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Laser soldering for highest-accuracy passive bonding applications

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The actual state of the art in the field of light coupling into photonic integrated circuits (PICs) mostly is based on eutectic bonding of a III-V-light source onto the PIC followed by an active alignment of at least one optical component. During the active alignment the light source needs to be electrically contacted so that the optical power coupled into PIC can be monitored and used as alignment signal. Depending on the number of optical components in the final device (e.g. ball or spherical lenses, isolators…) this method requires, including the laser diode, at least the alignment of two or more elements. Each of this alignment steps needs a highly sophisticated and specially developed alignment and bonding machine which makes the assembly and packaging of PICs to one of the largest cost driver for the final device. Therefore a reduction in the number of assembled components is highly favourable and directly reduces the production and final product cost and hence is lowering the barriers for a market entry. In this paper we present a diode laser based assembly machine specially developed for highest accuracy passive bonding applications. The aim of this machine is to directly butt couple a laser diode into a waveguide by a passive Top-Bottom-View approach preventing the need of further optical elements.

For this application a special machine was designed and developed which can be seen as e-drawing in figure 1. The key elements of this machine are a high accuracy motion stage with a bidirectional repeatability of down to +/- 14 nm as well as a vision system including microscope objectives leading to a resolution of ~ 0.3 µm/pixel for all cameras. An automated referencing system for the cameras was implemented.

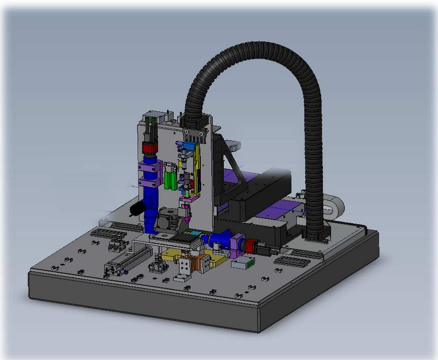

Fig. 40. 3D model of the high accuracy laser bonder which was tested.

For a reliable and repeatable detection of the reference marks with accuracies far below one micron, which is a key element for passive placement, special software tools have been developed. One of the major challenges within a soldering process is to keep the aligned position of both components during soldering when the components are heated up from room temperature to ~ 300°C. To keep the thermal input to the devices as minimal as possible a fast heat up and cool down of the devices is favourable. To accommodate for this a diode laser based soldering approach was chosen and implemented into the machine. With such an approach pure bonding times of below one second have been achieved in the past. As the solder pad inevitably needs to be at elevated temperatures during bonding a sophisticated design of the work holder is necessary to prevent any relative movements. By choosing a proper design as well as the best suited material combinations a work holder with negligible thermal expansion and shift could be manufactured.

To achieve the final goal of the most accurate passive bonding process all hardware and software routines needed to be optimized for the best accuracy and repeatability. Therefore external laser interferometer measurements on the linear accuracy, angular accuracy as well as on the repeatability of all axes have been performed to ensure and improve the quality of the motion system. The vision algorithms have been tested and optimized by measuring the position of the reference marks for hundreds of repetitions until the highest possible repeatability was obtained. After this the combined vison and motion accuracy and repeatability was tested. Figure 2 left shows the distance error between two reference marks measured repeatedly for roughly one hour. Standard deviations of down to 24 nm could be obtained. Due to the Top-Bottom View approach the reference marks on the laser die are not visible any more after bonding and hence a testing of the placement or bonding by visual inspection of the assembled device is not possible. However we have been able to measure the optical power coupled into the PIC which allows conclusions about the placement of the laser die. Figure 2 right shows the optically coupled power into the PIC for 17 subsequent assemblies. The first 5 assemblies have been done on day 1 whereas the last 12 assemblies have been done on the following day without any adjustments or test builds in between. This shows that the machine can reproduce exactly the same bonding conditions after more than a 24 hour break.

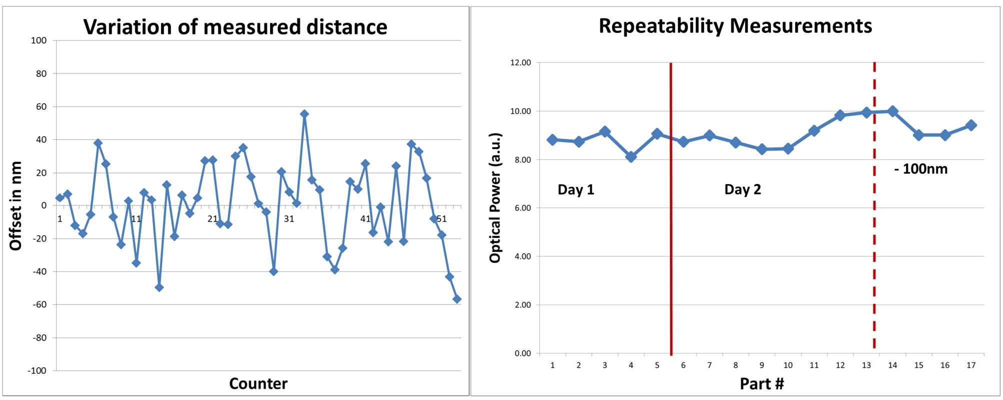

Fig. 2. Left: Optically measured distance between two fiducials for over 50 measurement cycles. Right: Optical power coupled into a PIC chip17 subsequent builds over two days.

These results show that the combination of a high accuracy alignment machine with the technique of laser bonding can produce extremely accurate and reproducible bonding results. Hence the presented machine is a very powerful tool for flexible small series or prototype production. A volume manufacturing machine actually is under development.