PRODUCTION OF SOLDER MICRODROPLETS USING A HIGHLY PARALLEL AND CONTACT-FREE PRINTING METHOD

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ABSTRACT

This paper reports for the first time on the design and experimental characterization of a highly parallel non-contact dispenser for molten solder micro droplets. The dispenser relies on reusable and exchangeable nozzle plates made from silicon, containing typically 1-25 nozzles of 50 µm diameter arranged in an application specific pattern. This enables parallel dispensing while a fast adaptation to different pad layouts is possible. In the presented configuration the non-contact dispenser prints up to 25 solder droplets of 0.5 nl volume simultaneously at a typical droplet velocity of approx. 2 m/s. This leads to well confined and spherical shaped solder bumps of 130 µm size (CV of 4 %) on a gold substrate.

1. INTRODUCTION

Modern packaging types such as Tape Automated Bonding (TAB), Chip Size Packaging (CSP) and Flip Chip (FC) require a bump formation for electrical and mechanical contacts. This connection between a die and substrate is one of the most critical elements of any flip chip package structure. Established techniques such as galvanic processes and stencil printing require lithographic processes which do not fulfil the cost requirements of small batch production or cannot meet the requirements of ultra fine pitch structures. As an example, the chip bonding on flexible substrates for production of smart cards and smart labels require a flexible, parallel and cheap process. The simultaneous deposition of solder bumps without lithographic steps allows for a significant cost reduction. Therefore solder bumping is the key technology in implementing flexible flip chip packaging.

2. PRINCIPLE AND DESIGN

Droplet generation

In the presented device the solder is dispensed by a direct liquid displacement method. A micro-machined silicon nozzle plate is integrated into a print module (see figure 1 for design details). The solder is placed in its solid phase at room temperature into the dispenser. An electrically controlled heater heats up the whole module and liquefies the solder at temperatures up to 360°C. Once the solder is liquefied the piston required for actuation can be inserted into the dispenser as depicted in figure 1. A thermally decoupled piezo stack actuator can move the piston at velocities up to 150 µm/ms and a stroke of up to 10 µm. The movement of the piston thus causes a volume displacement inside the actuator chamber, which acts on the whole liquid in the back of the nozzles simultaneously and expels the droplets from the nozzles. The retraction of the piston after droplet break off enables the refilling of the nozzles by hydrostatic pressure from the supply channels.

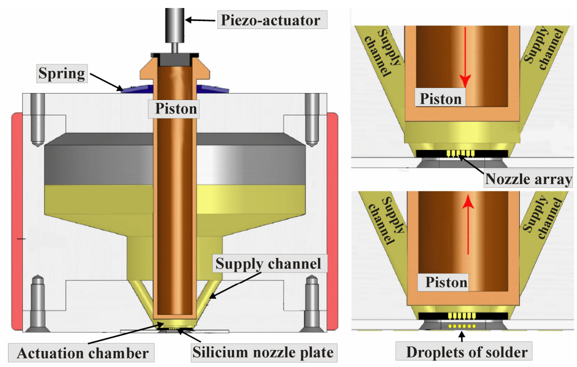


Fig. 1: *Working principle of the dispenser (schematic cross section)*

The electrical waveform driving the piezo is generated by an electronic amplifier developed especially for this purpose. In the used electronics the current is steered by a microcontroller to achieve a hysteresis free charging. To address the microcontroller, an own instruction set is used and commands are sent to the electronics using a RS232 connection. The shortest time the controller can manage is 1 µs. Due to this the shortest possible time to turn around the direction of movement is 10 µs. This is the duration the microcontroller needs to execute several security checks after the deflection phase ends. Since high currents (up to several Ampères) have to be provided in a very short time a large amount of energy has to be available instantly. This energy is stored in a capacitor which is dimensioned to 1000 µF.

Upon charging the piezo with a typical electrical signal like shown in figure 3, the piston moves in the direction of the nozzles. This volume displacement leads to a acceleration of the liquid in direction of the nozzles and to a pressure increase in the actuation chamber above the nozzles. If the pressure generated inside the print module is high enough to overcome the friction losses and the energy required to create the surface of a spherical droplet, free flying droplets are issued simultaneously from all orifices. The mechanical coupling between Piezo stack actuator and the piston is achieved by a spring disc acting. Therefore the piston retracts into its initial position when the piezo is slowly discharged and contracts back into its initial position at the end of the dispensing process. The molten solder in the reservoir then refills the nozzles by hydrostatic and capillary pressure.

For dispensing experiments the whole dispenser module was mounted on an automated stage as shown in figure 2 such that 4 inch full wafer substrates could be positioned precisely under the nozzle plate. By this lead-free solder droplets were deposited on full wafer scale in step and repeat operation. The alloy used in all experiments was an eutectic lead free solder (95.5 percent Sn-4 percent Au-0.5 percent Cu). The typical distance to the substrate was about 500 µm in the experiments and substrates were heated actively to 200 °C during bumping experiments.

3. EXPERIMENTS AND RESULTS

The presented dispensing module was characterized experimentally to study the influence of the driving parameters on the droplet formation process, in particular droplet volume and velocity. Therefore the piston movement, the droplet tear-off and the droplet volume were measured by additional equipment such as a laser-Doppler vibrometer (OFV 1102, Polytec), a video stroboscope camera (Mocon-RT, Visit GmbH) and a precision balance (Sartorius SC2) as described in the following.

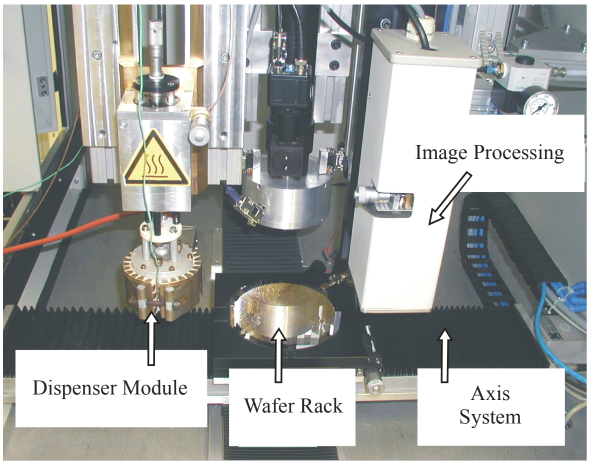


Fig. 2: *Prototype of the non-contact solder dispenser fixed onto the axis system.*

Piston movement and transient response

For the measurement of piston movement and transient response the laser-Doppler vibrometer was used. Due to the assembly of the dispensing module the laser could not be aligned in parallel to piezo actuation. The laser had to be collimated with an angle α onto the moving piston. This means that the measured results had to be multiplied with a correction factor to get the vertical piston stroke as indicated in figure 3.

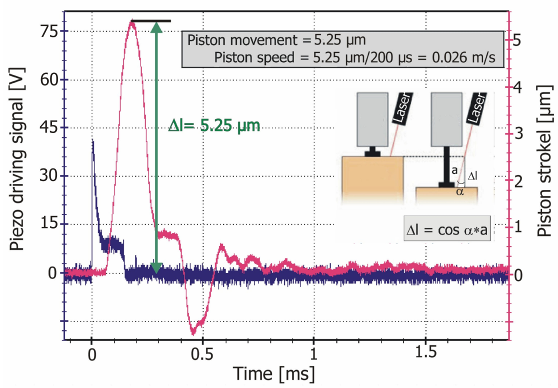


Fig. 3: *Piston movement as measured by the laser-Doppler vibrometer and driving signal of the Piezo* *<u>Insert:</u> Correction method (schematic) if laser can not be aligned in parallel to piezo actuation.*

Before starting dispensing experiments the spring disc which is acting on the piston was prestressed by continuously tightening of a micrometer screw to adjust the mechanical coupling between piezo and piston. Experiments have shown that if the pre-stress is too small the piston cannot be prevented from detaching thus "piston flight" occurs. Though a high pre-stress can prevent this "piston flight", it compromises with the intended piston movement: The Piezo cannot follow the given waveform due to high counter forces if the pre-stress is too high. Hence, the piston had be pre-stressed moderately to prevent the "piston flight" on the one hand and to allow the piezo to follow the given waveform on the other hand. The best transient response that could be achieved is displayed in figure 3. Only negligible "piston flight" can be observed which enables a satellite free single droplet tear-off.

Droplet ejection and tear-off

A common method to observe the droplet ejection and its tear-off is to record it with a camera. As the whole action lasts only for about 2 ms, a high speed camera must be used. However, the fact that the jet ejection process is exceedingly reproducible for the presented device simplifies the recording process and allows to use a stroboscopic technique where only one snapshot is taken with a defined time delay to the actuation signal. The camera used for this purpose was a Mocon-RT from Visit GmbH. The optical magnification is realised with a 2.0x microscope objective to which the camera is mounted. The piezo control electronics provides a rigger signal to synchronise the dispensing with the recording of the camera. The picture sequence can be saved and joined to a movie or analysed with standard imaging software.

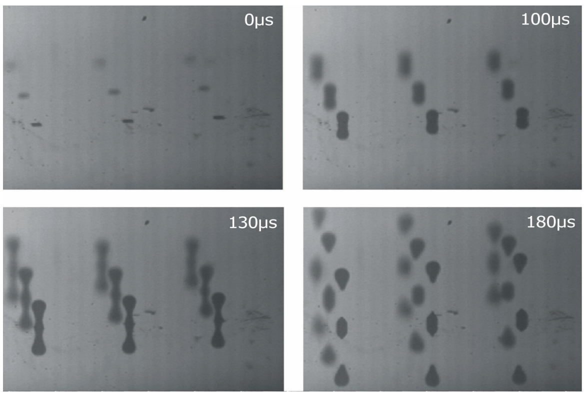


Fig. 4: *Example of a stroboscopic picture sequence to calculate the droplet velocity (3 x 3 droplet array, additionally appearing droplets are caused by mirror images on the silicon nozzle plate). In the right upper corner the delay time Δt after triggering the piezo is visible.*

After calibration of the system to achieve a satellite free single droplet ejection, stroboscopic images were recorded and evaluated to determine the droplets´ velocity. The velocity can be calculated with the droplet position on the pictures and the known time increment between successive pictures using the following formula:

$$v_d = \frac{\Delta s}{\Delta t} = \frac{s_2 - s_1}{t_2 - t_1}$$

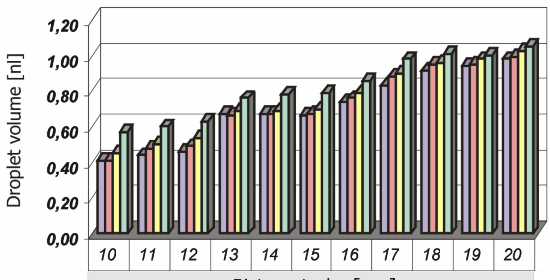
The experiments showed that the droplet velocity of ejected solder droplets can be varied in the ranges of 1–2 m/s by altering the driving waveform. The magnitude of the charging current is the dominating factor in this context.

Droplet volume

Measuring droplets in the nano-litre range is not a trivial task. A straightforward approach to determine the volume of a dispensed droplet is to weigh it. This is a reliable and easy-to-handle measurement method. Using the density of the medium, the volume is calculated with the simple formula

$$V_d = \frac{m_d}{\rho_m}$$

with the subscript d representing the droplet and m the dispensed media. In order to determine the droplets volume following procedure was performed: twenty solder-droplets were dispensed on a single aluminium-foil, the weight of which (tara value) had been determined beforehand using a Sartorius SC2 balance. After weighing the aluminium foil together with the droplets the tara value could be readily subtracted and the mean volume of the droplets was determined.



	10	11	12	13	14	15	16	17	18	19	20
290°C	0,41	0,44	0,46	0,67	0,67	0,66	0,74	0,83	0,92	0,94	0,98
300°C	0,41	0,48	0,49	0,66	0,67	0,67	0,76	0,88	0,95	0,95	0,99
320°C	0,45	0,50	0,54	0,69	0,69	0,70	0,79	0,90	0,96	0,98	1,03
340°C	0,57	0,60	0,63	0,76	0,78	0,79	0,86	0,98	1,01	1,00	1,05

Fig. 5: *Droplet volumes in [nl] for various solder temperatures and piston strokes in [µm].*

In the experiment the piezo stroke was varied in steps of 1 µm from 10 µm to 20 µm. The dispensed volumes at several temperatures are illustrated in figure 5. The results show that the droplet volume can be controlled by the piezo stroke and the temperature in the range from 0.4 nl to 1 nl. Both, the piezo stroke as well as the operating temperature exhibit an approximately linear effect on the dosage volume.

Final Experiment: Wafer bumping

The ultimate test for the presented solder deposition method is to produce solder bumps which can be subsequently used for flip-chip bonding. Bumping experiments were performed at a droplet volume of about 500 pl to deposit liquid solder droplets onto silicon wafer substrates. With the setup shown in figure 2 it was possible to dispense well shaped solder droplets onto a heated gold surface as shown in figure 6.

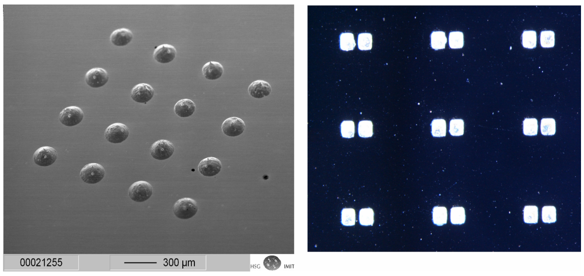


Fig. 6: (Left) SEM image of a 4x4 bump-array simultaneously printed on a heated gold surface. (Right) Simultaneously printed array on gold pads after reflow. The pad arrangement is identical to the contact pads of LEGIC MIM 256 microchips.

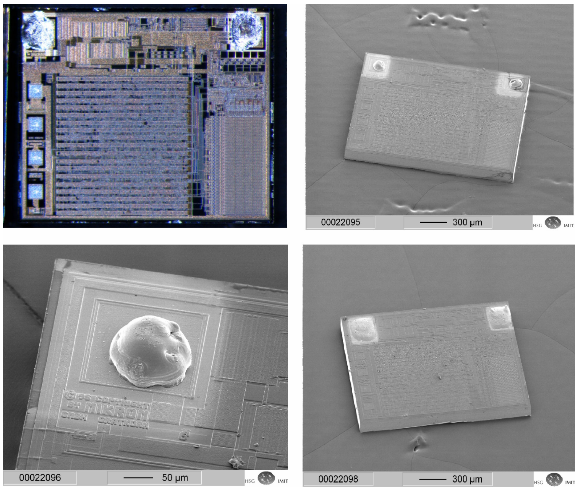


Fig. 7: (Top Left) Image of microchip after solder bumping and dicing. (Top Right) SEM image of the same die before reflow. (Bottom Left) Detail of the left contact pad of the die. (Bottom Right) SEM image after reflow

Further experiments have been carried out on a small lot of microchips. Therefore the fully processed dyes of LEGIC MIM 256 microchips where placed on the wafer rack and aligned azimuthally to the dispensing module. Approximately 200 µs after the piezo-stack is actuated the liquid solder impacts and adheres promptly onto the multilayer structure (TiW/Pt) covered by 1 µm of gold. The droplet freezing process produces approximately half dome shaped bumps, which can be distributed over the whole bond pad by a subsequent reflow process as displayed in figure 7.

4. CONCLUSIONS & OUTLOOK

The presented non contact dispenser for highly parallel dispensing of molten solder micro droplets has been successfully tested and characterized. It produces solder droplet arrays of various designs with high reproducibility and typical droplet sizes of 130 µm before reflow. The droplet can be used to form solder bumps on bond pads for various microelectronic applications. The exchangeable and reusable silicon nozzle plates enable a fast and application specific adaptation of the print pattern for the electronics manufacturing industry.

Future experiments will be dedicated to the testing of optimised nozzles to improve bump uniformity and to the integration of the dispenser in a complete flip chip bonding process based on laser welding.

5. ACKNOWLEDGEMENTS

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6. REFRENCES

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