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Large mode area waveguide based high-energy passively Q-switched laser in silicon photonics

Neetesh Singh[1*], Jan Lorenzen[1], Milan Sinobad[1], Kai Wang[2], Andreas C. Liapis[3], Henry Frankis[4], Mahmoud A. Gaafar[1], Stefanie Haugg[5], Henry Francis[6], Jose Carreira[6], Michael Geiselmann[6], Tobias Herr[1], Jonathan Bradley[4], Zhipei Sun[3], Sonia M. Garcia-Blanco[2], and Franz X. Kärtner[1,7]

[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]*Department of Electronic and Nanoengineering, Aalto University, Espoo 05140, Finland*
[4]*Department of Engineering Physics, McMaster University, 1280 Main Street West, Hamilton, Ontario L8S 4L7, Canada*
[5]*Centre for hybrid Nanostructures, University of Hamburg, Luruper Chaussee 149,, 22761, Hamburg, Germany*
[6]*LIGENTEC SA, EPFL Innovation Par L, Chemin de la Dent-d'Oche 1B, Switzerland CH-1024 Ecublens, Switzerland.*
[7]*Department of Physics, Universität Hamburg, Jungiusstr. 9, 20355 Hamburg, Germany*
**neetesh.singh@desy.de*

Abstract: We demonstrate high energy Q-switched pulse generation with the help of a large mode area gain waveguide in a silicon photonics device. Output pulse energy >150 nJ and laser slope efficiency of 40% is shown.

High energy pulses from a millimeter scale device is highly desirable for applications such as medical surgeries, space applications for planetary explorations and defense. Especially this is true for wavelengths which has a high-water absorption (~ 1.9 µm). Usually, benchtop systems can only provide the desired pulse energy; however, at the cost of a large system size and non-mass producibility. In this work, we overcome such a challenge, and demonstrate high energy pulse generation from a silicon photonics mass-producible compact device. We demonstrate for the first time large mode area (LMA) gain waveguide (supporting high energy storage and gain saturation energy) in a Q-switched laser cavity, allowing output pulse energy >150 nJ at a repetition rate of 1 MHz from a device having a footprint of 9 mm^2. The pulse energy demonstrated is comparable and outperforms many fiber-based compact Q-switched lasers [1, 2]

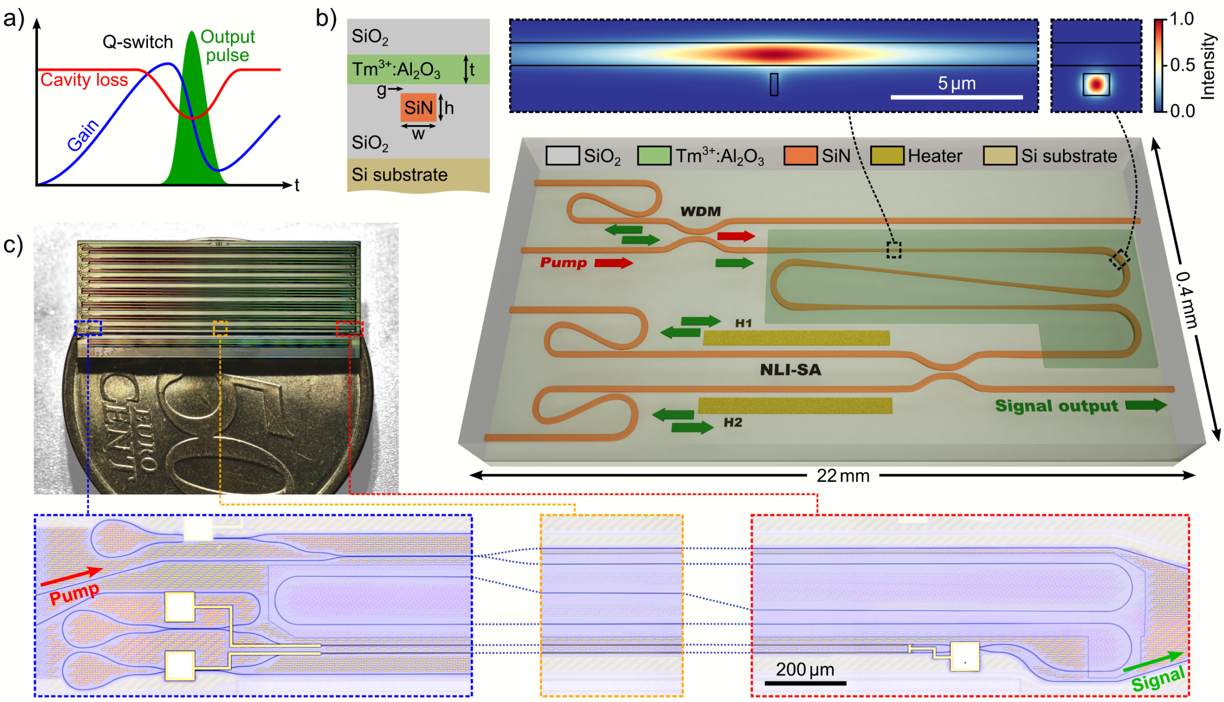

Fig. 1. a) Principle of passive Q-switching. b) A compact integrated LMA pulsed laser. WDM – wavelength division multiplexer; NLI-SA – nonlinear Michelson interferometer based saturable absorber; H1,2 – high and low power heater arms. Within the faint green box region, the LMA sections are over the straight SiN waveguides which are connected with each other through adiabatic tapers and circular bends. The NLI-SA splits the signal into two arms through a directional coupler and back reflects via loop mirrors. Inset: The LMA waveguide cross-section is shown along with the signal mode profiles in an LMA gain region and a bend. c) An optical image of the chip containing the device placed on top of a 50-cent euro coin.

The laser mainly consists of a gain section, cavity mirrors and a saturable absorber (Fig. 1). The pump is coupled to the gain section through a WDM. The pump is adiabatically coupled into the gain medium, which is based on thulium doped aluminum oxide film (~840 nm thick) which is cladded with a 1 µm thick silica layer. The signal and pump mode area is 27 µm^2. The signal and pump overlap with the gain layer is ~ 75% which can be more than 95 % without silica cladding or a thicker layer of alumina [3]. A narrow SiN layer not only reduces scattering loss (due to a weak modal confinement) but also helps to maintain only the fundamental mode in the LMA gain section, unlike an LMA fiber which tend to get few-moded losing energy to higher order modes, while also suffering from large bending radius [4]. The total cavity roundtrip length is 16.7 cm which includes a 12 cm roundtrip length of the gain section. We use a fast Kerr-type saturable absorber based on a nonlinear Michelson interferometer (NLI-SA). It acts as an intensity dependent reflector: the reflectivity back to the cavity increases with the signal intensity, which supports the Q-switched pulse formation (for details see [1, 5]).

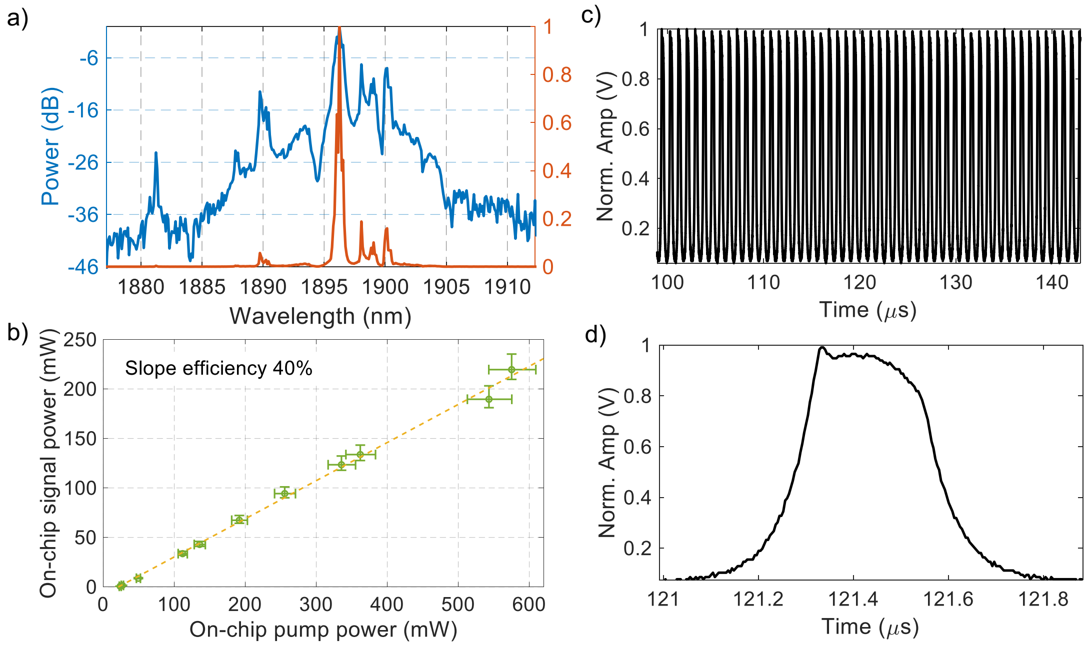

Fig. 2. a) Optical spectrum in logarithmic and linear scale. b) On-chip output signal average power with respect to on-chip pump power. c) Oscilloscope trace of the Q-switched pulse train. d) Zoomed in section showing a single pulse.

The device was pumped at 1.61µm. The measured Q-switched signal spectrum and temporal data are shown in Fig.2. The pulse repetition rate <1MHz, pulse width >200 ns and energy >150 nJ. The lasing threshold is approximately 20 mW and the slope efficiency is 40%.

In summary, we have demonstrated a high energy Q-switched laser in a silicon photonics platform based on LMA waveguide. The laser performance is comparable, and in many ways exceeds, that of a benchtop fiber lasers. This bodes well for a wide range of applications where size, weight and power are important, such as in deep space and point-of-care medical applications. Energy scaling seems possible with even larger mode area and optimized gain concentration as long as the device is operated within the damage threshold of SiN. With the help of cavity dispersion management low noise modelocked pulsed train can be generated which will find applications in nonlinear pulse generation and optical frequency synthesis [6].

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