"*glass*Pack" – Photonic Packaging using thin glass foils for Electrical-Optical Circuit Boards (EOCB) and sensor modules

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Abstract

The "*glass*Pack"-concept will be introduced as a new packaging technologies platform for a wide area of opto-electronic applications like optical backplane, electrical-optical circuit boards (EOCB) and sensors. The usage of thin glass foils of some tens of microns thickness as substrate and interconnection material is the crucial point of the concept. First realizations will be presented.

Introduction

Photonic packaging in such hybrid opto-electronic systems involves single packages, modules, and subsystems comprising of at least one optoelectronic device, micro-optical element or optical interconnection. The commonly used substrate materials are ceramic platforms, silicon, HTCC, LTCC or polymeric substrates. In contrast the main advantage of thin glass is their transparency. Thin glass is a commercial available and reliable material for display protection with high thermal resistance and excellent optical properties. Furthermore glass is a well known material and many technologies like polishing, plating, etching and refractive index tuning are already available and can be adopted.

The main ideas of the "*glass*Pack" concept are: selection of suitable glass foils as substrate material, realization of micro system compatible structuring technologies like cutting, drilling and milling, integration of optical waveguides by ion exchange for single and multi-mode applications, optical interconnects between fibres and integrated waveguides by laser fusion, integration of electrical wires and vias, assembly of electronical and opto-electronical components, and bonding of the thin glass foils to 3D-stacks and lamination to PCB base materials. Furthermore, the integration of micro fluidic channels into a "*glass*Pack" will be supported. The technical focus of that paper lies on the waveguide process itself and newly developed interconnection technologies for the optically functionalized glass foils. They can be laminated in between of polymeric base materials like FR4 for optical backplane or EOCB, and complete glass based packages on wafer level can be realized, respectively.

Application fields

Optical backplanes and PCB with opto-electronic components using glass fibers are the standard in today's high-end area. That led to approaches using the integration of glass fibers in the circuit board with passive elements and (MT) connectors. Because of high assembly costs the trend is being set by integrated polymer waveguide layers, manufactured using planar structuring processes, which are embedded into the circuit board assembly, so called EOCB [6]. The waveguides are always multimodal step index waveguides with core diameters in the range of 30…70 µm. The length of the waveguides and the obtainable optical attenuation are primarily determined by the properties of the various structuring technologies themselves [7]. Due to their material properties, the optical attenuation of polymer waveguides is higher than for glass, thus, the power/performance balance for, above all, the optical connections in the backplane area is critical. The transition to glass based waveguides foils can be regarded as a promising step in terms of reliability and low optical attenuation. Furthermore the "*glass*Pack" technology can be used to realize waveguide based coupling elements like shown in **Figure 11** for vertical out of plane coupling to the e/o modules and between daughtercard and optical backplane, respectively. This is exemplary shown in the challenging architecture presented in **Figure 1** providing two pluggable modules per daughter card, each module supplies 2 x 12 waveguide channels at 10 Gb/s in two vertical stacked waveguide layers [8]. For the 90° light deflection special *glass*Pack optical interfaces are proposed with two optical waveguide layers by the same process as for the horizontal waveguide layers itself. These coupling elements are under development currently and first results are shown in **Figures 12** and **13.**

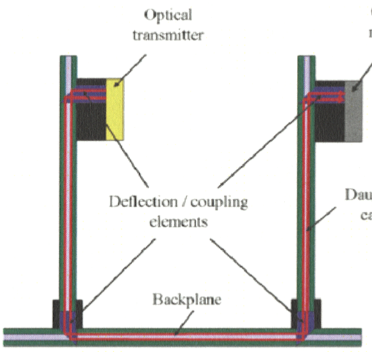

Figure 1: Schematic diagram of the demonstrator system with 2 modules per daughter card (only one is shown in the drawing), double layer optical waveguides and coupling scheme

Another promising field of application is multifunctional integration for sensors. The thin glass substrates available in different formats have excellent optical, electric, thermal, mechanical, and chemical

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properties, which make it suitable for harsh and hazardous environments or applications in the field of optical sensing. One of the most important *glass*Pack features is the suitability for wafer level packaging.

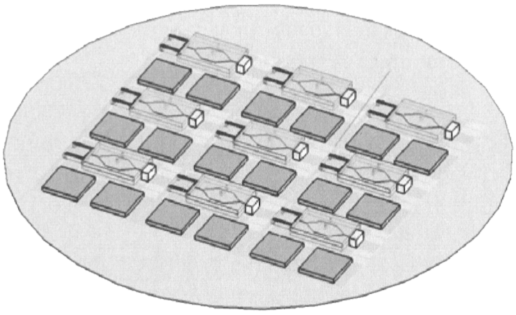

Figure 2: *glass*Pack technologies processed on wafer level

The choice of appropriate glass depends on the application. Optical waveguides and fluidic channels will be implemented inside the thin glass substrates. Electrical feed troughs' and wires on the surface form electrical circuits. Integrated waveguides, fluidic channels, or electrical wires implemented in various thin glass substrates can be stacked at wafer level resulting in 3D-packages (**Figure 2**). As an example a refractometric sensor has been realized (**Figure 15**) [4].

Thin glass properties

Using the display glass D 263 T supplied by Schott Desag AG the demands can be fulfilled. The glass D 263 T is commercially available in a thickness ranging from 0,03 mm up to 1,10 mm with the maximum dimensions of 440 mm x 360 mm [1]. The display glass used as testsamples has a thickness of 100 to 300 µm and a size of 4 inch. It is a borosilicate glass which is produced by melting very pure raw materials (Table 1). As such, it is very resistant to chemical attack. Further features are: easy cutting, high luminous transmittance between 380….2400 nm and excellent flatness.

Table 1: chemical composition of D 263 T (compounds in wt.%)

SiO_2	B_2O_3	Al_2O_3	Na_2O	K_2O	ZnO	TiO_2	Sb_2O_3
64,1	8,4	4,2	6,4	6,9	5,9	4,0	0,1

The refractive index as a function of wavelength is shown in **Figure 3** according data given by Schott Desag AG [1]. The fit function was calculated to describe the dispersion relation for wavelength λ > 800 nm. These wavelength range is important for intra system optical data and telecom applications.

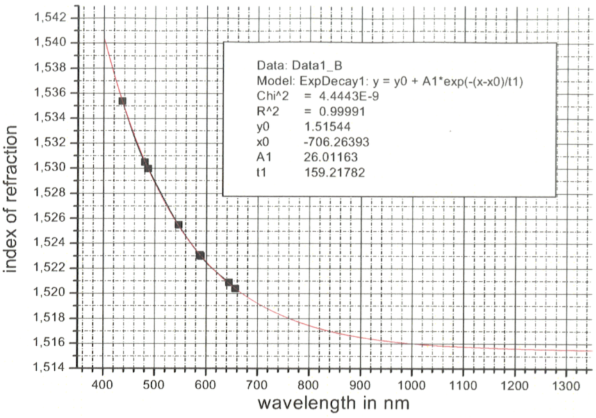

Figure 3: Extrapolated refractive index as a function of wavelength [2]

Ion exchange for optical waveguides

The required technique for realizing optical waveguides and lenses if required have to be integrated in the process cycle of photonic modules and printed circuits boards. That means it must be produced economically and with low environmental impact. Ion exchange technique in molten salts was chosen to reach this aim. At the glass interface monovalent alkali ions, mostly sodium, becomes very mobil under influence of hot salt melt. Alkali ions of the glass are exchanged by diffusion with alkali ions of the salt melt (B^+ in **Figure 4**). If these ions have other ionic radii and polarizability a variation of refractive index occurs. Therefore dopants could be Li, K, Cs, Rb, Ag, Tl and Cu [3]. But the toxic Tl is to handle with care.

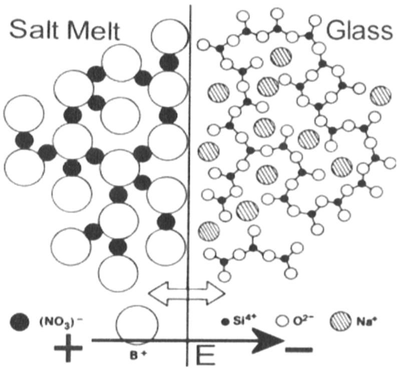

Figure 4: Principle of ion exchange in molten salts [3]

Due to the availability of the cat ions sodium and potassium in D 263 T (Table 1) it is possible to produce channel waveguides using this technique. The exchange efficiency is affected by temperature, concentration of dopants in the salt and the glass and the exchange time. Another increase in productivity is possible if the thermal statistic movement of ions can be enhanced by a directed force like an electrical field E (**Figure 4**) or a thermal gradient. If required the optical waveguides can be made also in a double side ion exchange process as depicted in **Figure 5**. For this process a electric field must not be applied.

The flow can be described as follows:

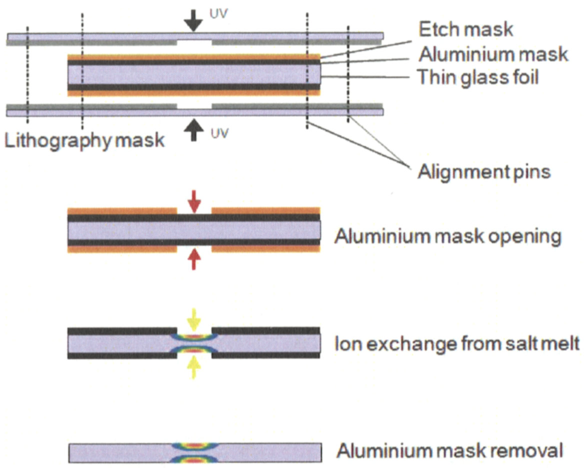

Figure 5: Thermal ion exchange for waveguide structuring from both sides

1) Determination of diffusion process parameters in the display glass for modifying the refractive index and waveguide structuring

2) Design of waveguides for optimum coupling of optical sources and detectors without signal distortion (size, numerical aperture)

3) Processing of designed waveguides by ion exchange in hot salt melt. Adjusting of optical and mechanical properties after ion exchange is possible with multi component salt melts. The maximum steady thermal diffusion speed at 350°C is about 0.5 µm per hour. Batch processing is possible.

4) Optical and mechanical characterization: measuring diffusion parameters with inverse WKB-method by mode line spectroscopy and RNF method. The maximum numerical aperture without glass damage after silver ion exchange is 0.39. For the realized waveguides we processed a salt melt for NA = 0.22.

To establish this new "*glass*Pack" technology it is necessary that materials and processes are compatible with each other. This is demonstrated by using sputtering and photolithography to apply a metal diffusion mask for the optical layer including the waveguide structures and the alignment structures in the same process. The waveguide structures are made by diffused dopands for the core material by thermal silver ion exchange. In **Figure 6** a part of a patterned metal mask on thin glass foil is shown. The metal mask has to withstand the very aggressive hot salt melt. On the left side the alignment marks are visible. These marks are used to realise the low loss optical interconnection to the optical coupling elements between horizontal waveguides and e/o- moduls in EOCB applications.

Figure 6: Diffusion mask for waveguides and alignment marks by the ion exchange process

The same part of the thin glass foil after removal of the diffusion mask is shown in **Figure 7**. The parallel waveguide lines and alignment marks can be clearly seen.

Figure 7: Ion exchanged wavguides after diffussion mask removal with positioning marks (1x8 cm)

Layers with up to 12 parallel multimode optical waveguides of 250 µm pitch and single mode waveguides for Mach-Zehnder-strctures within thin glass foils have been realized. The waveguides are of high thermal reliability and show an attenuation of about 0,1 dB/cm.

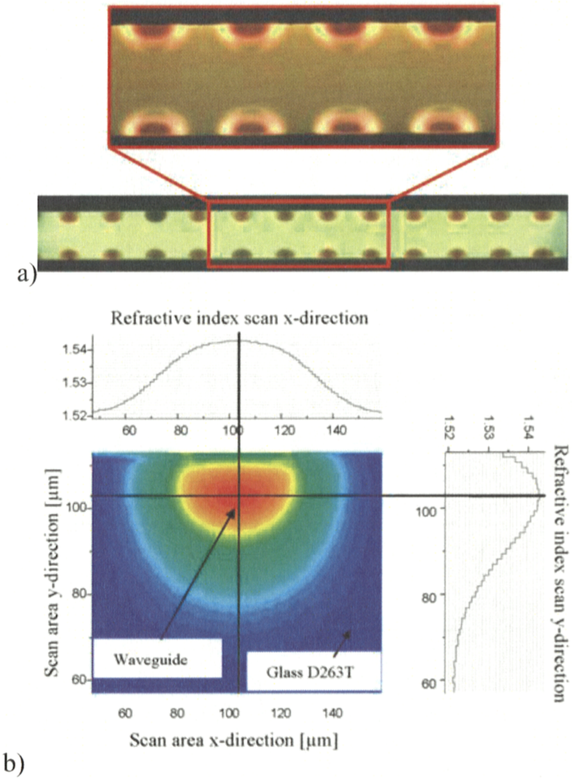

Figure 8: Cross section of double sided planar multimode waveguides, a) micrograph of optically structured display glass with 2 x 12 waveguides, b) refractive index distribution of one waveguide measured by RNF-method

In **Figure 8a** an optical micrograph of a cross section is shown. The waveguides are illuminated from the backside. The bright corona is caused by the graded index profile due to the isotropic under diffusion of the mask.

Electrical wiring and component assembly

Glass, being a highly electric isolating material, is very suitable as a substrate for high-frequency applications. Electrical wiring consists of wires, contact pads, and feed throughs. Suitable thin film technologies can evolve from IC and PCB industry [9]. The remaining challenge using glass as substrate material is drilling holes and depositing metal in the holes for electric and thermal feed throughs. Using a solid state laser [10], holes are drilled with minimum diameters of 200 µm through a D263T™ thin glass foil of 500 µm thickness as shown in **Figure 9**. Next, titanium-tungsten and gold is deposited as plating base. Instead of gold the deposition of copper is possible too, depending on the followed plating process. The deposition of the plating base occurs holohedral at the walls inside the holes. As a result, uniform metal deposition inside the hole is possible during the plating process. Glass as thermal insulator in combination with ICs or semiconductor optical devices requires thick metal wiring and thermal feed throughs for spreading the heat of the devices. **Figure 10** shows a polished micrograph section of a laser-drilled hole which was filled by gold metallization of 100 µm thickness.

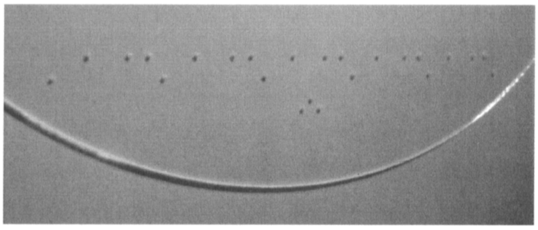

Figure 9: Part of a laser-drilled 4"-wafer

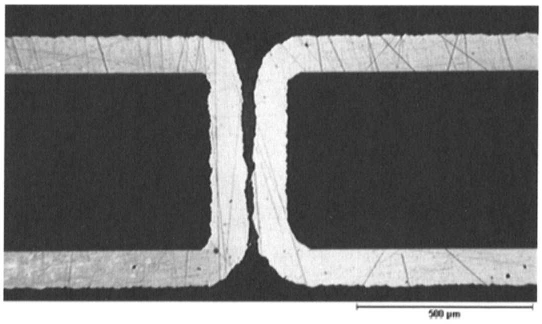

Figure 10: Polished micrograph section of a feed through in D263T™ thin glass foils having a thickness of 500 µm. The laser-drilled hole has a diameter of 200 µm

Mounting the devices near the feed through helps the heat spread through the glass foils to heat-sinks positioned underneath. Instead of gold, electro-plating of copper in various thicknesses from 10 to 100 µm in combination with a nickel barrier and finally deposited 100 nm flash gold provides a suitable metallization for soldering and wire bonding.

Optical interconnection

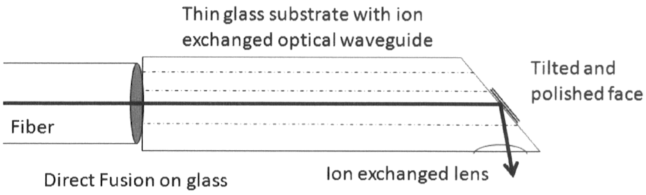

Figure 11: Schematic drawing of optical coupling element using the glassPack technology with beam deflection.

For the out of plane optical coupling special designed coupling elements are realized. They consist of planar waveguide arrays made by ion exchange and reflective mirror surfaces for the light deflection. The waveguides can be narrow for single or wide for multimode propagation. In **Figure 11** schematic cross section is shown. The coupling element itself can be realized as single layer element or as a stacked sandwich to realize more complex optical functionality and mechanical properties. So ion exchanged lenses in the bottom layer can be integrated to focus the out coming light to a small Photodiode or vertical grating structure, e.g. to couple to silicon photonics waveguide chips.

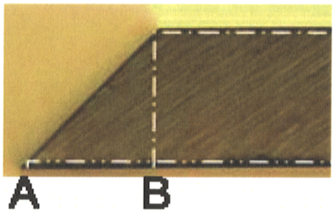

Figure 12: 45 degree polished thin glass substrate with double layer ion exchanged optical waveguides. Dashed lines indicate both of the waveguides. A and B indicate the position of the out of plane coupled beams.

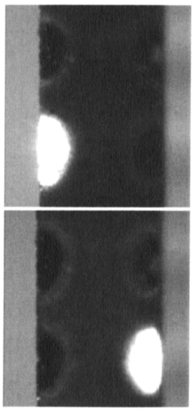

Figure 13: (upper) Light coming out of the position A (Figure 4) and (lower) light coming out of the position B

But even in single layer glass foils more optical functionality can be integrated by means of a double side ion exchange process as depicted in **Figure 12**. Waveguides are well aligned vertically and the 45 degree mirror is polished very precisely in order to achieve a 90 degree deflection element for double layer waveguide arrays. In **Figure 13** the deflection and the out coupling is demonstrated. The light coupling between optical circuits and a light source, detector or fiber is realized by polished end faces of the glass foil.

One benefit of using glass foils is the possibility of direct fusion bonding to silica fibers. The fiber end face is positioned in front of the polished end face of the integrated waveguide. A CO_2-Laser beam focused on the bonding zone melts both bond partners about the annealing point and fuses those together [5]. As shown in **Figure 14**, a reliable bond without intermediate layer results.

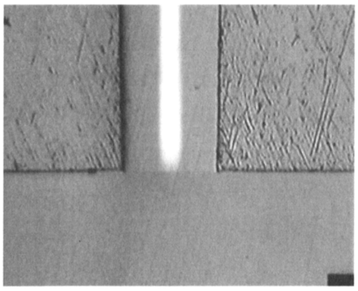

Figure 14: Polished micrograph section of a fused bond between a silica fiber and a thin glass foil

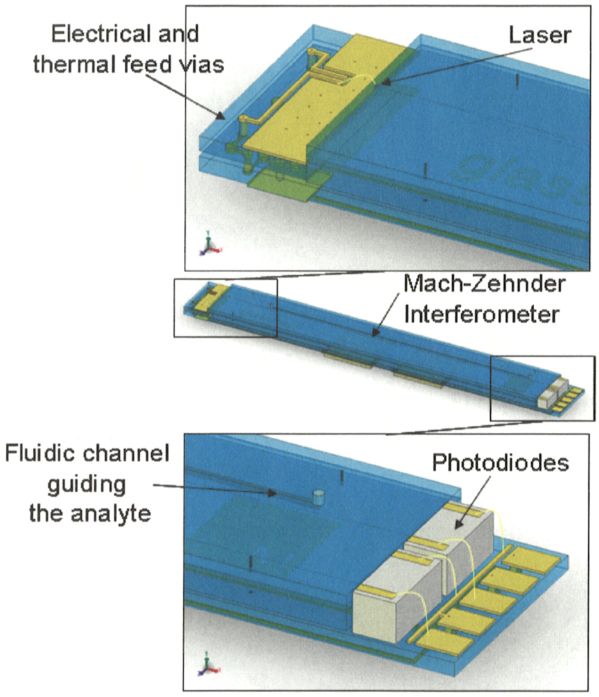

Figure 15: Design of the refractometric sensor with integrated MZI and fluidic channels, and optoelectronic components. The sensor has a length of 80 mm and a width of 10 mm

In the sensor demonstrator realized recently [4] the photo diodes and the laser chips are directly butt coupled to the waveguide chip. This approach is quite common and the coupling efficiency depends on the beam properties of the laser as well as the waveguide profile which can be adopted by controlling the diffusion parameters.

In **Figure 15** the positions of the butt coupled components are shown. Most critical is the active alignment of the Mach-Zehnder-waveguide plate to the very little already assembled laser dies (upper inset).

Conclusion and Outlook

We have demonstrated our generic "*glass*Pack" technology using thin glass foils with respect to two application excemples: multimode waveguide layers for EOCB and hybrid integrated sensor modules. The benefit of glass results in excellent optical, electric, chemical and mechanical properties. Suitable technologies like ion-exchange, laser drilling, electro-plating, and fusion bonding and direct optical butt coupling are used for EOCB waveguides and the refractometric sensor and show high potential to realize integrated wafer level packages in glass. Current developments focus on waveguide array coupling elements of very flexible designs. So such kind of coupling elements can be applied for multimode and multilayer optical coupling of electrical-optical circuit boards (EOCB) as demonstrated within this paper and to interconnect sensors and silicon photonic wires through high-index contrast vertical gratings to the micro optical periphery.

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