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Concept of a Bonding Technology for Dies below 150 Micrometers

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Abstract

Due to rising demand for electrically contacted bare dies, bonding rates are to be increased. Technically, however, current bonding processes are almost at their limit. The use of continuous and consistent kinematics of the carrier substrate which allows no mechanical forces during die transfer is made possible by an optically induced, contactless transfer of the dies. The transfer can be triggered with an 8 ns laser impulse at a wavelength of 1064 nm, which detaches dies from a glass wafer and attaches them onto a carrier substrate.

Keywords: Bonding; Laser; Automation; Contactless Transfer

1. Introduction

In the field of packaging bare electronic components, assembly processes are indispensable. During assembly, components like dies are applied to a carrier substrate and are subsequently contacted [1]. This electrical contact and mechanical fixation is called bonding. The demand for bonded dies increases constantly [2]. Thus modern die bonders need to process more electronic components at faster rates to remain economically feasible. Additionally, progressive miniaturization leads to ever smaller components [3]. Bonding components with edge length smaller than 150 µm with a precision of ±10 µm evoke problems in the mechanical handling of the dies [4]. For handling the smallest dies and increasing the assembly rate, a new assembly technology is required.

We are currently researching an optical induced, contactless transfer of bare dies, which is patented by the company Mühlbauer Group [5]. The transfer is triggered with a laser impulse, which dissolves the absorption layer of the wafer, causing a single die to detach and land on carrier substrate [6]. Further, this transfer technology does not exist in field.

Our process consists of the following three phases: the application of adhesive onto the substrate, the placement of components into the adhesive and the curing of the adhesive. During curing of the anisotropic conductive adhesive, the electrical contact is also established. The assembly challenges are highlighted by the general bonding process. The Laser Induced Forward Transfer must successfully detach dies from the wafer foil and attach these onto the carrier substrate in a controlled manner.

Besides handling small dies we want to increase the assembly rate to reach a throughput rate of 100,000 assemblies per hour. For this we plan to change the positioning method to moving the carrier substrate consistently. A consistent and continuous movement raises various challenges like no mechanical forces are allowed during die transfer. Furthermore, maintaining an equivalent good accuracy increases with smaller die dimensions.

2. State of the Art

For this paper a bonding process consists of pre-bonding, bonding and post-bonding. During pre-bonding the mechanical fixation on the substrate is prepared. In the bonding-phase the

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bare dies are applied to a carrier substrate. Finally, the mechanical fixation is established while an electrical contact is made in the post-bonding-phase. This phase is necessary to ensure the functionality of the electronic components [7].

2.1. Pre-Bonding-Phase

Basic procedures to mechanically fix bare dies are alloying, soldering and gluing [8]. Gluing is the most suitable solution for smallest component sizes [9]. First an epoxy resin based adhesive is applied. Adhesives can be divided into nonconductive, isotropically conductive and anisotropically conductive [10]. Anisotropically conductive adhesives are best suited for the highest throughput rates and are characterized by low electrically conductive filler content. The filler usually consists of metal balls or metal-coated polymers [9]. The proportion of conductive filler is well below the percolation threshold, making them nonconductive in an unprocessed state [11].

The adhesive can be applied by a contact based dispensing process. Contact dispensing involves a continuous outflow of the medium onto a carrier substrate. The adhesive is pressed through a capillary where it forms a drop meniscus at its end. Contact with the substrate causes the medium to settle on the substrate [12]. Alternatively, the adhesive can be applied using a contactless dispensing process. Here, the medium is ejected by for example a dispenser with a piezoelectric actuator with tappet [13]. As only small amounts of adhesive are required and a high throughput rate is desired, a contactless adhesive application is best suited [14].

2.2. Bond-Phase

The most promising technologies for bonding dies at highest rates are flip-chip (FC) and direct-die-attach (DDA) technologies. These technologies use conductive bumps to enable electrical contacting and are characterized by a face down assembly of the dies [15]. Different FC technologies are divided into groups according to the used bumps and their appropriate bonding techniques [16]. During FC assembly, the chips are detached from the wafer, rotated by 180° and attached to a carrier substrate [17]. With DDA technology, dies are placed directly from the wafer onto the carrier substrate using a die ejector. The die ejector pierces the wafer foil, detaches the die and releases it into the adhesive [18].

Smaller and thinner dies prone to be damaged by mechanical forces [4]. Moreover, the carrier substrate is in standstill during attachment of dies [1]. For these reasons the presented bonding technologies and other existing concepts are unsuitable to meet the requirements of an increased throughput rate at the use of no mechanical forces

2.3. Post-Bond-Phase

Compressing Thermodes cure the conductive adhesive. The adhesives viscosity is reduced by the application of pressure and heat. This results in a directional electrical conductivity [11]. Simultaneously the bare dies are mechanically fixed by the curing of the epoxy resin. Alternatively, some adhesives can be cured using ultra violet light [19]. This process is independent of the previous steps and does not need to work on the fly and therefore suitable for this project.

3. Concept Overview

A direct, contactless transfer of singularized, bare dies from a wafer to a moving substrate is the goal of this in figure 1 presented concept. The goal is divided into three subgoals. The first subgoal is defined by the throughput of the placement machine with 100,000 units per hour or 27 units per second at a maximum pitch of 15 mm [20]. This means that the pre-bonding phase and the bonding phase may each last a maximum of 36 ms. The second subgoal is the assembly of dies

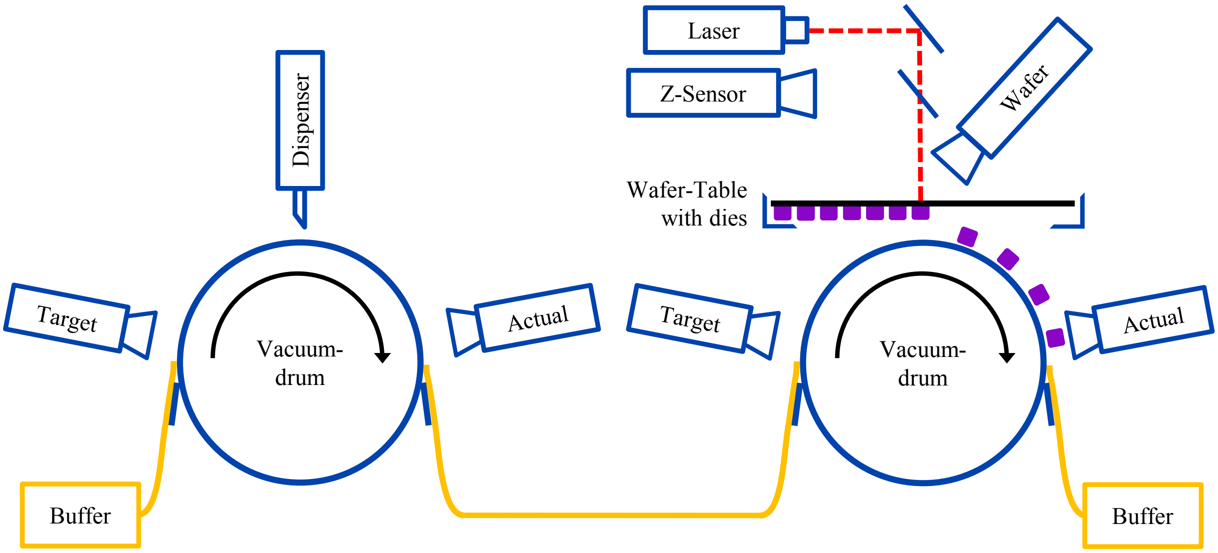

Fig. 1. Concept overview

with edge lengths between 30 µm and 150 µm [20]. This implies that occurring forces need to be so low, that no damage comes to a die. The third subgoal is the lateral placement accuracy with $c_p = \pm 10$ µm and $c_{Pk} \geq 1.33 = 4\sigma$ [20]. Thus the mechanical components must have a sufficiently high resolution and a single control cycle must be processed in less than 75 µs.

These sub-goals require a thermally curing, anisotropically conductive adhesive and electrically conductive bumps on the dies. As of yet, adhesive and dies are applied to the substrate in a stop-and-go method [2]. In this method, the positioning axes are subjected to a change in acceleration which leads to high dynamic forces. To minimize the dynamic forces, this concept works with a consistent movement method. Besides reduced forces, this method has the advantage that in comparison higher average speeds can be achieved. By increasing the speed, the first subgoal is reachable. The disadvantage of the continuous movement method, however, is that the adhesive and chip application must be contactless. A contactless adhesive application is state of the art [1], whereas a contactless transfer of dies is not. In order to transfer dies without contact, a laser based detachment system is used, which shoots dies from the wafer onto the substrate.

The concept presented here is divided into two sections, which correspond to the pre-bond and the bond phase. The continuous substrate, shown in yellow, is guided over two main drums. These drums have a negative pressure, which fixes the substrate on the drum. Due to the fixation, each placement point has a defined position. This position is first evaluated visually by the target sensor through a reference mark on the substrate. Depending on this evaluation, the control commands for a correction are derived. In case of epoxy application, an epoxy drop is applied with a Dispenser and is then evaluated at the actual sensor. Here, the quality of the drop and the accuracy in relation to the reference mark are evaluated. The target and actual camera evaluation functions equivalently during die application, where the derived control commands correct the position of the wafer table and a laser pulse detaches the die from the wafer. The wafer sensor thereby inspects the singularized wafer. Deviations due to wafer expansion can thus be integrated into the control circuit.

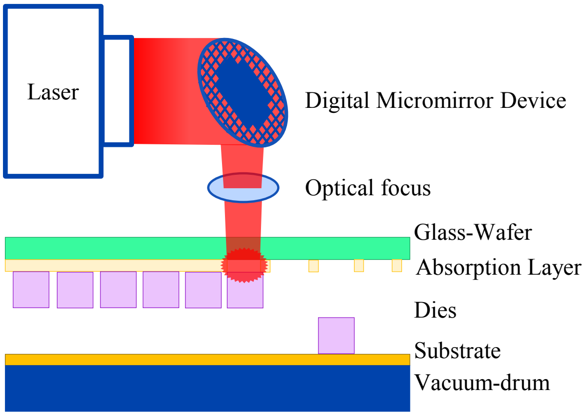

Fig. 2. Laser detachment process

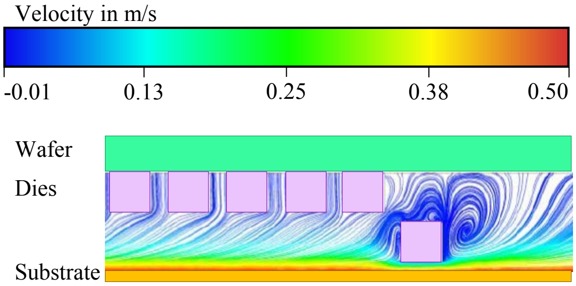

Fig. 3. Airflow simulation

The Z-sensor monitors the detachment process and the flight of a die. This allows the laser shaping to be adjusted so that the chips rarely detach from the wafer foil on one side. The Laser Induced Forward Transfer (LIFT) [21] applied to this concept is shown in figure 2.

The laser detachment process is initiated by a laser pulse at a wavelength depending on the absorption layer. The laser beam is deflected and shaped by a Digital Micromirror Device (DMD). This allows the realization of different intensity distributions on dies of different sizes. The pulse is directed to the backside of the dies, where it vaporizes an absorption layer. This leads to a forward directed impulse on a single, detached die. The detached die performs a parabolic flight in free fall. This depends on the speed of the wafer, the energy input of the laser impulse and the prevailing airflow. As a result of the airflow, depicted in figure 3, first simulations without the absorption layer show, that the acting forces lead to a die rotation at less than 5° in each axis direction. Concluding that the airflow resulting from the rotation of the drums will not have a significant influence on the course of the dies flight curve.

4. Implementation of the Concept

To achieve the sub-goal of a ±10 µm deposition accuracy, the axes are equipped with a 24-bit encoder. This means for the drums a resolved resolution of 37 nm per increment. For speed and position specifications of different axes, the respective cascaded control loops were optimized for an application scenario, so that the drums maintain speed with a standard deviation of below 2 mm/s and the wafer table can be positioned with a positioning accuracy of ±1 µm and a repeatability of below 1 µm.

A prototype with the FreeBSD operating system from Beckhoff Automation is used as the controller. To give an estimation of the quasi-real-time capability, 10,000 signals at a

Table 1. Comparison of stationary and moving substrate.

Parameter		Stationary	Moving
Substrate velocity	[mm/s]	0.00	500.00
Drop diameter	[µm]	452.10	731.30
Standard deviation	[µm]	15.40	17.50
Drop height	[µm]	108.30	38.90
Standard deviation	[µm]	6.82	7.28

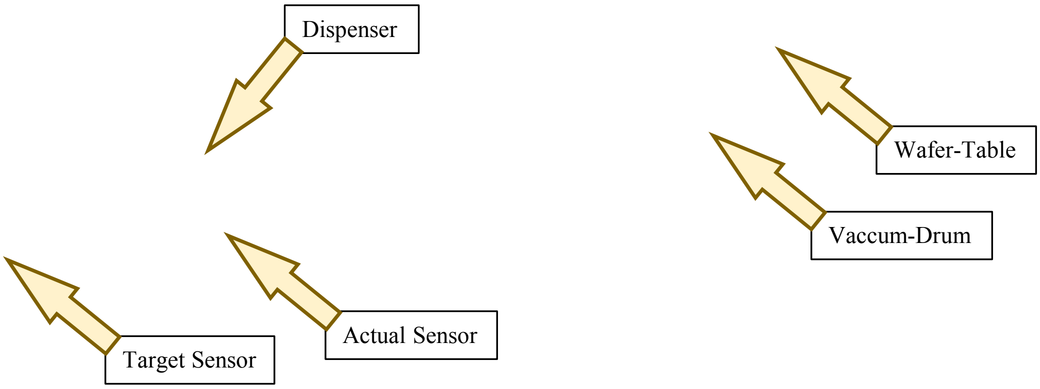

Figure 4: Implementation on a demonstrator

frequency of 1 kHz triggered a digital input, which was then measured by the controller. This resulted in a maximum latency of 250 µs. A test equivalently for the digital outputs of the controller were observed with an oscilloscope. Here, a maximum latency of 250 µs was measured. It is necessary to reduce these latencies. For this, we work on the operating systems schedulers and the TwinCat ADS response times.

The influence of the consistent kinematics is already investigated for the pre-bond phase. Here, the adhesive application on a stationary and on a moving substrate is compared. The results are summarized in table 1. For the same volume, the diameter of the drop widens by about 62.43% and reduces its height by about 35.91%. The drop propagation remains circular.

The presented concept is implemented in a demonstrator for the investigation of the individual processes and is shown in figure 4. The laser based placement head is located above the wafer table and is hidden by other machine components. Otherwise, all components can be recognized from the concept presented in figure 1.

The successful detachment of dies depends on various material and laser parameters. The best results were achieved with an 8 ns laser pulse with a wavelength of 1064 nm. The process of a single die detachment is shown in the series of images in figure 5. To be able to take this series of images no substrate is placed under the glass wafer. The highspeed camera is angled so that the detachment process can be observed from the lower side. The energy of the laser turns into light and heat while the transparent absorption layer evaporates. At 1 ms the die has travelled around 700 µm and already surpassed its destination. In the last image one can also see the airflow of the dissolved absorption layer.

5. Summary and Outlook

The sub-goals for the assembly concept consist of achieving a throughput rate of 100,000 components per hour, handling bare dies with an edge length of 30 µm to 150 µm with a placement accuracy of ±10 µm. We cannot yet prove that the concept is fully functional, but tendencies towards the sub-goals can already be seen.

The control systems for moving the positioning axis show sufficiently good behaviour to bring the components to the right place at the right time, although an optimization for different pitches is still pending. The real time capability of the control system is a critical aspect for reaching the 100,000 components. With a component pitch of 15 mm, a cycle time

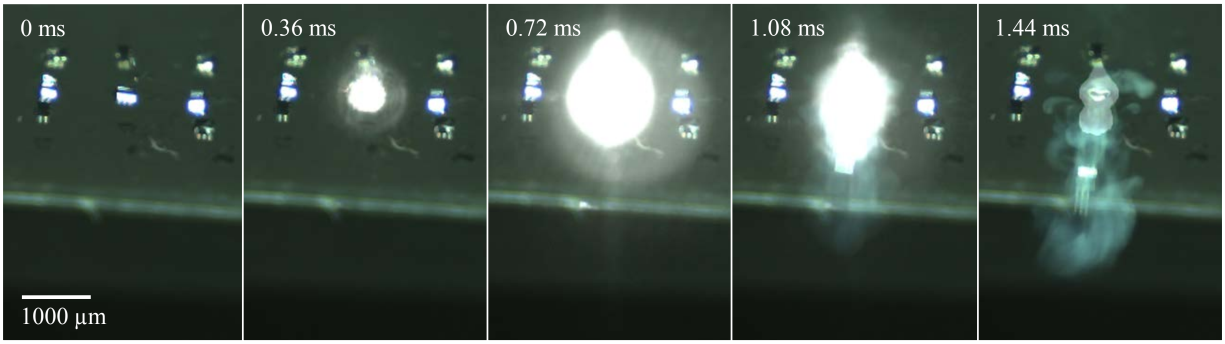

Figure 5: Inspection of the Laser Induced Forward Transfer

of 75 µs is required to achieve the placement accuracy. At present, the control runs safely at 250 µs. At a pitch of 15 mm this means a maximum placement accuracy of 93.75 µm or a maximum throughput rate of 9,600 units per hour. The laser detachment system can release smallest dies from the wafer without damaging them.

The next steps to validate the concept are to combine the laser detachment system with the demonstrator. This will then allow a cumulative estimate of the placement accuracy of the concept.

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