SECOND HARMONIC GENERATION IN THE TELECOM RANGE WITH A FULLY INTEGRATED SEMICONDUCTOR MICRODISK

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ABSTRACT

We report on a monolithic photonic chip for SHG in an AlGaAs microdisk with integrated waveguides for pump injection and SHG collection. Once this chip is fibered, SHG from a pump at 1.6 µm is observed with 10^{-3} W^{-1} external conversion efficiency. This result opens the way to fully integrated on-chip photon-pair generation in the telecom range.

KEYWORDS: *microdisks, whispering gallery modes, second harmonic generation.*

1. INTRODUCTION

Semiconductor microdisks are whispering-gallery mode (WGM) micro resonators with high Q factor and sub-wavelength size, allowing strong light-matter interaction. Micro-disks are used in an increasing number of photonic applications like nonlinear wave mixing, micro laser and optomechanics. Integrated in photonic circuits, microdisks can also be employed as lasers, biosensors, and for photon-pair generation.

Two popular photonic materials are silicon and aluminum gallium arsenide. Silicon benefits from the huge development of CMOS manufacturing for more than half a century, but its small indirect bandgap and centro-symmetry strongly limit its applications in nonlinear photonics. On the other hand, the direct bandgap of $Al_xGa_{1-x}As$, its huge $\chi^{(2)}$ and two-photon transparency at telecom wavelengths for $x \geq 0.18$ makes this III-V alloy interesting for $\chi^{(2)}$ integrated optics.

In the last years, second harmonic generation (SHG) in III-V microdisks has been demonstrated and measured by evanescent coupling with a tapered fiber [1,2] or observed via an out-of-plane objective [3]. In this work we present an $Al_{0.4}Ga_{0.6}As$ photonic circuit dedicated to SHG including a microdisk evanescently coupled to a first integrated waveguide for input at telecom wavelength and a second one for SHG output around 800 nm.

2. DESIGN AND FABRICATION

As shown in Fig. 1, suspended waveguides are placed on both sides of the microdisk where SHG occurs, so as to inject fundamental frequency (FF) and to collect second harmonic (SH). These waveguides are accessed by micro-lensed fibers that are connected to the laser sources and the photodiodes used in the experiment.

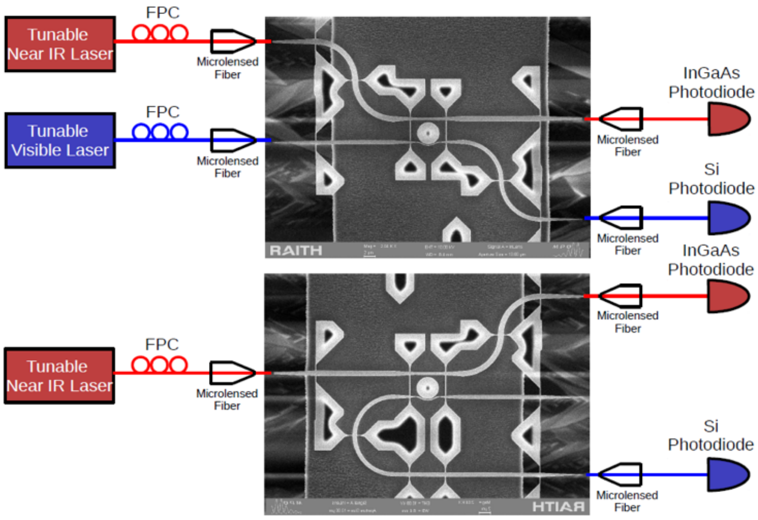

Figure 1. Schematic of the experimental setup for linear (top) and nonlinear (bottom) characterization. The insets show SEM images of the fabricated samples.

The microdisk is designed to reach quasi-phase matching between two WGMs. In [100] AlGaAs, this condition is achieved if azimuthal orders of WGM at FF (m_{FF}) and SH (m_{SH}) fulfill the condition $m_{SH} = 2m_{FF} \pm 2$. In an $Al_{0.4}Ga_{0.6}As$ disk with radius r = 1980 nm and thickness h = 155 nm, this occurs at λ_{FF} = 1616 nm (λ_{SH} = 808 nm) for: m_{FF} = 26 and m_{SH} = 12; radial orders p_{FF}=1 and p_{SH} = 2; and the fields at both wavelengths confined in fundamental order vertical modes.

Around the microdisk the waveguides are narrowed to reach optimal evanescent coupling at FF and SH. Our goal is to critically couple each of them just with the corresponding WGM. For characterization purposes, the intrinsic quality factors of the disk have been measured using under-coupled waveguides: $Q_{FF} \approx$ 40,000 and $Q_{SH} \approx$ 2,500 (the difference between these values can be ascribed to higher scattering losses on non-ideal sidewalls at SH). Away from the disk, the waveguides are widened to reduce the losses at the anchoring points. Anchoring is done by 100 nm wide tethers on both side and the waveguide is anchored a least every 20 µm. At their ends, the waveguides are adiabatically tapered until their single mode reaches an effective index ≈ 1.2 and expands so as to increase its coupling efficiency with micro-lensed fibers. The latter can approach the tips of the inverted tapers thanks to an ad hoc 100µm-high mesa.

The fabrication material is a 155 nm layer of $Al_{0.4}Ga_{0.6}As$ grown by molecular beam epitaxy on a GaAs substrate. This layer is patterned by e-beam lithography on Man2401 resist. Followed by ICP etching in a $SiCl_4$/Ar plasma. After this step, wet selective etching of GaAs defines the pedestals below the microdisks and releases the suspended waveguides.

3. Optical characterization

FF and SH waveguides are used one at a time for linear probing of microdisks WGM modes and together for the SHG measurement. Linear and nonlinear spectra are recorded by sweeping the wavelength of continuous-wave tunable lasers and collecting the light with broadband photodiodes. An external cavity diode laser is used around FF and a Ti:Sapphire laser around SH. Infrared (visible) light is detected with InGaAs (Si) photodiode.

WGM modes of the disk dig a dip in the linear transmission spectrum acquired via the FF and SH waveguides. WGM modes can be labelled by comparing their wavelength and free spectral range with simulation. FF (SH) loaded Q-factor is ≈12,000 (≈1,000), both with a contrast > 80%. Using both waveguides we have demonstrated SHG and its collection in the integrated waveguide. Fig 2 shows the case of a disk at phase matching, and the largest measured SHG efficiency for the overall experiment (AlGaAs chip plus input and output microlensed fibers) is 10^{-3} W^{-1}, recorded for 160 µW input at λ_{FF} = 1614 nm and an output of 25 pW at λ_{SH} = 807 nm.

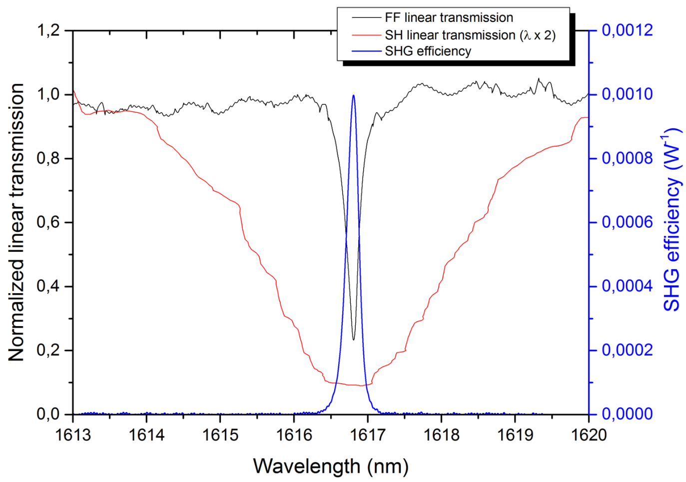

Figure 2. Superposition of linear transmission vs λ around λ_{FF}, (black), linear transmission vs 2λ around λ_{SH} (red) and SHG efficiency (blue).

Finally, let us stress that the SHG power is not equal at the two ends of the SHG collection waveguide: the power collected at the double back end is typically 10 times the power collected at the straight end. This result shows that both FF and SH WGMs keep turning in the disk without giving rise to standing waves, despite their degeneracy. This fact explains the design in the bottom panel of Fig 1, where the output waveguide includes a half turn to compensate the half turn in the disk. This leads to a chip with input on one side and output on the other side, which is more convenient for positioning the micro-lensed fibers.

CONCLUSION

In conclusion we have demonstrated SHG from 1616.8 nm to 808.4 nm in a monolithic chip with integrated waveguides for input and output. The overall efficiency between micro-lensed fibers FC connectors is 10^{-3} W^{-1}. Phase matching requires a precision of ± 5 nm on disk radius, which approximately corresponds to our fabrication tolerances. This work constitutes a step towards the use of microdisks as integrated photon-pair sources via spontaneous parametric down-conversion on-chip, which is currently under way.

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