Watt-class CMOS-compatible power amplifier

Neetesh Singh[1], Jan Lorenzen[1], Milan Sinobad[1], Kai Wang[2], Mahmoud A. Gaafar[1], Henry Francis[3], Michael Geiselmann[3], Tobias Herr[1], Sonia M Garcia-Blanco[2], and Franz X. Kärtner[1]

[1]*Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Germany*

[2]*Integrated Optical Systems, MESA+ Institute for Nanotechnology, University of Twente, 7500AE, Enschede, The Netherlands*

[3]*LIGENTEC SA, EPFL Innovation Par L, Chemin de la Dent-d'Oche 1B, Switzerland CH-1024 Ecublens, Switzerland*

Watt-level optical amplifiers have various applications such as laser detection and ranging, modelocked lasers, frequency combs and laser surgery. However, power amplifiers are usually limited to solid-state and fibre-based technologies, as in integrated photonics the very property of tight mode confinement becomes an impediment to high power applications due to small optical mode cross-section, and thus limiting powers to a few 10s of milliwatt range at best [1]. Semiconductor based slab coupled waveguide amplifiers [2] can allow for large mode area thus high power; the integration, however, has proven to be challenging. Rare earth doped chip-scale amplifier recently reached signal level >100 mW, however, that is at the expense of a complex fabrication process [3]. The situation is even worse beyond telecom wavelength window, in the mid-infrared, where only a few mWs of amplified signal has so far been achieved [4]. Here, we demonstrate for the first time a CMOS compatible watt-scale power amplifier with signal amplification up to >0.9 W in a compact footprint of 3.6mm^2 in the eye safe window. The signal power reaches a level enjoyed by commercial bench top fiber amplifiers [5].

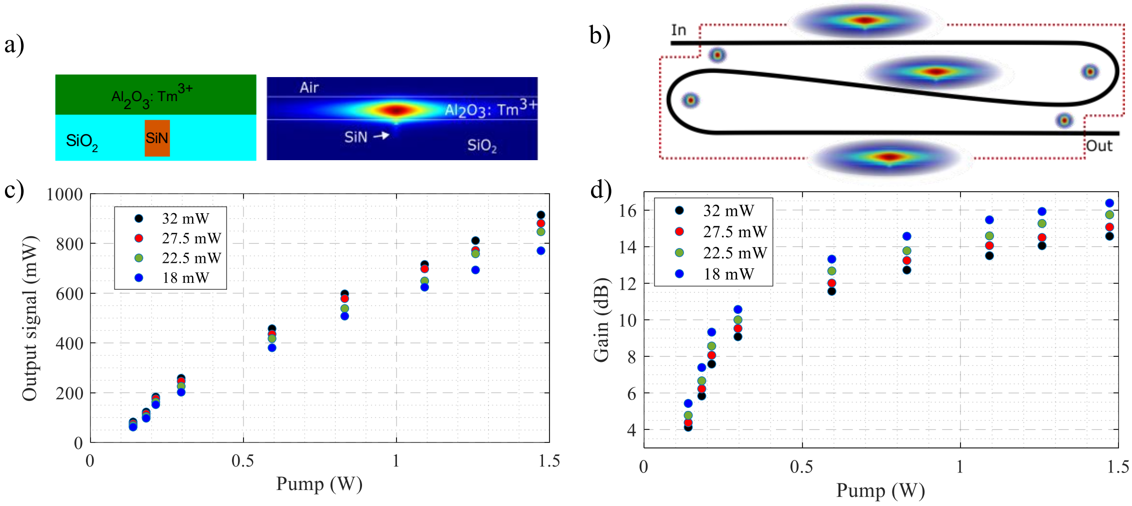

Fig.1. a) Gain waveguide and the optical mode. b) Device layout with large mode and tightly confined mode sections (around the bends and input and output region). Gain layer within the red box. c) Measured on-chip output signal power vs on-chip pump power for different on-chip input signal power. d) Gain as a function of pump power. Pump and signal coupling losses were 3.5 dB/facet and 2.5-2.8 dB/facet, respectively.

We utilize recently developed large mode area (LMA) gain waveguide [6, 7]. Such a device supports mode area in the range of 10s of µm^2 allowing for high gain saturation power comparable to fiber based systems. The device here supports only fundamental mode, unlike an LMA fiber amplifier, with mode area >30µm^2, and the pump (at 1.61 µm) and signal (at 1.85 µm) overlap of >98%. The mode profile and the device architecture are shown in Fig1a. and b, respectively. The large signal and pump mode are mainly confined in the gain sections (Al_2O_3:Tm^{3+}) which are in the straight sections of the amplifier (Fig.1b) and they are adiabatically transitioned into tightly confined modes in the silicon nitride layer in the bends, allowing for a compact footprint. The device was fabricated in a CMOS foundry on a silicon-nitride-on-silicon platform which was subsequently deposited with alumina layer doped with thulium gain ions. The amplified signal power as a function of pump power is shown in Fig.1c and d. Here we see the amplified signal for the maximum pump power reaches >0.9W for an input signal of 32 mW (limited by the source). The gain is higher for lower power input signal as expected reaching up to 16 dB (in a 6 cm long device). The conversion efficiency is >60% and the gain saturation power is expected to be several 10s of mWs. In conclusion, we have demonstrated a CMOS-compatible watt-class power amplifier within a compact footprint with the help of recently studied LMA waveguide, outperforming state of the art integrated amplifiers.

Funding: EU Horizon 2020 Framework Programme - Grant Agreement No.: 965124 (FEMTOCHIP).

References

1. K. V Gasse, et. al."27 dB gain III-V on silicon semiconductor optical amplifier with >17 dBm output power," *Opt. Express*, 27, 2019.
2. P. W. Juodawlkis, et. al. "High-Power, Low-Noise 1.5-µm Slab-Coupled Optical Waveguide (SCOW) Emitters: Physics, Devices, and Applications," *IEEE J. Sel. Top. Quantum Electron*, 17, 2011.
3. Y. Liu, et. al. "A photonic integrated circuit based erbium doped amplifier," *Science*, 376, 2022.
4. N. Volet, et. al. "Semiconductor optical amplifier at 2 µm wavelength on silicon," *Laser Photonics Rev.* 11, 2017.
5. Advalue photonics - 2 Micron Fiber amplifier (Ap-Amp), www.advaluephotonics.com.
6. N. Singh et. al. "Towards CW modelocked laser on chip – a large mode area and NLI for stretched pulse mode locking", *Opt. Express*, 28, 15 (2020).
7. N. Singh et. al. "Chip-scale, CMOS-compatible, high energy passively Q-switched laser," arxiv2303.00849 (2023).