Surface Integration of Optoelectronic Components and Polymer Optical Waveguides in Planar Optronic Systems

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Abstract—*Planar optronic systems with a high density of integrated optoelectronic and optical components can be widely adopted in diverse applications for effective sensing, signal processing and data transmission. However, their integration in optronic systems remains challenging, particularly in individual positioning and entire assembly accuracy. In this work, we introduce a bonding technique named optodic bonding for mounting and contacting optoelectronic components as well as an automated surface integration technique for handling and fabricating polymer waveguides. A study focusing on the positioning and assembly accuracy regarding the process parameters and their influences is conducted. The feasibility and reliability of the assembly using both techniques for realizing an accurate integration is discussed.*

Key words: optoelectronic integration, optical polymer waveguide, planar optronic systems, positioning accuracy

1. Introduction

Sensor networks allowing spatially distributed functionalities are increasingly finding applications in various fields. Planar optronic systems with fully integrated optical and optoelectronic components are the promising solution [1]. One key challenge for realizing such systems is the positioning accuracy of the integrated components. We deal with this issue by taking a bare laser diode as light source and a polymer optical waveguide as transmission structure. Innovative techniques for realizing their integration are presented. We exhibit the attained positioning accuracy of each technique and discuss the feasibility for an ultimate assembly.

2. Surface Integration of Optoelectronic Components

2.1 Optodic bonding

We developed a bonding process to integrate micro optoelectronic components onto the substrate of the optronic system. This process is based on the flip-chip technology and is named optodic bonding since the entire bonding process is driven and completed by an innovatively designed optode (Fig 1). Here, we utilize UV light to enable the curing instead of the thermal energy in the thermode to realize the mechanical mount and electrical interconnection between components and systems. Accordingly, UV-curing adhesives are employed as bonding materials.

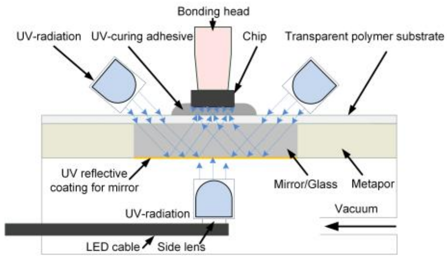

Figure 1: schematic illustration of optode

Two types of optodes, the sideway optode and the optode from the bottom [2] [3] illustrated in Fig 1, were designed and realized.

2.2 Positioning accuracy

As previously noted, achieving a high positioning accuracy remains a challenge. It has large effects on the coupling efficiency between light source and optical waveguide. A bare laser diode with a dimension of 300 x 250 x 100 µm was chosen as light source and integrated into the optronic system by optodic bonding. The embedded waveguide of laser diode lies parallel along the longer side of 300 µm.

Optodic bonding was carried out in a manual flip chip assembly system, which provides a lateral alignment accuracy of 5 µm. In the vertical direction, a small positioning deviation caused by the bonding process may result in a great loss of light coupling. The most important process parameter is the pressure distribution applied on the bare chip. The used bonding head is square-shaped and appr. 600 µm with a vacuum hole in the middle for picking and sticking dies. The hole has a diameter of circa 150 µm, which is applicable for the micro laser die. A homogeneously possible pressure distribution is required for a high positioning accuracy because uneven pressure can cause localized elastic stress and an uneven deformation of the fillers in the adhesive [4]. One crucial factor effecting the

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pressure distribution is the surface planarity of the bonding head. In accordance with ISO 25178, the planarity can be briefly evaluated by calculating one of the 3D roughness parameters *Sa*, which stands for the arithmetical mean height of the surface in the unit µm. The measured *Sa* of 0.297 µm indicates a pretty smooth surface of the bonding head.

The positioning deviation of the bonded dies can be described with a tilt angle, which can be measured by confocal microscopy. Ten samples were investigated and indicated an average tilt with a standard deviation of 0.429 ± 0.198° along the longer side of 300 µm and of 0.323 ± 0.252° along the shorter side of 250 µm. These results exhibit a high accuracy of positioning except that the standard deviation along the shorter side is apparently relatively large, which might be compensated by collecting a larger amount of samples. A maximum absolute tilt deviation along the embedded waveguide, i.e. the longer side can be calculated and do not exceed 3.3 µm.

3. AUTOMATED SURFACE INTEGRATION OF POLYMER OPTICAL WAVEGUIDE

3.1 Strategy for the surface Integration

In planar optronic systems, the length, position and trajectory of optical waveguide are variable. They are defined by the position of light source and detector as well as the planed function of the waveguide. Our goal is to achieve an automated handling and bonding system, which allows a flexible surface integration of polymer optical waveguides. For this purpose, we developed a 4-axes assembly gantry robot. The assembly robot has 3 linear axes and a rotation axis as presented in Fig 2.

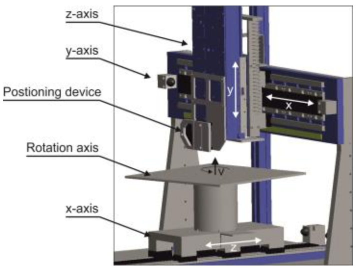
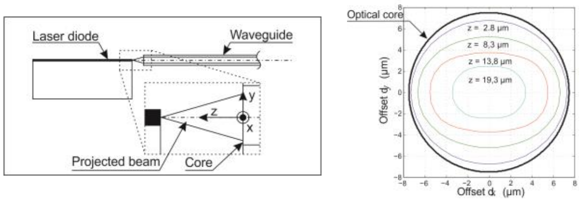


Figure 2: Illustration of assembly gantry robot

The substrate can be adjusted in the z-direction and the rotational axis v. The positioning device for handing the waveguide can be adjusted in the x- and y-direction [5]. For the waveguide, we used polymer optical fibers as core material, which are bonded to the substrate surface using a UV-curing adhesive. The diameter of the employed core varies between 10 and 100 µm. The UV-adhesive is functionalized as cladding material and has a matching refractive index to realize the internal total reflection. The handling of the optical core is realized with the help of a micro-gripper while the bonding is realized using a micro-dispensing process. We follow two strategies for the surface integration of the optical fibers. The first one consists of a direct integration onto the surface. The second one consists of an integration into a pre-milled trench structure.

3.2 Involved processes and their influence on the position accuracy

The position accuracy of the integrated waveguide in respect to the light source is relevant for the coupling efficiency. In the developed process, this accuracy depends on the used axis and the dispensing process. We simulated the position deviation to define tolerance limits for a coupling efficiency of at least 1 dB for a core diameter of 15 µm. Fig 3 shows the used simulation strategy (Fig 3 (a)) as well as some resultant limits for different distances between the laser diode and the waveguide end-facet (Fig 3 (b)).



(a) (b)

Figure 3: (a) Assembly of laser diode and waveguide, (b) simulation results depending on x-, y- and z- directions

Results in Fig. 3 (b) reveal positioning tolerances depending on the distance between laser diode and integrated waveguide. For instance, at a distance of 2.8 µm, a tolerance up to appr. 6 µm is allowed for the x- and y-direction. We integrated piezo-motors for the system axes in the x- and y-direction with a resolution of 10 nm and a max. positioning error of 50 nm. In this way, the necessary accuracy for the axes is assured.

4. DISCUSSION AND CONCLUSION

We assume that the emission profile of the laser diode remains the same for a limited tilt deviation up to 3.3 µm. For a distance of 19.3 µm between the laser diode and the waveguide, a maximum positioning tolerance of appr. ±3.5 µm in the x-direction and of appr. ±2.5 µm in the y-direction can be estimated from Fig. 3 (b), within which a coupling efficiency of 1dB can be guaranteed. A tilt deviation of 3.3 µm oversteps the tolerance range of y-direction, thus cannot achieve this coupling efficiency. Nonetheless, it will stay within a maximum tolerance range of a distance larger than 13.8 µm, which facilitates the surface integration of the waveguide. Therefore, deploying introduced integration techniques, the assembly of laser diode and waveguide into planar optronic systems can be accurately completed. Nevertheless, further improvements are still promoted, e.g. homogenizing the bonding pressure distribution, determining the form accuracy of dispensed cladding structure and its shrinkage factor during the curing process, which also affects the position of the waveguide core.

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