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High-Optical-Quality Oxide-Free InP-on-Si Hybrid Interface

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Abstract: Oxide-free bonding of InP on Si has already demonstrated a perfect crystallographic interface, without defects, amorphization or voids, the dislocations necessary to accommodate the large lattice mismatch being located in the grain boundary that does not extend further than a single atomic layer [1]. Here we demonstrate through the sensitive measurement of propagation losses of a hybrid mode supported by a hybrid shallow ridge and strongly sensing the hybrid interface that the oxide-free hybrid interface does have a perfect optical quality: no significant additional propagation losses could be measured compared to an oxide-mediated bonded hybrid waveguide or a comparable monolithic waveguide.

The future of all optical networks links relies upon hybrid silicon photonics, wherein III-V semiconductors provide light emission and amplification that silicon is not able to efficiently perform. Bonding them without intermediate layer allows electrical injection through the hybrid interface [2-3], which opens the route to all optical and electrical 3D integration. For efficient device performances, such an oxide-free hybrid interface has to demonstrate no optical losses for the propagating modes which strongly interact with the hybrid interface, being near the mode profile antinode in usual designs.

Previous optical characterization was dedicated to optical functionalities related to the nanostructuration of the silicon waveguide [4-5]. In order to consider only the propagation losses introduced by the hybrid interface, without additional contribution related to the modal structure arising from nanostructuration, we have produced hybrid shallow ridges fabricated on an InP membrane bonded on a SOI wafer. Propagation losses then originate from both the etched walls and the hybrid interface.

We have measured 3 different shallow ridge waveguides: (i)- oxide-free bonded hybrid waveguides, (ii)- thin-oxide-mediated bonded hybrid waveguides, and (iii)- monolithic InP waveguides, both (ii) and (iii) being references. We took care to use shallow ridge geometries having comparable horizontal extent of the mode.

Device (i) is achieved with oxide-free surfaces preparation and oxide-free annealing at 500°C during 90 min. Oxide-mediated bonding is performed including a 2 nm-thick SiO_2 layer deposited by ALD (Atomic Layer Deposition) on both InP and Si, and annealing at 300°C during 3 h [6]. For both cases, a 400 nm-thin InP membrane is bonded on top of the 300nm-thick Si guiding layer on a SOI stack, kindly provided by SOITEC. After substrate removal, shallow ridges are patterned by e-beam lithography using an HSQ resist and then etched by an ICP Cl_2-H_2 process, through all the InP membrane and down 60 nm in the Si guiding layer. Fig.1-(a) shows a cleaved-facet SEM picture of an oxide-free bonded hybrid waveguide. In order to protect the waveguides during cleaving, a thin resist layer is coated over the surface. The calculated TE mode intensity is shown on Fig.1-(b) evidencing the large overlap of the interface by the mode.

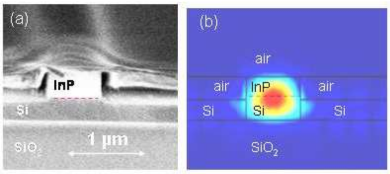

Fig. 1: (a) SEM picture of a hybrid waveguide cleaved facet; (b) TE modal intensity (same scale)

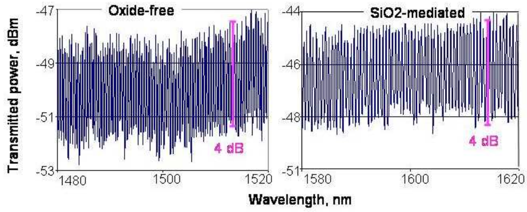

Fig. 2: Transmission measurement showing a 4 dB fringe contrast for *left*-oxide-free hybrid waveguide and *right*-SiO2-mediated bonded hybrid waveguide

Waveguides with two cleaved facets have been measured on an end-fire set-up including polarization-maintaining tuneable sources and injection fibre for TE polarization. Collection is performed with a microscope objective allowing simultaneous observation of the guided mode and collection in the fibre.

Propagation losses are calculated based on the fringe contrast. A 0.48 µm-wide oxide-free hybrid waveguide transmission shows a 4 dB contrast (Fig.2-*left*), as well as the ALD-mediated 0.5 µm-wide hybrid waveguide transmission (Fig.2-*right*), both waveguides being 650 µm long. This 4 dB fringe contrast, assuming a facet reflectivity r= 0.56, corresponds to propagation losses α=5.0 cm^{-1}, which is also very close to the value for similar InP monolithic ridges waveguides etched with the same ICP process.

Neither of the two bonding processes contributes to extra optical losses on the optical mode sensing the hybrid interface during its propagation. The oxide-mediated bonding being already well qualified as not impacting propagation losses [7-8], we thus demonstrate here that oxide-free bonded interface reaches the same high optical quality.

Conclusion: The oxide-free hybrid interface has already shown to be crystallographic defect-free; we demonstrate here that it is optical-defect-free. This hybrid interface has the potential for electrical injection through the interface, thus allowing to fully performing the 3D optical-electrical integration.

References

[1] A. Talneau et al., Appl. Phys. Lett., **102**, 212101 (2013)
[2] K. Tanabe, K. Watanabe and Y. Arakawa, Sci. Rep., **2**:349 (2012)
[3] K. Pantzas et al., IPRM 2014, Montpellier, May 2014
[4] K. Bougot-Robin et al., Optics Express **22**(19), 23333-23338 (2014)
[5] A. Talneau et al., Optics Letters, **40** (22), 5148 (2015)
[6] A.Talneau et al., MNE , La Haye 2015
[7] A. Spott et al. , Optics Letters, **40** (7), 1480, (2015)
[8] G.-H. Duan et al., Invited paper, IEEE. J. Sel. Top. Quantum Electron., to appear in 2016