Reactive joining of sensitive materials for MEMS devices: characterization of joint quality

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1 Introduction

Reactive joining is a novel bonding technology whereby the components are heated only briefly and only within the joining zone, which can generally not be achieved by conventional joining methods (e.g. by reflow soldering). The thermal energy required for the soldering process is provided directly in the joining zone by reactive multilayer systems (RMS). RMS consist of a stack of layers of at least two different materials with an individual layer thickness of few nanometers, which upon activation react exothermically forming intermetallic compounds (Fig. 1). For joining, RMS foil preforms, e.g. structured by laser cutting for the individual application, and a solder of choice are placed between the components to be joined (Fig. 1). The heat generated after RMS activation leads to melting of the solder and to bond formation. RMS thus allow low-stress and heat-reduced assembly of temperature-sensitive substrates or

electrical components from microsystem technology [1, 2]. The reaction of the RMS leads to a sudden volume contraction caused by shrinkage of the RMS material and lateral discharge of liquid solder. As a consequence, the reaction process is accompanied by a thermo-mechanical shockwave which can deteriorate the bonding quality or even destroy sensitive components to be bonded on a substrate.
In this work the volume contraction of the joining zone was detected with a piezoelectric accelerometer [3] and also determined from cross-section analysis. In addition, the joining quality of the bonding area was investigated by non-destructive testing like scanning acoustic microscopy and computer tomography. The shear strength of the joints was determined by means of shear tests.

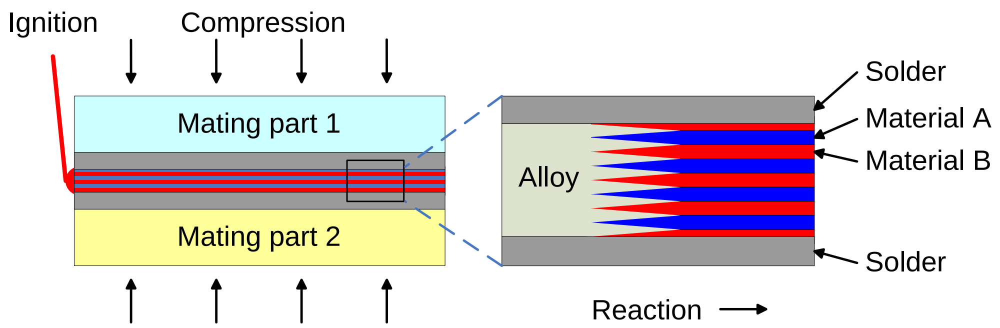


Fig. 1: Schematic of reactive bonding

2 Characterization methods and experimental results

2.1 Used materials

Aluminum oxide, glass, silicon and copper substrates are widely applied materials in the electronics industry and MEMS technology and have pronouncedly different thermal and mechanical properties. Therefore, an experimental study was performed by joining these substrates with nickel-aluminum RMS. Solder-plated and non-plated reactive foils were investigated with different thicknesses (from 20 µm thickness to 60 µm). Pure tin and tin-silver-copper alloy (SAC305) were used as solder materials as free-standing foils with different thicknesses.

2.2 Acceleration measurements during reactive joining

A piezoelectric acceleration sensor was integrated into the joining setup (Fig. 2). For the assembly, alignment and pressure application a flip chip bonder (FINEPLACER®, Finetech GmbH) was used. Vertical accelerations were recorded during the reaction processes [3]. The measured acceleration curve of exemplary reactively joined ceramic components is shown in Fig. 3. A high acceleration occurs during reaction due to shrinkage of reactive foil and melted solder outflow.
It has been noticed that measured acceleration does not correlate with damage of sensitive substrates. However, a correlation between measured acceleration signal

amplitudes and the determined total shrinkage of the joining zone on the basis of cross-sections was found for ceramic substrates.

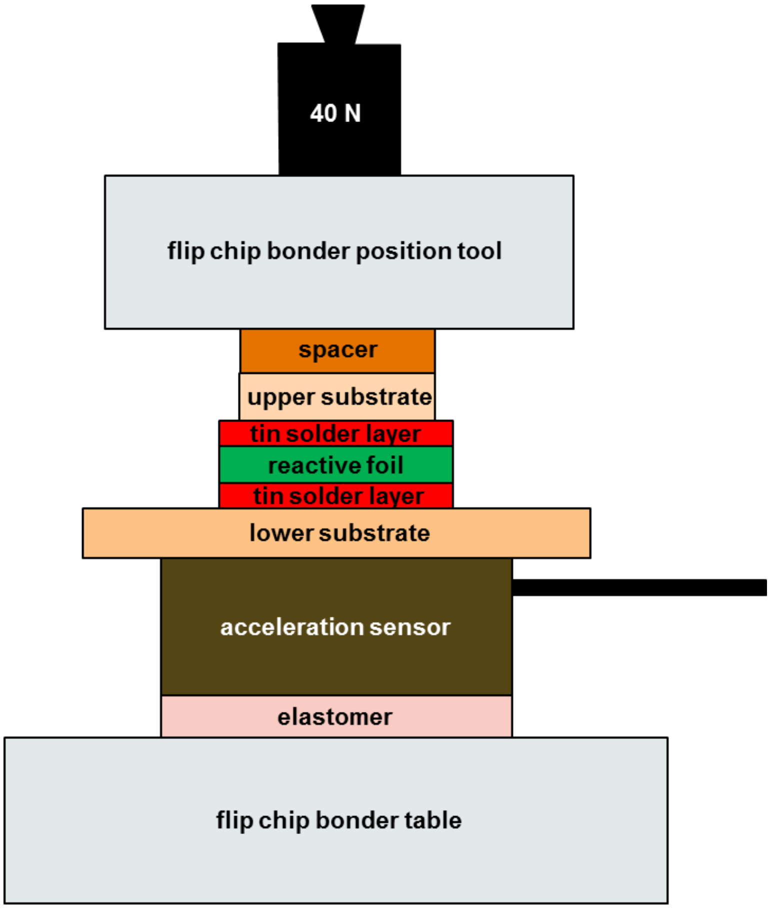


Fig. 2: Schematic illustration of the experiment setup

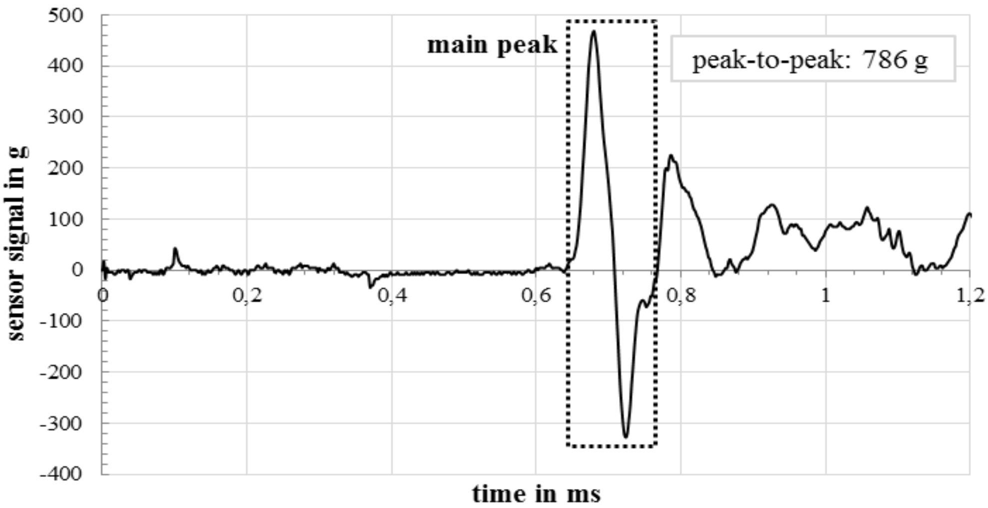


Fig. 3: Measured acceleration curve of ceramic substrates, reactively joined with 53 µm SAC foils and 60 µm Ni/Al-foil

2.3 Determination of the shear strength of the joined samples

The bond strength was determined by means of shear tests. Generally, high strength values were determined for reactively joined components. The maximum average shear strength determined is about 50 MPa measured for the aluminum oxide components (Fig. 4). The shear strength for copper substrates amounts about 20 MPa. Upon shear testing of borosilicate glass and silicon failure of substrates occurred before failure of the joint. Therefore the shear strength determined for these substrates is lower and amounts to a maximum of 20 MPa.

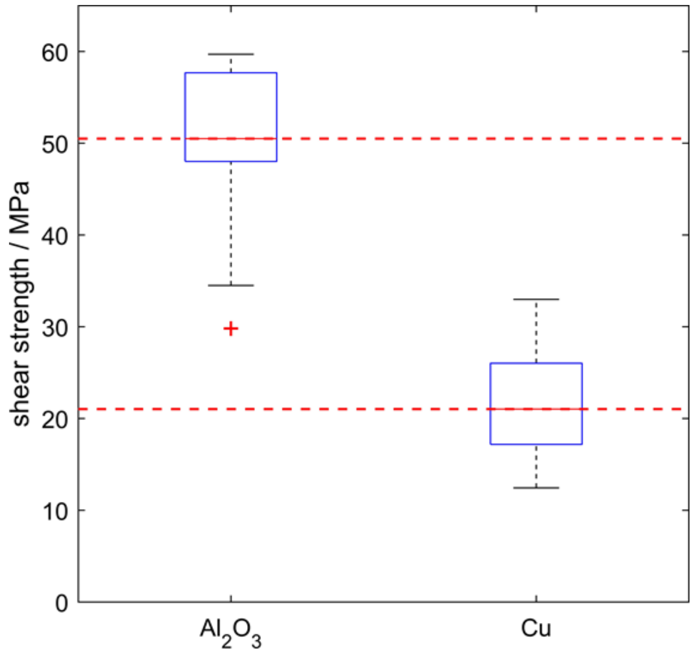
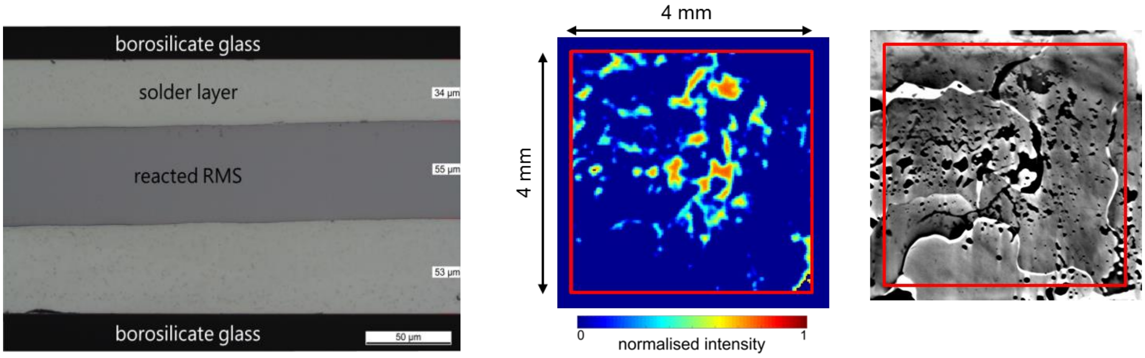


Fig. 4: Boxplot of shear strength for aluminum oxide and copper, joined with 60 µm Ni/Al-reactive foil (with 1 µm InCuSil plating) and 10 µm Sn foil.

red: average of measured values
blue: 25 % and 75 % quartile
black: whisker
red cross: statistical outlier

2.4 Scanning acoustic microscopy, computer tomography and optical microscope imaging of cross-sections

The joining quality of the bonding area was investigated by scanning acoustic microscopy (SAM), computer tomography (CT) and by cross-sectional analysis. These methods allow detecting potential defects in the joining zone, for example pore formation or cracking. The present example (Fig. 5) demonstrates a glass-glass bond with moderate bonding quality, with some pores in the joining zone but without cracks in the glass: The cross section image of the bonding interface confirms a good link between the glass surface and the solder except for some defects and pores. These pores are easily visible in the images obtained by SAM and CT. Crack formation in the glass initially posed a considerable problem, but could be avoided by the use of thicker solder layers. However, there is still room for improvement with respect to the reduction of pores as these pores could deteriorate the lifetime of the bonding.



cross-section | scanning acoustic microscopy | computer tomography

Fig. 5: Borosilicate glass substrates, joined with 60 µm Ni/Al-reactive foil and 75 µm tin foils (SAM and CT were made from substrate side)

3 Conclusions

A series of typical microsystem materials was successfully joined with RMS and an extended characterization of the resulting bond quality was performed. The experimental results for aluminum oxide confirm that lower shrinkage values are accompanied by lower acceleration signals. Contrary, for sensitive materials like glass the results are somehow ambiguous. This could be related to cracks which have been observed at the bonding interface. There is no correlation of measured acceleration with damage of sensitive substrates. Nevertheless, optimized bonding conditions were found to avoid cracks within the glass by using thinner reactive foils or thicker solder layers.

4 Acknowledgement

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