

Precise integration of flexo-printed optical waveguides into printed circuit boards via opto-electrical layout registration

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Due to increasing integration density, optical data transmission is a solution for interference-free data transmission and galvanic isolation at circuit board level. The flexo-printing process can be used to print planar optical waveguides additively. These are integrated into the conventional circuit board manufacturing process, with layout registration for the first time, for potential cost-effective and suitable mass production.

1 Introduction

Photonic integration into printed circuit boards (PCB) enables a wide range of future applications. To establish this in the market, the process must be cost-effective and suitable for mass production [1]. Flexo-printing enables a possibility to integrate an additional layer in a conventional PCB manufacturing process. In previous studies waveguides were produced with this process and were already integrated between PCB materials, but without any alignment to enable a registration of waveguide position [2].

For final integration into a PCB, registration and high alignment precision of the waveguide layer are required. Only if these conditions are met, it is possible to passively assemble submounts (Fig. 1a) to couple light into such an optical waveguide (Fig. 1b), or to subsequently detect light.

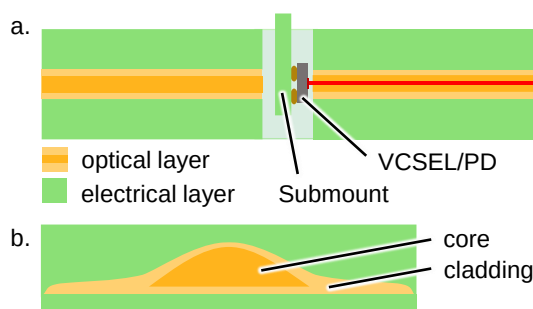


Fig. 1 a. Illustration of optical layer integration into PCB and submount with a VCSEL for couple light into waveguide or photodiode (PD) for detecting light. b. Schematic cross-section view of a flexo-printed optical waveguide.

In this study, optical waveguides are manufactured using a new machine (nsm challenger 650) with optical alignment capabilities. By coordinating fiducials in optical printing process and PCB manufacturing, it is possible to register optical waveguides in PCBs for the first time. This paves the way for the practical use of flexo-printed waveguides in PCBs.

2 Material and Methods

Flexo-printing is a rotative, additive printing process used for production of planar optical waveguides, shown in Fig. 2. In this process, varnish is transferred from an anilox roller to a printing form, which transfers previously defined optical waveguide structures to substrates. Each individual printed layer is cured by UV light. Optical alignment is necessary to define the position of printed optical waveguides on the substrate.

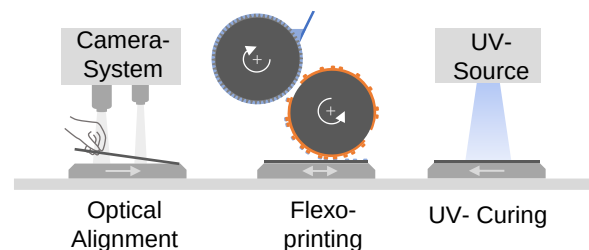


Fig. 2 Flexo-printing process for manufacturing optical waveguides, using a UV light source to cure varnish layers and optical alignment to ensure registration of optical waveguides on substrate or in PCBs.

To ensure layout registration between optical and electrical layout, manufacturing is performed in three defined steps shown in Fig. 3. The optical waveguides and PCBs are produced in accordance with fiducials that have been applied previously and are aligned with each other.

The final position of optical waveguides can be affected by various process steps. These include the application of fiducials using lithography process, printing form tolerances, inaccurate alignment between print layout and fiducials as well as deviations in final geometry of PCB. Systematic errors caused by not fully form-stable waveguide substrate are also possible as a result of material deformation during handling or lamination. All of these factors can affect the position of optical waveguides in x-y-

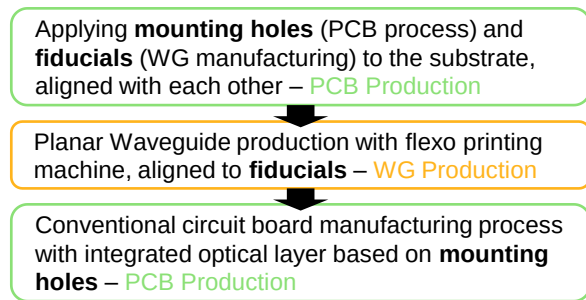


Fig. 3 Process flow for integrating optical waveguides (WG) into a PCB.

plane through offset in either direction or rotation. A vertical offset is also possible but is not considered in this work.

The optical waveguides embedded in PCBs for which the position is investigated are flexo-printed double splitters, 30 mm long (s_x) and 8 mm wide (s_y) shown in Fig. 4. The position deviations and their causes are evaluated for various process steps.

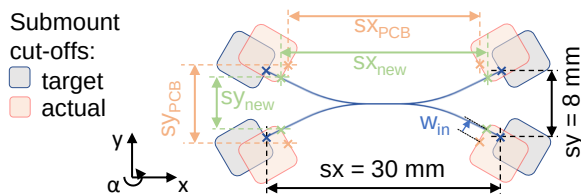


Fig. 4 Definition of x-y plane and rotation, and illustration of the produced and integrated double splitters with target and actual cut-off sections for submount assembly.

3 Results

In the first production step, fiducials and mounting holes are applied to polyimide- (PI) substrate. However, with the thin PI-substrate used, slight fraying of the mounting holes and wrinkles formed on the surface of the polymer material are already visible after the first step. This could lead to systematic deviations in optical registration relative to the electrical layout during final lamination process.

The second step involves manufacturing optical waveguides using flexo-printing process. The same layout (two double splitters each) is printed four times onto the prepared substrate to cover the entire area of PCB production. Next, for each of the four prints, the offset in x and y direction (dx , dy) is determined using one fiducial, and the rotation of the print ($d\alpha$) is determined using a diagonally positioned fiducial. The result is a deviation of $dx = 21.65 \pm 13.37 \mu\text{m}$, $dy = 7.95 \pm 6.58 \mu\text{m}$, and $d\alpha = 0.002 \pm 0.003^\circ$ (coordinate system in Fig. 4).

The next step involves lamination of optical waveguides into eight PCBs. Three PCBs from various locations on the production panel were randomly selected for further investigation, to evaluate a representative sample. Fig. 4 shows all variables used in the subsequent analyses. Measurements of the

PCB geometry (cut-out positions $s_{x\text{PCB}}$, $s_{y\text{PCB}}$) reveals deviations ($\text{diff}_i = s_{i\text{PCB}} - s_i$) of $\text{diff}_x = -553 \mu\text{m}$ and $\text{diff}_y = 66 \mu\text{m}$. For this reason, an offset of the optical waveguides is expected, which is also confirmed when analyzing the waveguide position in cross-section. However, the offset values are not consistent for all splitter ends. For the measured double splitters, the values for inward offset w_{in} of the four splitter ends are $608.29 \pm 47.11 \mu\text{m}$, $269.72 \pm 6.70 \mu\text{m}$, $-126.03 \pm 6.70 \mu\text{m}$ and $175.80 \pm 5.98 \mu\text{m}$. Due to the deviations in PCB geometry, these values are quite high. If the expected distances $s_{x\text{new}}$ and $s_{y\text{new}}$ between waveguide end facets are calculated considering the layout deviations ($\text{diff}_{x,y}$), the deviations between measured and calculated values $s_{x\text{new}}$ are small ($51 \mu\text{m}$ and $71 \mu\text{m}$). The deviations for $s_{y\text{new}}$, in contrast, are larger and roughly similar in magnitude but of opposite sign ($-291 \mu\text{m}$ and $214 \mu\text{m}$). As the values for all three analyzed PCBs are comparable, this suggests a systematic offset of dx in the optical layer during the manufacturing process. If a value of $dx = 220 \mu\text{m}$ is also factored in the expected distances the difference between calculated and measured distances $s_{y\text{new}}$ decreases to $-37 \mu\text{m}$ and $-40 \mu\text{m}$. Therefore, all four values are within or less than the standard deviation of the measured distances. This analysis does not account for a systematic y-offset or rotation of the optical layer.

4 Conclusion

In this study waveguide integration into PCBs via opto-electrical layout registration is successful implemented for the first time. Nevertheless, there are several deviations in all process steps with lowest tolerances in the optical waveguide manufacturing process. Next steps are to identify and reduce main factors affecting tolerances like PCB layout variations and systematic deviations caused by waveguide substrate.

Acknowledgements

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