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Vertically-coupled AlGaAs microdisks using selective lateral oxidation

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Abstract: This paper presents a planarization-free method to realize microdisk resonators that are vertically-coupled to buried access waveguides. The novel 3-dimensional integration scheme exploits selective lateral oxidation of aluminum-rich AlGaAs layers. Microdisk devices resulting from a first fabrication run demonstrate the proof-of-principle of this approach. Their optical characterization is currently being carried out and will be presented at the meeting.

Introduction

Integrated whispering gallery mode (WGM) resonators in the form of micro-ring, micro-disk or micro-racetrack resonators have attracted a lot of attention since they can provide large field enhancement in a compact format and, thereby, enable the fabrication of selective filters, low-threshold emitters, high-speed modulators, sensitive sensors or nonlinear converters [1-3].

In order to couple light in and out of these resonators, most devices use evanescent coupling which can be realized either by lateral integration i.e. by having the access waveguide and the resonator in the same plane or by vertical integration where the waveguide lies (typically) below the resonator. The latter approach is generally preferred as it offers greater fabrication tolerances and enables different materials to be used for the resonator and its access waveguide. The conventional method[4,5] to make such vertically-coupled resonators begins with the definition of the access channel waveguides followed by the deposition of a cladding layer. The surface of this overlayer is corrugated and needs to be planarized to be able to make the desired high-quality factor resonators. Furthermore, the thickness of this cladding layer also needs to be precisely controlled since it adjusts the degree of coupling, making this planarization a critical processing step. Finally, after re-alignment, the definition of the resonator completes the device fabrication sequence.

Here, we report an alternative method to fabricate such vertically-coupled resonators which exploits the lateral oxidation of buried layers and thus does not require any planarization.

Microdisk device design

The device design consists in a buried oxide-confined rib waveguide that is vertically-coupled to a GaAs-based microdisk resonator. The multi-layer stack is based on AlGaAs alloys. The waveguide claddings ($Al_{0.7}Ga_{0.3}As$ and $Al_{0.3}Ga_{0.7}As$) were chosen to be asymmetric such that a greater field penetration occurs towards the resonator. The 716nm-thick resonator/waveguide coupling region includes two 68nm-thick $Al_{0.98}Ga_{0.02}As$ layers to be laterally oxidized, sandwiched between three $Al_{0.3}Ga_{0.7}As$ layers. The partial oxidation of these layers will form oxide apertures and thus induce lateral waveguiding. The upper layer (located at 100-nm beneath the disk core) is also used to increase the vertical confinement in the disk whilst the lower is essentially there to set the lateral confinement of the access waveguide. This layer was positioned relatively far (150-nm-away) from the GaAs-based core of the access waveguide to provide single-mode operation for (weakly-confined ($\Delta n \sim 10^{-2}$)) large-width modes, thereby reducing the dependence on lateral offset of the waveguide/resonator coupling. The (0.68μm) thickness of the GaAs-core resonator was also set to support vertically only the quasi-TE fundamental mode.

Fabrication process

The AlGaAs (vertical) structure was grown on a (100) GaAs substrate by molecular beam epitaxy (Riber 412). The wafer was post-processed using two photolithography steps using direct laser writing

(Heidelberg DWL 200). The two mask levels are respectively used to define the access waveguides and the resonators in SPR700 photoresist with a re-alignment accuracy estimated to be better than 0.25µm. These patterns were transferred in the AlGaAs stack by an ICP-RIE plasma etch using a $Cl_2/N_2/Ar$ gas mixture and the etch depth was monitored by optical reflectometry. Simultaneous wet thermal oxidation of both $Al_{0.98}Ga_{0.02}As$ layers was carried out in a custom furnace with in-situ optical monitoring[6], equipment now commercially available from AET Technologies. During the oxidation, the sample was held at a substrate temperature of 420°C, in a reduced pressure environment (~0.5 atm.), and exposed to a mixed $H_2/N_2/H_2O$ gas steam generated by an evaporator-mixer system at 95°C. The oxidation front progressed linearly at a rate of 0.31µm/min and was stopped when the oxide aperture width reached 4µm. The samples were then polished to a substrate thickness of ~150µm, cleaved and mounted on Si sub-mounts.

Figure 1 shows a top-view optical microscope image of one of the fabricated micro-disks with schematic cross-sections. We note that the oxidation of the two AlGaAs layers is not strictly identical, a phenomenon we believe to be the result of oxide-induced strain distribution in the asymmetric vertical structure. The bottom waveguide aperture width was measured to be ~3.7µm by using a focused ion beam (FIB) and scanning electron microcopy (SEM) characterizations, while the upper confining layer aperture width was observed to be ~1.8µm larger.

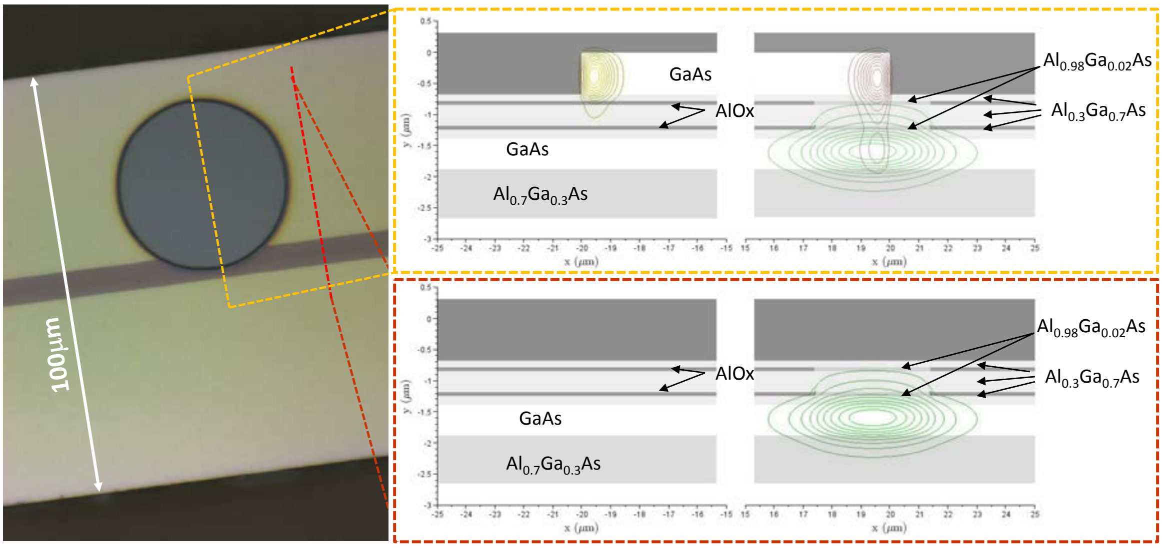

Fig. 1: Top-view optical microscope image of a fabricated AlGaAs/AlOx vertically-coupled microdisk resonator and rib waveguide, and associated schematic cross-sections showing the corresponding vertical structure and calculated normalized E-field profiles[7,8].

Conclusion

We have devised a novel approach to vertically integrate microdisk resonators on top of their access waveguides by exploiting selective lateral oxidation of aluminum-rich layers on a GaAs platform. The optical characteristics of the devices are being assessed and will be reported.

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