A similar device, with longer dual-order mode arms, could be expected to yield conversion well in excess of 10 Gbit/s.

![Graph showing bit error rate characteristics at 2.5 Gbit/s](image)

**Fig. 3** Measured bit error rate characteristics at 2.5 Gbit/s

- □ back-to-back
- ○ 1550 – 1560 nm out-of-phase, co-propagative conversion
- ○ same-wavelength (1560 nm in and out) out-of-phase, co-propagative conversion

Conversion penalty <0.2 dB with respect to back-to-back, and no extra penalty is incurred for same-wavelength conversion.

**Conclusion:** A dual-order mode Mach-Zehnder wavelength converter has been realised, for the first time to our knowledge, using exclusively active waveguides. Such an all-active implementation is highly advantageous from a fabrication effort point of view. Almost penalty-free conversion was obtained at 2.5 Gbit/s in the co-propagative mode, with high input signal rejection. No extra penalty was observed for same-wavelength conversion. Conversion at 5 Gbit/s was also demonstrated. With modifications (specifically longer arms), co-propagative conversion well in excess of 10 Gbit/s can be expected, while retaining a high input signal rejection ratio and the fabrication advantages of the all-active configuration.

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**References**


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**Gallium-doped sol-gel glass waveguides on Si substrates by SC-RTA**

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The fabrication of silica-on-silicon channel guides by spin-coating and rapid thermal annealing (SC-RTA) of sol-gel glass doped with gallium, germanium and phosphorus oxides is described, and methods of depositing clear, crack-free films are discussed. Low loss is only obtained for lightly-doped guides with controlled process temperatures.

Methods of depositing multicomponent glasses on Si substrates are required for silica-based planar waveguide devices such as rare-earth-doped amplifiers. The sol-gel process allows rapid investigation of synthesis routes with safe precursors. Using spin-coating and rapid thermal annealing (SC-RTA), we have demonstrated channel guides in SiO₂ doped with TiO₂, GeO₂, B₂O₃ and PO₄ [1]. The best results are obtained using the last three [2]. Other authors have discussed incorporation of Al₂O₃, Er₂O₃, and Yb₂O₃ in planar and strip-loaded active guides by a similar sol-gel route [3 – 5].

As the number of components rises, it is difficult to avoid unwanted reactions in the sol and obtain glasses with desirable properties. For example, phosphosilicate sols are highly reactive, while silica-titania and alumino-silicate glass crystallise at high temperatures. Here, we describe the incorporation of Ga₂O₃ in germanophosphosilicate glass (GePSG). Only limited attention has been paid to gallium doping, which has been shown to enhance lifetime in Er³⁺-doped silica deposited by flame hydrolysis and solution doping [6].

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**Fig. 1** Synthesis route for GaGePSG sol

Sol preparation was based on a two-step acid-catalysed hydrolysis of Si(ΟEt)₄, (Fig. 1). In the first step, on average one OR group per Si(ΟEt)₄ molecule is replaced by OH (R = 1; state S). PO₄ is then incorporated as an alcohol solution and the solution
hydrolysed again to replace a second group (state S/P). The solution is then dehydrated, to prevent gelation when GeO₂ is added as a solution of GeO(OH)₂ (state S/P/Ge). GaO₃ is incorporated as a solution of Ga(OE)₃ (state S/P/Ge/Ga). Owing to moisture sensitivity, this component is handled under N₂. All glasses contained 10 mol% P₂O₅ (to allow reflow smoothing) with varying proportions of GeO₂ and Ga₂O₃. Thick (5μm) films were built up as multilayers, by spin-coating of 3μm Si wafers at 2000rev/min and annealing in O₂ at 850°C to yield individual 2400A thick layers.

that only cores lightly-doped with gallium would be compatible with reflow.

Channel guides were formed from 8μm × 4μm cores containing 1.25mol% Ga₂O₃ and 10mol% P₂O₅ on 10μm thick PSG buffers containing 5mol% P₂O₅. With these compositions, core and buffer have similar melt temperatures, so deformation of the underside of the core was observed. The cores were clad with borophosphosilicate glass (BPSG) containing 5.75mol% B₂O₃ and 6.75mol% P₂O₅, which was reflowed to eliminate voids.

![Fig. 4 TE mode fibre-device-fibre insertion loss spectrum for GaP2S2G guide](image)

Further problems were encountered in the reflow of cores deposited on PSG buffers rather than Si. At temperatures predicted by Fig. 3, cracking of the core and delamination from the buffer were found (inset to Fig. 3). This is ascribed to stress caused by the gallium-rich layer described earlier. With care, it was possible to fabricate long unbroken cores. The TE mode fibre-device-fibre insertion loss of 3.4cm of a singlemode guide is shown in Fig. 4. Low and spectrally flat loss is obtained, and there is no evidence of O-H absorption, a characteristic of other PSG-based materials [1]. Losses rise at long wavelengths due to the use of a relatively thin buffer, and are not inherent in SC-RTA. At λ = 1.5μm, the insertion loss is consistent with coupling losses of 0.5dB/facet and propagation losses of 0.2dB/cm.

In conclusion, we have demonstrated for the first time the formation of thick gallogermano-phosphosilicate glass layers on Si substrates by SC-RTA. We have also formed channel guides in GaP2S2G, but find that this material is not truly compatible with high-temperature processing.

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References

Fig. 2 GaGeP2S2G compositions investigated

Fig. 2 shows the locus of compositions investigated, with an indication of problems. Only a limited range of glasses could be formed. For gallogermano-phosphosilicate glass (GaP2S2G), rapid gelation of the sol occurred as the Ga₂O₃ content rose above ~3.75mol%. For gallogermano-phosphosilicate glass (GaGeP2S2G), similar problems were encountered with prior work on GeP2S2G; heavily doped soles failed to wet both Si and SiO₂, and gel films were crazed by sinuous ‘worm-cast’ cracks [2]. Again, it is assumed that P₂O₅ has a role in controlling reactions in sol and gel. Clear GaP2S2G glasses were only formed with a Ga₂O₃ content up to ~2.5 mol%, while clear GaGeP2S2G required even lower doping.

Fig. 3 Variation of refractive index and reflow temperature for GaP2S2G

In view of the difficulty of incorporating both Ga₂O₃ and GeO₂, further work was based on GaP2S2G. Ga₂O₃ has a strong effect on the refractive index, as illustrated by Fig. 3, which shows the variation of the index at λ = 0.663μm with composition. Ga₂O₃ also has a strong effect on the apparent viscosity, as characterized by the temperature needed for reflow of 7μm × 5μm cores. This dependence is also shown in Fig. 3; the addition of 5mol% Ga₂O₃ increased the reflow temperature by ~200°C. However, samples heated to high temperatures were covered by a porous surface layer, presumably of outdiffused Ga₂O₃. It was therefore expected...