Polymer Optoelectronic Bus for High-Speed Data Transmission Systems

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Abstract. In this paper, high-speed planar waveguides of optoelectronic data bus are suggested replacing low-throughput backplane electrical interconnects. Optical polymer polydimethylsiloxane (PDMS) and cost-efficient soft lithography technology are proposed for optoelectronic bus fabrication. In accordance with polymer optoelectronic data bus fabrication process work-out results the chosen materials and technology applicability was confirmed. As an optoelectronic bus characteristics measurement results, 14 dB/cm propagation losses value was obtained by general use materials.

1. Introduction

Nowadays, the throughput limit achievement of electrical interconnects is observed in high-performance data processing systems. The modern solutions for increasing data transmission speed consisted in fiber optic connection between data processing systems modules that complicated these systems maintenance.

As an alternative, optoelectronic data buses representing as backplanes with array of embedded polymer planar optical waveguides are proposed to use. The ability to 10 times backplane throughput increasing and fabricating on printed board surface from low-cost optical materials pointed out the undoubted relevance of the polymer optoelectronic data buses development.

The increasing of backplane throughput is provided by placing an optoelectronic bus on its surface. This bus contains a planar optical waveguides array, that topology being developed individually for separate backplane, and optical emission input/output elements. There are two optoelectronic bus analogs: the optoelectronic bus model designed in ILIT RAS [1] with 3 Gb/s throughput and the new generation backplane prototype constructed in HDPUG Inc. [2, 5] with integrated between backplane layers optoelectronic bus and 40 Gb/s throughput. The IEC standards group IEC 62496 was defined regulating the optoelectronic buses creation and their characteristics measurements.

Presented above optoelectronic buses are made of optical polymeric materials, such as PDMS, PMMA etc. Optoelectronic bus production costs and the mechanical stresses effects on signal losses by accordance thermal expansion coefficient value (CTE) with printed board are reduced using polymers [3]. In this paper, the bus is fabricated by optical polymer polydimethylsiloxane (PDMS). It is revealed that PDMS is able to change the refraction index by the base/cure mixture ratio variation (Figure 1), that enables forming optical waveguides from one material (PDMS) and further reducing propagation losses.
2. Polymer optoelectronic data bus

2.1. Polymer optoelectronic bus construction

In this paper, optoelectronic bus model contains straight polymer planar optical waveguides (figure 2). These waveguides are placed at FR4 subtract, that is conventional PCB subtract. It is worth noting that waveguides core layers are covered only bottom cladding layer without top cladding layer to simplify coupling with optical fiber.

The polymer optoelectronic bus parameters are represented in Table 1. Infrared light wavelength 850 nm was chosen due to low-cost and common semiconductor light sources. Planar waveguide core width was about 10 μm for singlemode planar waveguides. After some fabrication technology working out and measurements core width increasing was taken in accordance to multimode fiber core cross-section (50х50 μm$^2$) applied to input/output light in/from polymer planar waveguides of optoelectronic data bus. In addition, high efficient butt-in-coupling planar waveguides with multimode fiber was ensured by clad 40 μm width. PDMS base/cure agent 20:1 for clad and 5:1 for core was selected to meet the total internal reflection conditions. Based on light source waveguide and Cai el. results [4] PDMS theoretical refraction index was estimated.

Table 1. The main optoelectronic bus parameters

| Parameter                        | Value (core / clad) |
|----------------------------------|---------------------|
| Material                         | Polydimethylsiloxane (PDMS) |
| Refraction index n               | 1.41 / 1.404        |
| PDMS mixing ratio                | 5:1 / 20:1          |
| Width h, μm                      | 50 / 40             |
| Planar waveguide total width H, μm | 130                |
| Light wavelength λ, nm           | 850                 |
| Optical fiber type               | multimode           |
| Optical fiber diameter D, μm     | 125                 |
| Optical fiber core diameter d, μm| 50                  |

Figure 1. The values of refractive index for PDMS in different mixing ratios of the base to curing agent [4]

Figure 2. Planar optical waveguide model
2.2. Soft lithography technology

To create the optoelectronic bus model, a fabrication process based on soft lithography technology has been developed. We had to refuse direct photolithographic patterning because of Sylgard 184 (PDMS) UV-curing impossibility. Similar to microfluidic devices fabrication hard maser mold was applied to polymer layers patterning. The optoelectronic bus production scheme is depicted in Figure 3. This fabrication process contains some soft lithography unconventional procedures. Instead of master mold imprinting PDMS layers are covered by doctor blading. Also, it is optoelectronic data bus which peeled off in the end of production.

The quality control of technological operations performance was carried out according to the developed step-by-step operation control methods. It must be noted that master mold fabrication by projection photolithography technology and optoelectronic bus pilling out are the most essential and limiting stages. Therefore additional control procedures are required after them.

2.3. Measurements and results

The model characteristics measurement scheme and methods meet the requirements of IEC 62496-2: 2017 [5]. Propagation losses measuring scheme contains IR light source, receiver and multimode fibers. Light as a signal was launched into the waveguides through butt-in-coupling using v-shaped grooves for fixing fiber position relative to the planar waveguide cross-section (Figure 4a, b). At the beginning insertion losses value to/from optical fiber is estimated and collected in receiver memory. After measuring signal losses of optoelectronic bus model this value is automatic subtracted.
The attenuation of the optoelectronic bus best sample is 14 dB/cm. It is worth noting that signal losses value was reached applying general use materials without additional cleaning operations that are as soon as light transmitting materials. Figure 5 represents magnified view of polymer planar waveguide section. It is apparent that waveguide core contains internal defects (air bubbles) and roughened surface that may be cause in high total signal losses.

![Polymer planar waveguide section.](image)

Although, 14 dB/cm signal losses value substantially corresponds with 40 Gb/s optical bus [6]. The main causes of their occurrence are lack of top cladding layer, low level of working out novel fabrication process and high losses in poor butt-coupling efficiency. The losses reduction might be obtained by variation of fabrication conditions and by addition materials purification. Beyond that it is necessary to arrange special input/output elements with enhanced numerical apertures or with supplementary elements for decoupling prevention [7].

3. Conclusion

Thus, the model of polymer optoelectronic data bus for the new generation high-speed backplane has been developed:

- optoelectronic data bus design was determined and PDMS was chosen for bus fabrication allowing cost-efficient production and signal loss reduction;
- polymer optoelectronic bus analogs inferior in the characteristics of the materials being used were identified;
- PDMS planar optical waveguides fabrication process was developed and successfully worked out providing the necessary topology repeatability.

Summarizing the optoelectronic bus model parameters measurement results, the selected materials and fabrication methods applicability was confirmed and the demand for further optical signal loss reducing researches was emphasized.

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