2 EOCB Fabrication and Production

Actually, the Arbeitsgebiet Mikrostrukturtechnik (AG MST) has developed a new optical layer fabrication technology based on transparent silicones which comprises all essential features for a low cost mass production of large area electrical-optical circuits boards.[43, 44] This technology is becoming transferred to a worldwide first industrial production of EOCBs within the frame of a BMBF project named “Prospeos” which stands for “Prozesssichere Stückzahlproduktion elektrisch-optischer Schaltungsträger”.

2.1 Polysiloxane Based EOCB Lab Fabrication

Reactive ion etching and UV-curing have been reported for polysiloxanes waveguide fabrication. With respect to our fabrication technology, we have adopted casting in combination with the doctor blade technique as a new polysiloxane waveguide fabrication method. The main advantages of this technology are that there are no restrictions on the waveguide cross-sections, which is important for multimode waveguides, and that it has the unique feature of simultaneously fabricating optical waveguides together with integrated micro mirrors and passive alignment structures for OE-module coupling. First a casting mould for the waveguide core layer is generated. This is accomplished by SU-8-photolithography. The resist is dried and exposed through a photolithographic mask. After development of the resist the master mould is finished (Fig. 2.1). In the reported experiments standard 6”-photoresist technology has been applied, and the extension to larger formats (300 mm × 400 mm) is realized as well. In case of large area formats (Fig. 2.2), doctor blading is used instead of spin coating because of the better thickness uniformity of the resist on rectangular substrates.

The basic prerequisite for the replication process is a robust mould or stamp. A further special requirement for optical waveguide fabrication is an extremely low surface roughness (< 40 nm) to guarantee low scattering loss. Taking advantage of its high resolution and and chemical resistance we are employing SU-8 photoresist patterns directly as mould. No special release layers are required to separate the polysiloxane materials from the mould.

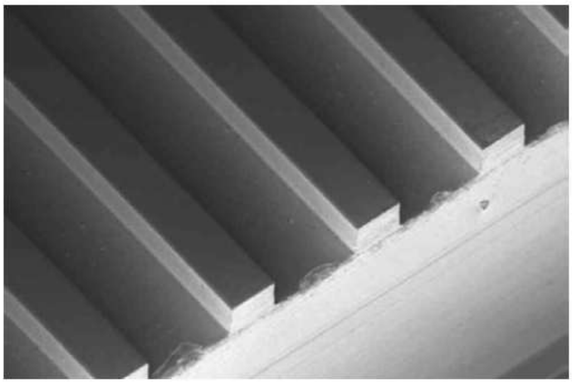

Fig.2.1 *SU-8 master form with straight channels*

Fig.2.2 *Large size SU-8 master form*

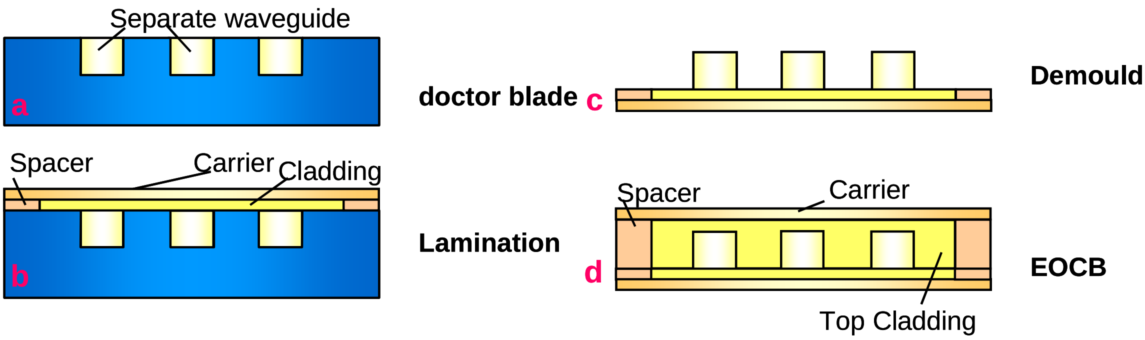

Fig.2.3 *Fabrication and self-packaging process of PDMS based optical layer*

The fabrication process starts with groove filling and blading of the core material (Fig 2.3a). The blading may be realized by hand or a stencil printer (Fig. 2.4) which is originally implemented in SMD techniques for reliably controlled process conditions e.g. control of blading angle, pressure and velocity for large size mould. After curing of the core material, the first cladding layer is applied. In the next step the first carrier (FR4, Kapton or copper) is laminated to the waveguide sandwich when the cladding is still in the liquid prepolymer state (Fig. 2.3b). After a second thermal curing, the complete core-cladding-carrier sandwich is demoulded (Fig. 2.3c). In the last step the second cladding layer is applied by casting and the second carrier is laminated on the liquid cladding material. After a third curing step the self-packaged optical layer is finalized (Fig. 2.3d). After fabrication, the optical layer embedded between two standard PCB-carriers can be integrated into any conventional electrical multilayer board by using standard PCB production processes.

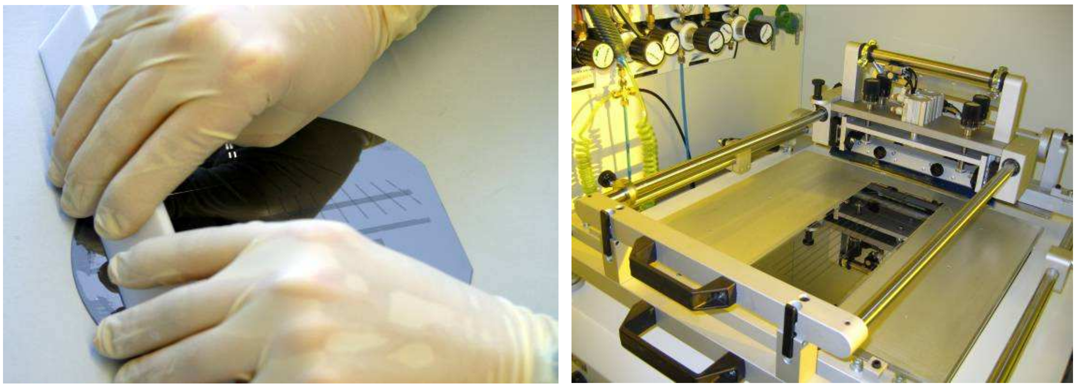

Fig. 2.4 *doctor blading by hand and stencil printer applied for controlled blading*

2.2 Polysiloxane Based EOCB Production

The described fabrication process above developed in laboratory scale at the University of Dortmund now is transferred to an industrial production line (format 460 × 305 mm2) within the framework of the BMBF-founded research project “Prospeos”. In Fig. 2.5 a preliminary set-up of EOCB production machine and line is shown. A mobile stacker is placed in front and at the end of the line for easy sample handling and transportation.

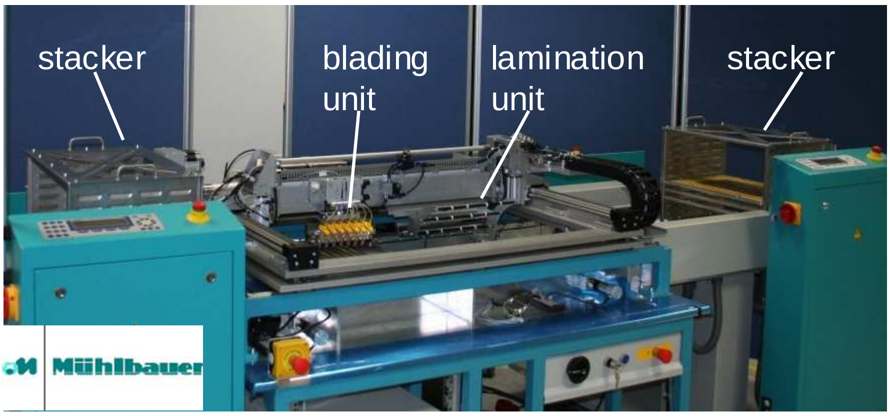

Fig. 2.5 *Preliminary set-up of EOCB production machine*

The samples (14 samples at once) are stored in the stacker after one production cycle and inserted at the beginning again. The production unit consists of three main elements: A spray coater, a blading unit and a curing oven. In between there is space for manual operations like sample handling and retooling works. The first unit is a spray coater (Systronic/ Mühlbauer) where the moulds are coated with polysiloxanes and adhesion promoter, respectively. The automated blading unit is specially developed by ASEM GmbH in close cooperation with the University of Dortmund. Here the core material is applied by a peristaltic delivery, followed by blading and carrier lamination. In the curing oven the polymers are cross linked. Alternatively to inline curing the whole stacker could be placed into a fan oven. For producing the complete optical layer four cycles are necessary. In order to be processable by the shown processing techniques the basic polysiloxane materials had to be modified. To enable spray coating, the cladding material was blended by silicone oil to lower the viscosity to values < 1000 mPas. By spray coating polysiloxanes layer thicknesses between 20 and 200 µm could be achieved. To extend the pot life of the processable polysiloxanes materials from a few hours to some days inhibitors have been used. A critical point in using polysiloxanes materials in EOCBs is the realization of a mechanically stable interface between the optical PDMS layer and the adjacent PCB materials like FR4 or Kapton.

2.3 Overview about the Thesis Work

The industrial production line of polysiloxane based Electrical-Optical-Circuits-Board (EOCB) is under development within the German national industrial project Prospeos. However, in order to produce highly qualified EOCBs and assure their long-term reliable operation, it is necessary to identify the critical quality aspects on EOCBs and consequently pursue the respective quality control from these aspects. Considering from EOCB application environments, the quality control will be performed mainly from optical and mechanical two aspects.

Additionally, the important quality requirements from market requests and PCB compatibility etc. can be summed up from the following items:

- Bandwidth of 10 Gbps
- Low loss optical layer fabrication (loss< 10 dB/ m at 850 nm)
- Optical layer lamination to Printed Circuit Boards (T= 180 ℃/ 2h)
- Lead-free soldering process (T> 250 ℃/ 10s)
- Environmentally stable

In terms of the identified quality aspects and quality requirements the influences of the materials, processes, and reliability etc. on the optical, mechanical and thermal performances of the final EOCBs should be focused and studied. Quality monitoring methods as well as test and optimization procedures need to be identified and verified as well.

In detailed, first in chapter 3 the optical aspects in EOCBs will be discussed.

In this aspect, the main problem is how to realize the low optical waveguide loss of EOCB after the whole process under meeting the request of bandwidth. The low optical waveguide loss may be affected from the following quality factors.

(1). Refractive index and Bandwidth

Guided wave optics confines radiation in the optical waveguides through the phenomenon of total internal reflection (TIR), where the core material is surrounded by a cladding material with a lower refractive index. The coupling and propagation characteristic of the waveguide i.e. bandwidth is thus defined by the core-cladding index difference. The respective refractive indices of practically applied core and cladding polysiloxanes in Prospeos project will be studied and measured as well as their numerical aperture and its thermal stability considering the operation environmental change of EOCB. Additionally, the bandwidth of EOCB also needs to be verified in terms of request of 10 Gbps/ 1m.

(2). Optical loss

In general, all optical waveguide devices need to have low optical loss, in particular at the major communication wavelengths. Actually, two main losses contribute to optical waveguide loss of EOCB, and one is the material intrinsic loss, e.g. scattering loss, electronic transition loss and molecular vibration absorption etc. The other is responsible for extrinsic loss which can be traced back to contaminating dust, pores, crystallites and core-clad interface roughness from the fabrication process.

First, with respect to material intrinsic loss various mechanism and reasons causing the optical loss in polysiloxanes will be identified from molecular views through optical spectroscopy methods e.g. FTIR. After that, some modification and improvement methods will also be proposed in order to fulfil the technical request of 10 dB/ m.

Additionally, within EOCB fabrication process core-clad interface roughness, structural interlayer between core and cladding layer, and packaging substrates are identified to be the main loss contributors. So, in the part their influences will be identified and respective controlling and improvement methods will be proposed as well in terms of the request of 10 dB/ m.

In chapter 4 the mechanical aspects in EOCBs will be focused.

It is vital for the reliable operation of EOCB to realize mechanically stable interfaces between core and cladding layers, cladding layers and the whole optical PDMS layers and the adjacent PCB substrate materials like FR4, Kapton and copper coated boards etc. In case of bubbles and insufficient interfacial adhesion among them, thermal stress due to CTE (Coefficient of Thermal Expansion) and Young's modulus mismatch will lead to delamination and resulting damage of the boards when processed for lamination and soldering etc.

The main work in the chapter is divided into two parts:

(1). Realization of EOCB robust packaging

First curing mechanism of polysiloxanes is studied. After that, with respect to core and cladding polysiloxanes different curing conditions within waveguide fabrication process will be defined and optimal conditions will be proposed as well to achieve mechanically stable interfaces in optical layer, i.e. core and cladding layers, and 1st cladding layer and 2nd cladding layer. Furthermore, in order to realize one robust packaging of polysiloxanes optical layer between PCB layers one highly efficient surface adhesion promoter will be studied and identified. PCB surfaces (e.g. elements distribution and topography etc.) will also be studied as main points to identify appropriate etching conditions and to match with the adhesion promoter from chemistry view. In the end, based on the aforementioned methods one novel EOCB packaging solution will be proposed and transferred to the real production line.

(2). Design for reliability

For an industrial implementation of EOCBs, a reliable production technology as well as a corresponding quality management must be developed. Consequently the environmental stability of the optical and mechanical properties of fabricated PDMS based EOCBs will be necessary to be verified.

Due to potential operation environments and long-term reliability of EOCBs, and also referring to the standards for optical components in telecommunications (Telcordia) and general PCB tests (IPC and IEC) experimental stability verification design will be done and the test items should be determined as follow, e.g. dry heating, damp heating and thermal shock etc.

With respect to different test items, different acceleration models will be built considering their different physical properties and phenomena. Additionally the respective operation life will be estimated based on the defined aging conditions as well.

Moreover, considering from practical application market and referring to other similar products, one reliability objective for EOCB products will be defined based on the deduced acceleration factors above. Thereafter, the sample sizes will be determined with one set statistical confidence, e.g. 90%. Thus, in terms of the sample sizes, the experimental samples with respect to different test items will be prepared for the acceleration aging tests.

In chapter 5, one summary of the whole work and the brief outlook to future work will be presented.

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