



# **EFFICIENT JOINING USING REACTIVE MULTILAYER SYSTEMS**

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## **1 ABSTRACT**

Established joining techniques like welding, soldering or brazing typically are characterized by a large amount of heat input into the components. Especially in the case of heat sensitive structures like MEMS this often results in stress induced deformation and degradation or even in damaging the parts. Therefore, there is an urgent need for a more reliable and reproducible method for joining, which is characterized by a well defined and small heat input for only a short time period. So-called reactive nanometer multilayers offer a promising approach to meet these needs.

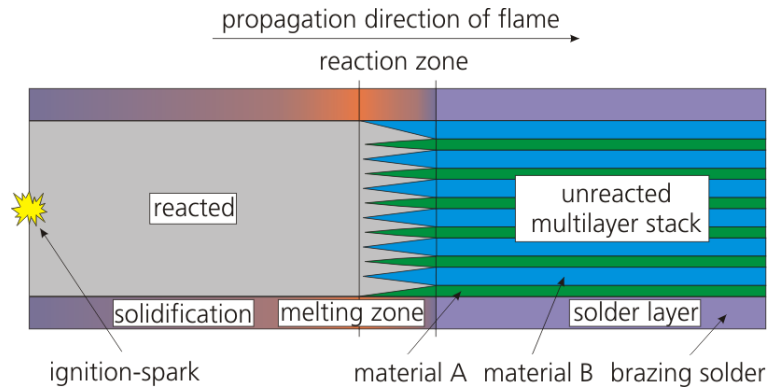
Reactive nanometer multilayers consist of several hundreds or thousands of alternating nanoscale layers, which can exothermically react with each other. Placing a reactive nanometer multilayer coated with a solder or brazing layer between two surfaces, it can be used as a controllable local heat source for joining. After activating the chemical reaction by an electrical spark, laser pulse or mechanical impact, a self-sustaining intermixing reaction starts, which propagates through the whole film resulting in a stable intermetallic compound, such as NiAl. The peak temperature of the reaction can be well above 1400 °C, but this temperature is only reached for milliseconds, so that the heat is localized to the solder layers. The components itself remain at room temperature during the entire process.

## **2 PRINCIPLE OF REACTIVE MULTILAYER SYSTEMS (RMS)**

The application of volume heating for joining various materials has been state-of-the-art for many years. While volume heating still has its place for traditional joining techniques, lots of applications could benefit from the use of localized instead of volume heating. Conventional joining methods typically require high temperatures to create strong bonds. These high temperature levels are acceptable for applications using traditional metals which are able to withstand thermal stress induced by expanding during joining and cooling down after joining. Furthermore high levels of volume heating may degrade microstructures. With the development of highly engineered materials and structures, such as MEMS, it is no longer acceptable to use high amounts of heat for joining. Additionally, high amounts of heat to join dissimilar materials, like metals and ceramics create a problem as the materials have very different thermal expansion coefficients and thus they weaken the created bonds during cooling down. Using adhesives as alternative joining technique has the advantage of preventing the use of volume heating. This is a suitable solution for applications that do not require very tight bonds but high thermal and electrical conductivities [1]. Therefore, there is an urgent need for a more reliable and reproducible method for joining, which is characterized by a well defined and small heat input for only a short time period thus creating metallic bonds with high thermal and electrical conductivity. So-called reactive nanometer multilayer systems (RMS) offer a promising approach to meet these needs.

Already in the 1970ies Russian researches described the effect of self-propagating high temperature synthesis (SHS) while manufacturing high temperature stable TiC. They were able to demonstrate that, due to the ignition of a powder mixture in a reactor, a burning reaction propagates inside the reactor [2]. The nanoscale production of reactive systems in the form of periodic multilayers is known since the late 1980ies. Wickersham described the SHS by means of magnetron sputtered Zr/Si multilayers with individual layer thicknesses of only a few nanometers [3]. In the following years SHS have been reported also in other systems, like Ni/Al and Ni/Si [4-7]. A strong increase of publication activities, including the theoretical description of the phenomenon, can be recognized since the mid 1990ies [8-12]. All these publications describe the emergence and spread of a burning reaction front associating with a phase transformation. The application of nanometer multilayers for joining techniques is firstly mentioned in an U.S. Patent of the "University of California, Oakland, USA" from 1993 [13].

For the production of reactive nanometer multilayer systems (RMS) with total thicknesses of up to 100 micron, consisting of hundreds or thousands of 10-100 nm thick single layers (Fig. 1), physical vapour deposition techniques, like magnetron sputter deposition (MSD) and ion beam sputter deposition (IBSD) have been used. The RMS can be coated directly on the corresponding components or can be produced as freestanding foils for a higher degree of flexibility in application.



**Figure 1: Principle and function of reactive nanometer multilayer systems (RMS)**

In RMS there is a defined quantity of chemical energy stored, which can be used as a local heat source. After activating the chemical reaction by an electrical spark (Fig. 2), laser pulse or impact, an intermixing reaction of the reactive materials starts. If the quantity of the heat release by the intermixing reaction is sufficiently high, a self-sustaining reaction starts which propagates through the reactive nanometer multilayer, releasing locally a large amount of energy. The reaction results in a stable intermetallic compound, such as NiAl.



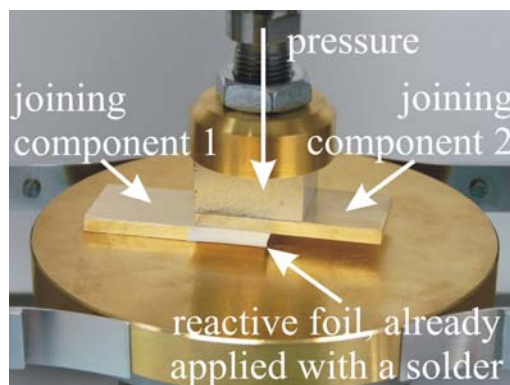
**Figure 2: Ignition of a reactive nanometer multilayer foil by an electrical spark**

The use of quickly reacting reactive nanometer multilayer films as local heat sources for soldering and brazing minimizes the heat and stress load of components to be joined, because volume heating provided by an open flame or a furnace is no longer necessary. Furthermore the amount of heat released by the layer structure can be precisely tuned.

The use of RMS opens new fields of applications, such as the joining of thermosensitive components, the joining of thermally and mechanically very different materials (e.g. ceramic-metallic compounds) or the joining with very high precision (e.g. x-ray mirrors).

By using RMS it is possible to create bondings with very high thermal and electrical conductivities, so that applications in power electronics are promising. Even exotic cases, like using RMS under water or in oxygenfree environments, hermetic sealing of sensor housings (MEMS) and the safe ignition of fuel or explosives are possible.

By designing the RMS, it is possible to influence the propagation velocity of the reaction, the released amounts of heat and the peak temperature. Thus it is possible to optimize the RMS for a specific application. Local temperatures of up to 1400 °C and propagation speeds in the range of 3-10 m/s can be achieved. Besides the further development of known material combinations such as Ni/Al and Ti/Al, alternative systems are currently investigated to open new application fields.



**Figure 3: Principle of reactive joining using a freestanding RMS foil which is already applied with a solder layer**

When RMS are used for the joining of components, this can be done in two different ways. First, using unsoldered RMS systems and separate solders, such as solder foils or presoldered joining partners. On the other hand RMS, which are already applied with a solder or brazing metal can also be used. However, in the first step the RMS is placed between the components to be joined. In the second step a pressure is applied to the components which may range from 0.1 MPa to 50 MPa (Fig. 3). This is needed to assist the wetting of the solder on the components during the very short process times. Now, the RMS can be ignited. A selfsustaining intermixing reaction starts, which travels through the reactive film, releasing the heat in process times far below 1 s. Within this

time, the solder melts, wets the surfaces of the joining components and solidifies, resulting in a strong bond with very high thermal und electrical conductivities.

First joining experiments showed shear strengths of up to 50 MPa and electrical contact resistances less than 0,1 mOhm. Various material combinations have been joined successfully, including brass-brass, aluminum-copper, titan-titan, titan-aluminum, silicon-silicon, silicon-ceramics and brass-diamond. However, the application of RMS for joining is obviously not limited to these material combinations [14].

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