High Optical Quality, Electrically-driven-compatible InP-on-Si Hybrid Interface elaborated at 300°C

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Abstract:

In the domain of Silicon photonic integrated devices, the ability to electrically operate the hybrid III-V on Si or SOI interface constitutes the last integration milestone yet to be achieved. This final milestone will open the full 3D field for completely new design of hybrid devices, and will bring immense gains in terms of thermal-budget improvement, chip power consumption, footprint and the integration of driving electronics to boost data transfer rates.

We demonstrate here that Ozone-activated bonding of III-V on Si, operated at 300°C to be CMOS-processing compatible, provides the thinnest -1nm thick- oxide-intermediate layer already achieved, and provides a high optical quality of the interface. Such a hybrid interface is very promising for electrical injection through the interface.

Oxide-free III-V on Si hybrid interface, obtained by bonding at a temperature above 400°C, has already demonstrated a high structural [1] and a high optical quality [2-3], and also electrical operation through the interface [4], but the annealing temperature necessary for such a bonding, which has to be larger than the congruence temperature of InP, prevents the oxide-free bonding approach to be introduced in the CMOS technology chart flow.

Reducing the bonding temperature in order to be compatible with CMOS processing requires an intermediate layer, which should be as thin as possible for electrical operation. Electrical operation through a GaAs on Si hybrid interface including a 2nm thick oxide layer has been demonstrated [5], but due to the relatively thick oxide layer, semiconductors materials had to be heavily doped in order to allow tunnelling operation.

We present here structural and optical characterization of an III-V on Si hybrid interface obtained by Ozone activation of both surfaces and annealing at 300°C.

Activation consists of hydroxyl dangling bonds that polymerize under annealing to generate covalent oxygen bridges. Both InP and Si surfaces are prepared oxide-free, and then activated by ozone during 30s. XPS measurements performed on the Si surfaces have evidenced –OH dangling bonds in the case of O3 exposure during 30s. Immediately after O3-activation, surfaces are put in contact and introduced in the oven. After annealing at 300°C during 3 hours under vacuum, bonding is ensured by covalent oxygen bridges formed following the reaction

$$InP\text{-}OH + Si\text{-}OH \rightarrow InP\text{-}O\text{-}Si + H_2O \quad [6\text{-}7]$$

For structural characterization, a 400nm-thick InP membrane has been bonded on an Si substrate. TEM characterization (Fig.1) shows a 1nm-thick, very homogeneous oxide layer at the interface. Such a thin layer is the thinnest reported for oxide-mediated bonding of III-V on Si.

For optical characterization, a 400nm thick InP membrane is bonded on an SOI wafer including a 300nm-thick Si guiding layer on top, kindly provided by SOITEC. Shallow

ridges are patterned by e-beam lithography using an HSQ resist and etched by an ICP Cl2-H2 process, through all the InP membrane and 30 nm down in the Si guiding layer. 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. Propagation losses are calculated based on the fringe contrast. A 0.30 µm-wide, 470µm-long O3-activated hybrid waveguide transmission shows a 4 dB contrast (Fig.2). This 4 dB fringe contrast, assuming a facet reflectivity r=0.56, corresponds to propagation losses α=5.0 cm-1, a value that can be favourably compared to monolithic waveguides.

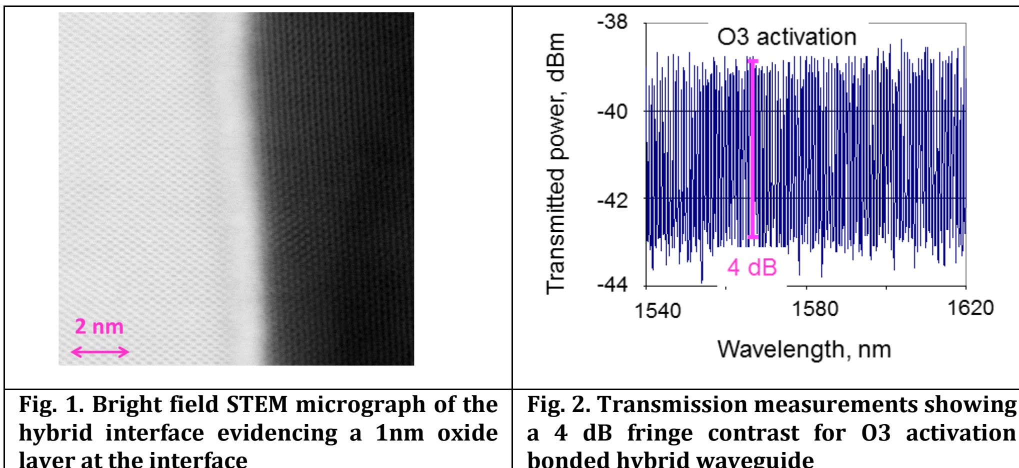

Fig. 1. Bright field STEM micrograph of the hybrid interface evidencing a 1nm oxide layer at the interface	**Fig. 2. Transmission measurements showing a 4 dB fringe contrast for O3 activation bonded hybrid waveguide**

Conclusion: The high structural and optical quality of III-V on Si Ozone-activated bonding interface evidenced by the low propagation losses for the hybrid mode shows that the ozone-activation procedure proposed here is an efficient approach for bonding on silicon at T=300°C, a temperature which is CMOS-processing compatible.
Its relevance for electrical injection is under investigation.

References

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