Micro-transfer-printing: Alternative to polymeric adhesive bonding

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Abstract— **This extended abstract studied the use of spin-on-glass (SOG) for micro-transfer-printing (µTP), as an alternative to conventional polymeric adhesive such as BCB and Intervia. Once cured, SOG behaves as transparent oxide layer and is suitable for rugged environments. The authors demonstrated the µTP of both 200 nm thick lithium niobate films and 3.2 µm thick a-Si cladded lithium niobate chiplets on SOG layer as thin as 50 nm.**

Keywords—micro-transfer-printing; spin-on-glass; thin film photonics; rugged environment; glass interposer.

I. INTRODUCTION

Micro transfer printing (µTP) has become an increasingly practical route for heterogeneous photonic integration, allowing III-V, thin-film, and 2D material devices to be placed onto silicon photonics platforms with sub-micron accuracy and without being constrained to a single material system. Much of what determines whether a printed device performs as intended comes down to the dielectric layer sitting between the coupon and the target substrate — it has to hold the two together, accommodate whatever surface topology exists underneath, and ultimately function as optical cladding once the device is in use.

Common materials include benzocyclobutene (BCB) and Intervia (a photosensitive epoxy-based polymer), which are spin-coated as thin films (sub-100 nm when diluted with PGMEA, degassed and filtered) onto the target wafer prior to printing [1]. However, these typically come with higher refractive index (RI) between 1.54-1.58 at datacom wavelengths and may not be suitable for all optical waveguide coupling platforms [2]. Coefficients of thermal expansion of about 20-50 ppm/°C [3] generate significant interfacial stress during thermal cycling, risking delamination of printed coupons. Above 350°C these organic materials typically decompose, precluding any post-print high-temperature processing.

In this extended abstract, the authors explored the use of spin-on-glass (SOG) as an alternative adhesive material [4] in µTP due to its inorganic composition and better refractive index match with the typical foundry-deposited silicon oxide cladding. Two types of SOGs were studied – undoped silicate-based and polysiloxane-based. Both SOGs are potentially attractive candidates for rugged (high temperature, toxic, vacuum or cryogenic environment) applications. While silicate-based SOG may be more prone to film cracking when thicker [5], research has shown that it can be mitigated if the film thickness and densification steps are properly controlled.

II. EXPERIMENTAL PROCEDURE

A. Coating and Curing

Two commercially available SOGs - silicate-based with RI 1.44 from Desert Silicon and polysiloxane-based with RI 1.41 from Futurrex were acquired for demonstration. Both materials were spin-coated at 3000 rpm for 40 seconds as recommended to achieve a uniform coating thickness of 50 nm on glass slides. We explored various curing conditions such as overnight ambient curing and step curing up to 200 °C prior to printing the thin films. The samples were then subjected to various aging conditions, ranging from -70 °C and up to 300 °C.

B. µTP and Aging Results

Fig. 1 shows the µTP of 200 nm thin films on step-cured SOG layers. We chose the 200 nm thin film as they are thin enough to be transparent, allowing visual inspection on the SOG layers underneath. The films have dimensions of 1000 µm x 80 µm and were made of lithium niobate (LNOI). At coating thickness of 50 nm, there are no visible cracks on either silicate- or polysiloxane-based SOGs after curing, after thin film printing and under various aging conditions. While both materials survived -70 °C environment, we started to see divergence in terms of adhesion at high temperature, specifically at + 250 °C (Fig. 2) and + 300 °C (Fig. 3). The observations were summarised in Table I.

TABLE I. RESULTS OF VARIOUS AGING CONDITIONS

Aging conditions	*Silicate SOG*	*Polysiloxane SOG*
-70 °C / 1 hour	No visible changes	No visible changes
+ 250 °C / 1 hour	No visible changes	Delamination
+ 300 °C / 1 hour	No visible changes	Delamination

C. Shear Strength of SOGs

We also studied the shear strength of the two SOGs under various conditions (Table II) using glass pieces with surface area of 1.8 mm x 1.8 mm. After step-curing (Time 0), we can see that polysiloxane-based SOG's adhesion strength was stronger and remained consistent up to 150 °C, after which its strength dropped drastically. These results matched that seen on µTP samples. Meanwhile, as thicker coating layer (at least 2 µm) is necessary to attach the glass pieces meant for shearing tests, we were unable to collect full set of data for silicate-based SOG, as

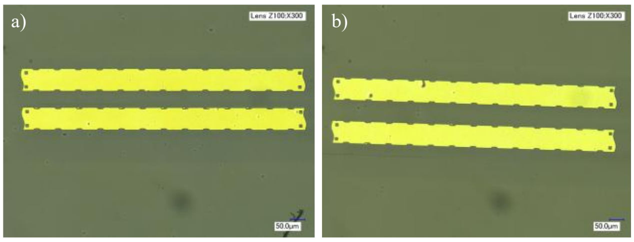

Fig. 1. µTP of 200 nm thin films on a) silicate-based SOG and b) polysiloxane-based SOG after step curing up to 200 °C. No cracks and delaminations were observed on both spin-coated samples at 50 nm thickness.

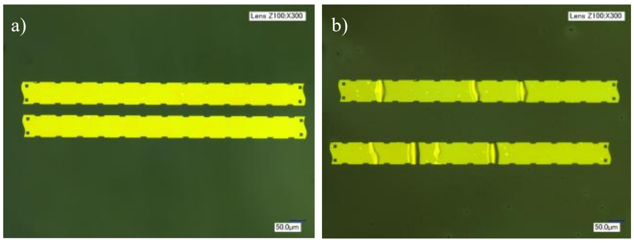

Fig. 2. 250°C / 1 hour aging results of 200 nm thin films on a) silicate-based SOG and b) polysiloxane-based SOG. Delamination observed on polysiloxane-based SOG, while silicate-based SOG remains stable.

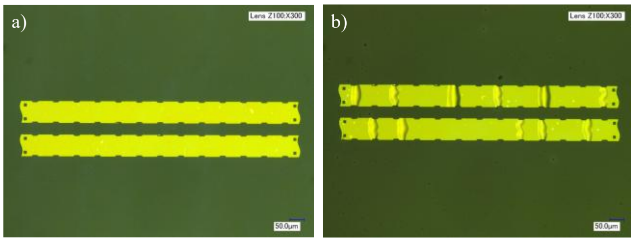

Fig. 3. 300°C / 1 hour aging results of 200 nm thin films on a) silicate-based SOG and b) polysiloxane-based SOG. More delamination observed on polysiloxane-based SOG, while silicate-based SOG remains stable.

we encountered film cracks after -70 °C aging as the material is too thick. We wish to emphasize that the observation here did not necessarily mean that silicate-based SOG is inferior in any way. In fact, at thin layer such as 50 nm, this material performed better than polysiloxane-based SOG at high temperatures, as shown in earlier section. Further studies are required to properly evaluate the shear strength of silicate-based SOG.

TABLE II. SHEAR STRENGTH RESULTS

Aging conditions	*Silicate SOG*	*Polysiloxane SOG*
Time 0	4.406 MPa	9.594 MPa
-70 °C / 1 hour	Cannot be tested	10.76 MPa
+ 150 °C / 1 hour	Cannot be tested	7.451 MPa
+ 250 °C / 1 hour	Cannot be tested	0.053 MPa
+ 300 °C / 1 hour	Cannot be tested	0.015 MPa

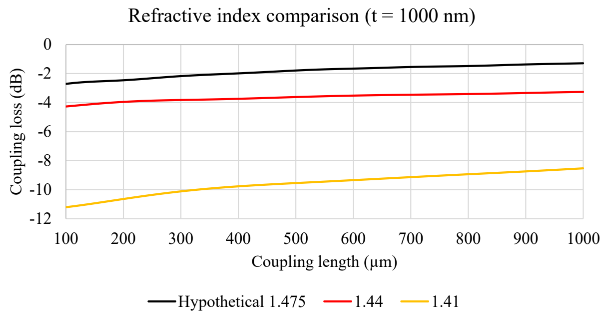

Fig. 4. With a gap of 1000 nm between optical layers, low RI drastically increases coupling loss.

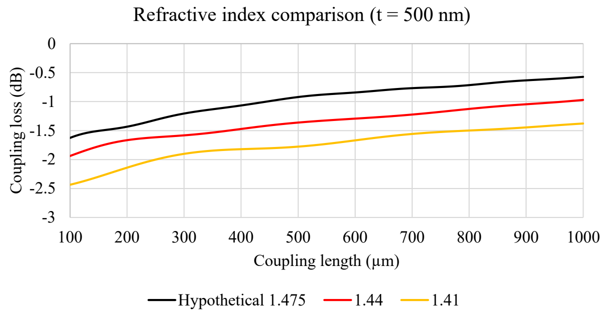

Fig. 5. Coupling loss closing the gap between various RI as distance between optical layers reduces to 500 nm.

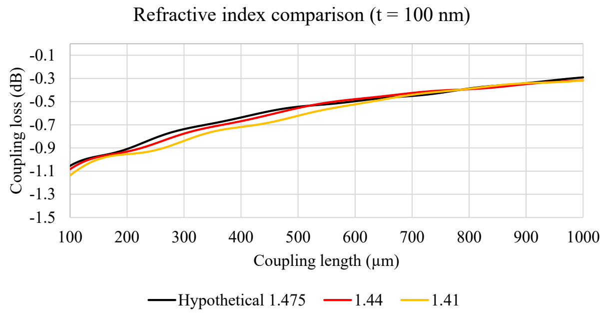

Fig. 6. At 100 nm distance between optical layers, effect of RI becoming almost irrelevant.

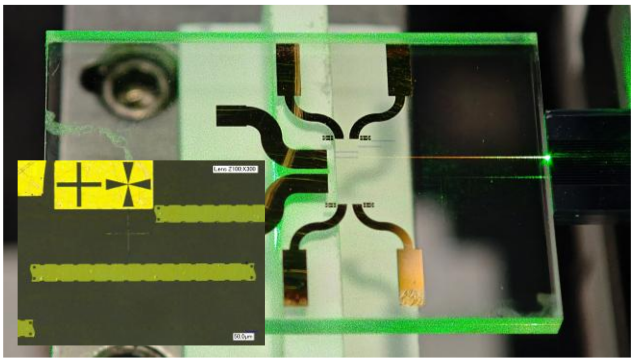

Fig. 7. Propagation of green laser through optical waveguide on glass interposer. Inset: µTP LNOI films on the glass interposer.

III. Application on glass-based optical interposer

A. Effect of Refractive Index on Glass Waveguides Coupling

We further simulated the effects of refractive index of the SOGs, assuming silicon nitride (SiN) coupling into the glass waveguides following the geometry and material properties described in [6]. We scanned the evanescent coupling length of SiN taper from 100-1000 µm under different coupling gaps (100 nm, 500 nm and 1000 nm) and RI (1.41, 1.44 and 1.475). EME simulation results showed that with minimal coupling gap between two optical layers, the effect of RI on evanescent coupling may diminish (Figs. 5-7).

B. µTP of Thin Films on Optical Interposer

We also coated an optical glass interposer sample developed in [7] using silicate-based SOG at 50 nm thickness, step-cured up to 200 °C and µTP lithium niobate (LNOI) films within the proximity of the surface waveguides (Fig. 7). The optical interposer was co-developed with TEEM Photonics for evanescent coupling to the ion-exchanged glass waveguides only within the region with fiducials, while the rest of waveguides were embedded below the surface to prevent power leakages. As the glass waveguides are transparent, we relied on fiducials and positions in the GDS design file for µTP. We then coupled green light into the optical interposer and found that the LNOI films with higher RI obstructed (absorbed) the light from propagating beyond the LNOI films. Simple optical measurements showed that a glass waveguide with LNOI film transmits approximately 55% less signal than those without, but more studies are needed to properly characterize the behavior using waveguiding chiplet structures.

IV. Summary

We proposed and studied the use of SOGs as alternative adhesive layer for µTP. Coating thickness of 50 nm using commercially available materials can be achieved. Thin films from 200 nm to 3.2 µm remained printable on SOG layers cured up to 200 °C. Aging tests ranging from -70 °C to + 300 °C showed that adhesion of silicate-based SOG can withstand higher temperatures better than polysiloxane-based SOG. However, more experiments are needed to study the coupling performance of real photonic devices.

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