are interesting. Especially components with high power densities may be bonded using RMS [8, 9]. Although this application seems promising, no current industrial use of RMS for electronics assembly is known to the authors. One of the goals of our work is to supply the automation necessary to make this use viable in industrial processes.

The good electrical conductivity of bonds produced with RMS makes their use in another field interesting: the bonding of high-current conductors. These usually have large cross-sections and are made of electrically and thermally conductive materials, while being protected by insulation material with low temperature tolerances. Bonding with RMS offers much lower heat input than traditional soldering in these applications [10, 11]. Similar applications have been investigated regarding the electrical contacting of photovoltaic cells [12].

A general application of RMS lies in the bonding of dissimilar materials. Especially combinations of materials that are hard to join using conventional techniques are possible. Successful bonding of ceramics and metal, as well as glass and metal has been shown [13, 14]. Unusual materials such as titanium or amorphous metals can also be bonded [15, 16].

2. Automated Application of RMS

Currently, the application of RMS is done manually. Although work has been done to automate this process in single applications [17], no current automated industrial application is known to the authors. The absence of a general automated solution represents a major drawback in the industrial use of the RMS bonding process. To generally enable an automation of the bonding with RMS, there are several challenges to meet. Before those challenges will be addressed in section 2.2 and a design of an automated assembly system is proposed in section 2.3, the basic assembly procedure is assessed.

2.1. Assembly Procedure

For the bonding using RMS, a package of the joining partners and the RMS has to be build and compressed with a specific pressure, before the reaction of the foil is initiated and the parts are thereby ultimately joined, see figure 2. This general bonding process, as described in section 1, can be divided into five steps:

1. Positioning/Placement of the first component
2. Placement of the RMS
3. Placement of the second component
4. Pressure application and ignition (joining)
5. Removing of bonded product

In manual labor, those steps can be carried out with minimum equipment such as tweezers, a hand press and pointed electrodes connected to a 9 V battery, for example. The handling of the components can normally be done without any specific tools. For an automated assembly on the contrary, various tools, at least one handling systems and a well defined set of process parameters is required. Thus, a systematic process design is necessary not only for the individual process steps, but also for the transitions between them. The process design and structure has to address the challenges mentioned in 2.2 and is depending on the type of product, see 2.3.

2.2. Challenges

There are several challenges to overcome when automating the bonding with RMS. These challenges can be listed according to the process steps and are described in the following.

The handling of the sensitive RMS requires special care. Grippers and processes have to be specially adapted. This issue is regarded in detail in section 3.

The handling of components on the other hand is rather simple, as suitable applications already exist; e.g. in the electronics industries for small components. The dimensions, weight and material of the components demand no special attention and the position accuracy required of about 40 µm can be achieved with specialized handling systems and grippers for the electronics industry. Nevertheless, part specific issues can always occur in any application.

Whether a pre-fixation of the RMS is needed depends on the design of the assembly system and the process. If a need is identified, suitable methods need to be evolved. They can be deduced from existing solutions as, for example, from the electronics industry, where components also tend to be very light and solder paste is used. This paste holds the components after placement until they are soldered. Tacky flux is another example of this strategy.

One key issue to reach high quality bonds is a uniform pressure application. It will not be a problem to provide the needed pressure in the required extent. Problematic could be the achievement of a uniform pressure distribution over the entire joining area. Especially, if the top side of component 2 is not flat, an even introduction of the pressure is hard to realize. Elastic cushions, bellows or a freely mounted mechanical pressure instruction can possibly be used to solve this problem. However, before this issue can ultimately be assessed, tolerances of uniformity need to be defined.

The ignition of the RMS is normally done with an electrical impulse. This is noncritical when done manually because one can always place the electrodes exactly on an easily accessible point on the RMS. In an automated process, this ignition point has to be specified in advance. An ignition flag could be needed to access the RMS as well as a very precise positioning of the electrodes in order to establish a reliable ignition. Another possibility, which is limited to the joining of parts on a PCB, is the integration of special circuit paths in the PCB to bring the ignition current to the joining area. Despite the electrical ignition being a very reliable method, it bears the risk of damaging electrical sensitive parts. Other methods for ignition, as optical and thermal ignition, have their own specific advantageous and disadvantageous. Optical ignition on the one hand, for example using a laser, is especially interesting when accessibility to the RMS is poor but requires complex equipment. Thermal ignition on the other hand, as for example in an oven, requires no access to the RMS but annihilates the important characteristic of not heating the entire joining package when bonding with RMS. These problems in ignition have to be overcome in order to automate the joining with RMS successfully.

A last issue which must not be overlooked is the danger of contamination. Contamination of the RMS can lead to impurities in the joining zone and thus a reduced bonding quality. Contamination can result from environmental dust, worn grippers, remainders of used RMS and so on. Cleaning of parts and system could be needed and might also be necessary prior to the pick and place process if RMS arrive dirty. How this cleaning can be done is still to be assessed.

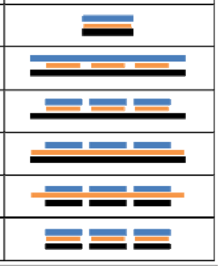
2.3. Process and Structure Design of an Automated Assembly System

To establish an automated assembly system, a detailed analysis of the process flow is necessary. The process flow is not only depending on the process steps but also on the product structure. The process steps are basically given by the joining method and are listed in section 2. The product structure depends on the individual product.

In order to ensure maximum flexibility of the assembly system, general product structures have been identified by characteristic product criteria. A first criterion is the size of the joining area, which is determining the necessary joining force. In cases where the force is less than about 100 N, the handling system which places the second component could most likely be used for the application of the joining force. As joining pressures of 0,1 N/mm² are needed in soldering and 10 N/mm² in brazing, this leads to maximal areas of 1000 mm² and 10 mm², respectively. Are parts to be joined with a larger joining area, a dedicated pressure application and ignition unit must be installed.

A second criterion is the product configuration, see figure 3. Possible applications have been analyzed, revealing that only two main product designs out of the six theoretically possible configurations of component 1, nanofoils and component 2, seem to be of interest: case 1 (1:1:1) and case 3 (1:n:n), see figure 3. The other configurations are unlikely or can be achieved by repeating given structures, as in case 6. The first structure occurs in all assembly scenarios of single parts. The second structure is present when multiple small parts are to be assembled to one single substrate, as could be in PCB assembly. The influence this criterion has on the process flow is only relevant if the placement of the RMS and its ignition are locally separated. This is either the case if parts

No.	Product structure, configuration[1]	Product structure, sktech[2]
1	1:1:1	
2	1:n:1	
3	1:n:n	
4	1:1:n	
5	n:1:n	
6	n:n:n	



1 Amount of parts of **Component 1 : RMS : Component 2**
2 Component 1 — RMS — Component 2

Fig. 3: Different product structures of component 1, RMS and component 2.

are too large (criterion1) or if a parallelization of processes is desired to increase output*. In that case, a pre-fixation of the RMS may be necessary to prevent their displacement.

In general, it seems feasible to build a flexible assembly system in which both product structures can be assembled and which incorporates a modular pre-adhesion system. In this modular design, the modification of single modules or a change of component routing enables the assembly of a large variety of products.

Based on process flow and product structure, four essential units have been identified which are needed to realize an automated assembly system for the joining with RMS:

1. Handling system for RMS, components and product, including different grippers, an ignition system and probably a pre-fixation system
2. Pressure application and ignition unit. Either integrated in the handling unit (if only small parts are to be assembled), or as separate unit.
3. Feeder/supply for RMS and components
4. Control unit

An additional transport system for component 1 and the finished product could be advantageous to increase output and to simplify the handling unit and will be necessary if component 1 or the product is too large or heavy for the handling system. Despite pressure application and ignition being two different process steps, it is adequate to regard them as one unit since ignition must always take place under pressure.

There are possibilities to realize alternative process flows, e.g. by an incorporation of co-moving pressure and fixation units. Currently, no advantages can be seen in utilizing such systems so no further consideration is made regarding their usage.

3. Gripping of RMS

As shown in section 2.1 handling of the RMS is one key challenge in automated bonding with RMS. The corresponding requirements are investigated in section 3.1 before suitable gripping methods and devices are evaluated in section 3.2.

3.1. Requirements

A gripping system for this application has to conform to the following requirements:

- sufficient gripping forces to reliably handle the RMS
- careful handling (no damage to the foil, no ignition)
- no contamination of the RMS foil
- sufficient placement accuracy
- useful for immediate industrial application

Most gripping principles seem not to be suitable for this application. Mechanically gripping the foil shaped pieces of RMS does not work; either the foil cannot easily be placed (when gripping it vertically) or it cannot be gripped at all, when gripping it horizontally on the thin edges. Such a gripper is also likely to damage the RMS foil.

The RMS foil is not magnetic, so magnetic gripping does not work. Adhesive grippers are routinely used for small components, either fluidic or cryogenic. These gripping methods wet the RMS surface and might contaminate the RMS if the fluid used does not evaporate completely. In some scenarios such grippers might be adequate.

In special applications of RMS, such as assembly in vacuum, electrostatic gripping might be a solution.

A good choice to handle delicate foil materials are Bernoulli-grippers. As most of the applications we consider in the work have small component dimensions, the RMS foils also have small dimensions. Unfortunately the smallest commercially available Bernoulli-grippers do not work with such small part dimensions.

The simplest and most common gripping principle for small components is vacuum gripping. Vacuum grippers are already used in a multitude of industrial applications.

3.2. Evaluation of gripping process

To evaluate the suitability of vacuum gripping for RMS handling we tested several commercial and special purpose vacuum grippers. As a starting point standard industrial suction grippers were tested, made of NBR (nitrile butadiene rubber) and HT1, a high-temperature material with good abrasion resistance. A special purpose gripper made of porous material was tested due to the tendency of the foils to be deformed by the standard grippers. As a benchmark we examined an industrial gripper for electronics assembly. Examples of the investigated grippers are shown in figure 4.

* As the actual time needed for the joining, i.e. the reaction of the RMS, is negligible with <25 ms, a parallelization of processes may not even be reasonable in high volume fabrication it will not be regarded further.

Fig. 4: Vacuum grippers: commercial HT1 suction gripper, special purpose porous gripper (developed at IWF), commercial electronic assembly gripper (left to right)

Initial experiments with suction grippers have shown that the foils tend to deform when being gripped. This does not damage the foil as it can be bent slightly without damage. However, this deformation may cause the placement accuracy to worsen. The more flexible the gripper is the more the foil tends to deform, some support by the gripper is needed to minimize the deflection. This led to the construction of the porous gripper shown in the middle of figure 4. In this gripper a porous material serves as the contact area to the foil, which is therefore very well supported.

The contamination potential of the grippers was evaluated by gripping a piece of RMS foil repeatedly and visually inspecting the foil afterwards. Gripping a piece of foil just once did not leave enough contamination to be conclusive upon visual inspection.

Grippers made of NBR did cause visual contamination on the RMS surface after 10 grip-release cycles, while grippers made of HT1 did not. The porous gripper did also not contaminate, while the commercial electronic assembly gripper did, albeit less than the NBR suction gripper. The seal of this gripper seems to be the cause of this contamination. As a result of these experiments an abrasion resistant material should be used when gripping RMS to avoid contamination.

To evaluate the gripping forces we measured the maximum gripping forces of the aforementioned vacuum grippers on RMS. We gripped a piece of RMS foil attached to a force gauge and then slowly moved the gripper until it separated from the foil. The highest force registered during each of those experiments is interpreted as the maximum achievable gripping force with the gripper. In figure 5 the results of these experiments are shown for a pressure difference of 325 mBar. As one would expect both the 5 mm diameter grippers exerted the same force, while the 7 mm diameter gripper and the electronic assembly gripper (with a diameter of 5.5 mm) registered higher forces. The special porous gripper achieved the lowest gripping force, but its gripping force (45 mN at a pressure difference of 325 mBar) was still high enough to lift the RMS foil. As the foil used in our experiments has an area density of 0.0354 g/cm², only 0.34 mN/cm² is required to lift the foil if acceleration during handling is neglected.

As in many microscale handling tasks, the gripping of the part is easy compared to the placing i.e. releasing of the part. This is because the adhesive forces cannot be overcome by the extremely low weight of the object. To reproducibly place the RMS, an air kiss is executed during the placement. This is possible with all vacuum grippers.

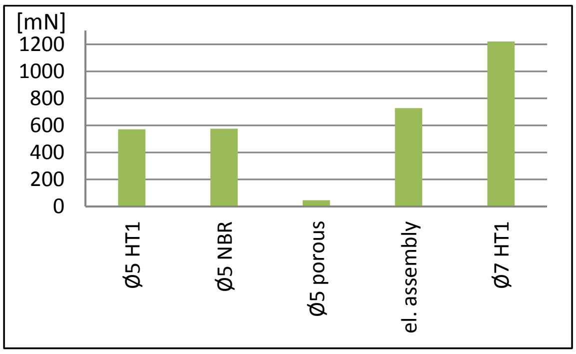


Fig. 5: Gripping Forces of different vacuum Grippers on RMS with a pressure difference of 325 mBar

All investigated grippers provide enough gripping force to reliably transport the RMS. The pieces of RMS foil were not damaged by the gripping forces exerted by industrial suction grippers, so industrial vacuum equipment is sufficient.

As our initial experiments showed standard industrial suction grippers are suitable for the automated handling of RMS, as long as they are made of abrasion resistant material. Further investigation showed that an air kiss is needed to avoid having the foil stuck on the gripper. Especially the standard suction grippers showed a tendency to stick to the foil. An air kiss reliably separated the foil from the gripper. With the porous gripper no air kiss is necessary, as this gripper showed no such behavior.

The chosen gripping method greatly influences the placement accuracy of the gripping process. As can be seen in section 1.2 many applications of RMS exist in microtechnology or electronics assembly. These fields of application require high placement accuracy. The placement accuracy is defined by the interaction between the foil and the gripper and the accuracy of the handling system.

To investigate the placement accuracy of the examined grippers a highly accurate handling system was set up to position the grippers. The grippers were mounted facing down with an adjustable table underneath. This setup allowed us to position the grippers and foil specimens exactly normal to each other. Pieces of foil were gripped and released and the position of the foil measured with a camera mounted overhead. This way the influence of different gripping-process parameters on the pick and place accuracy can be assessed.

Our experiments showed that the strength and duration of the air kiss did not have a major effect on the placement accuracy, as long as it was sufficient to separate the foil from the gripper.

Geometric inaccuracies of the foil and deflection caused by the gripper had a distinctive influence on the placement. These were observed with the standard suction grippers. Highest accuracies were achieved with the porous gripper, which minimizes the deflection of the foil because of its large contact area.

The placement height also influences the placement accuracy. With the standard suction gripper a placement deviation of less than 30 µm could be achieved as long as the placement height was smaller than 0.2 mm. With the porous gripper similar results were achieved. At larger placement heights the placement accuracy seems to worsen exponentially.

The highest placement accuracy is possible when the foil is placed already contacting the workpiece. This requires either very precise positioning of the gripper or a compliant mounting of the gripper to avoid damage to the RMS or the workpiece. In this “contacting” scenario the porous gripper showed a slightly better positioning accuracy than the suction gripper or the electronics assembly gripper.

If a placement height of less than 0.2 mm can reliably be reached and the required placement accuracy is not too high standard suction grippers can be used. An elastic mounting strategy together with a contacting placement method allows higher accuracies to be reached with standard grippers. An even higher accuracy can be reached with the porous gripper which minimizes deflection of the foil. Care should be taken to choose a gripper material with a good abrasion resistance to avoid contamination of the foil.

With these results solutions for the handling and gripping of RMS are found. This provides an essential prerequisite for automated RMS bonding processes. The focus can now be set on process specific issues of the RMS joining method, especially providing the required joining pressure and the automated ignition.

4. Conclusions

RMS provide an innovative way to produce solder bonds. In this paper we have shown their working principle and possible applications. We have shown the need for an automation concept adapted to this bonding process as well as the requirements and the resulting process structures for an industrial application of RMS. Key challenges to be overcome in the development of the required automation technology were identified.

Furthermore we have shown that one of these challenges, the handling of the RMS, can in most cases be solved with standard gripping technology, depending on the circumstances. Special grippers where proposed for high accuracy positioning.

Our further work will be directed towards refining the automated RMS bonding to enable their use in industrial bonding application.

Acknowledgements

This research project (AIF FKZ KF 2441305WO2) is supported by the Federal Ministry of Economic and Technology (BMWi) through the Arbeitsgemeinschaft industrieller Forschungsvereinigungen "Otto von Guericke" e.V. (AiF) (Association of Industrial Research Organisations). The work is carried out as a cooperation between the Institute of Machine Tools and Production Technology, TU Braunschweig and InnoJoin GmbH & Co. KG, Bremen. We would like to thank all funding organizations.

References

[1] : Poret, J.C. et al., 2008. Nanofoil Heating Elements for Thermal Batteries, Proceedings of the Army Science Conference (26th), Dec 2008, ADM002187.

[2] : Acchione, T., Hisert, J., 2010. Measuring the Performance of Low-Melting Metallic Sputtering Targets Bonded at Room Temperature (Ambient),SVC - 53rd Annual Technical Conference Proceedings. Society of Vacuum Coaters., 2010.

[3] : Duckham, A., et al, 2009. Stress-Free Bonding of Large Linear Sputtering Targets for LCD Displays. 53th Annual Technical Conference Proceedings of the Society of Vacuum Coaters, 2009.

[4] : Indium Corp., NanoFoil® User Guide, http://documents.indium.com/qdynamo/download.php?docid=932.

[5] : Stark, R., Wärme- und eigenspannungsarmes Fügen für die Mikrotechnik, Abschlussbericht AIF 15.912N, Berlin 2012.

[6] :Qiu, X., Zhu, J., Oiler, J., Yu, H., Reactive Multilayer Foils for MEMS Wafer Level Packaging. 59th Electronic Components and Technology Conference, 2009. pp. 1311-1316.

[7] : Naundorf, J., Wulkesch, H., Siemens Aktiengesellschaft, Verfahren zur Erzeugung einer hermetisch dichten, elektrischen Durchführung mittels exothermer Nanofolie und damit hergestellte Vorrichtung. Patentschrift, DE 10 208 021 167 B3 2010.01.21.

[8] : Van Heerden, D., Rude, T., Newson, J., Knio, O., Weihs, T. P., Gailus, D. W., Thermal Behavior of a Soldered Cu-Si Interface. Twentieth Annual IEEE Semiconductor Thermal Measurement and Management Symposium, 2004. pp. 46-49.

[9] : Caswell, G., Nanobond® assembly – a rapid, room temperature soldering process. European Microelectronics and Packaging Conference, 2009. EMPC 2009. , vol., no., pp.1,6.

[10] : Herr, M., Fügen von Hochvolt Komponenten mittels Reaktiver Nanometer-Multischichten, Berlin, Techn. Univ., Diss., 2012.

[11] : Wolf, G., Robert Bosch GmbH, Elektrische Verbindung paarweiser Leiterenden und Verfahren zur Herstellung der Verbindung. Patentschrift DE 10 2009 001 850 A1 2010.09.30.

[12] : Kallies, E., Hofmann, E., Zschetzsche, J., Fussel, U., Anwendung von reaktiven Nanometer-Multischichten fur das Kontaktieren von Solarzellen. DVS BERICHTE; 7-12 DVS congress 2012, DVS, Düsseldorf, 2012 ISBN: 9783871555930.

[13] :Raić, K. T., Rudolf, R., Todorović, A., Anžel, I., Multilayered Nano-foils for Low-temperature Metal-ceramic Joining. Metalurgija, Vol. 14, br. 2 (2008), str. 143-154.

[14] : Tillmann, W.; Wojarski, L.; Liu, C.; Janczak-Rusch, J.: Verlöten von Glas und Metall, bbr SH Future 01/2011, p. 4.

[15] : Duckham, A. et. al., 2004. Reactive nanostructured foil used as a heat source for joining titanium, Journal of Applied Physics, vol. 96, p.2336.

[16] : Swiston, A.J. Jr., Hufnagel, T.C., Weihs, T.P., Joining bulk metallic glass using reactive multilayer foils. Scripta Materialia, Vol. 48, Issue 12, June 2003, pp. 1575-1580, ISSN 1359-6462, http://dx.doi.org/10.1016/S1359-6462(03)00164-7.

[17]: Siemens Electronics Assembly Systems GmbH & Co. KG, Vorrichtung, Bestückautomat und Verfahren zum thermischen Verbinden von Bauelementen an ein Substrat, Patentschrift, DE 10 2010 004 193 A1 2011.07.14