Nano Scale Disruptive Silicon-Plasmonic Platform for Chip-to-Chip Interconnection

Report on new applications and their opportunities

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Executive Summary

The present document reports on the new applications of the developed systems in the NAVOLCHI projects. The document presents the main advantages of the developed systems for the plasmonic interconnects and presents their possible application and opportunities in other fields. Specifically, the document describes how the plasmonic laser could be utilized in other applications like sensor systems and biomedical applications. Also the plasmonic amplifier could be utilized to realize more complicated and more efficient sources (e.g. disk lasers coupled to waveguides), albeit optically pumped. Alternatively the develop systems could be used for wavelength conversion. The approach followed for the development of the plasmonic amplifier enables all-optical wavelength conversion at rates matching state-of-the-art convertors in speed, yet with significantly cheaper materials.

Change Records

Version	Date	Changes	Author
0.1 (draft)	2015-07-15	Start	Christoforos Kachris (AIT)
0.2	2015-07-24	Amplifier	Dries Van Thourhout (UGHENT)
0.3	2015-07-27	Laser	Victor Calzadilla (Tue)

Contents

1. Developed System and new applications

1.1.NAVOLCHI Plasmonic laser

In the NAVOLCHI project, we have made great progress towards realisation of an extremely compact metallo-dielectric nanolaser coupled to a waveguide. We developed the full process for fabrication of these devices and demonstrated light generation in this device with a high coupling effiency into the waveguide. The wall plug power efficiency that we obtained is several orders of magnitude higher than the best result reported so far [1]. Due to a failry high resistance in these first prototypes we could not yet demonstrated laser operation. However, due to their good waveguide coupling efficiency these devices may also find applications in the following fields:

- **Sensors**: It has been demonstrated that nanoscale cavity sources show high performance in certain sensing applications due to the large surface-to-volume ratio, which make them highly sensitive to the environment. By monitoring the emission intensity, a nanolight source can be used to sense the enviromental conditions. For example, recently an optically pumped plasmon nanocavity laser source achieved a sub-part-per-billion explosive molecule detection [2].

- **Biomedical**: it has been suggested that nano- and micro-scale lasers based on fluorescent labelled DNA as gain medium may find applications in optical DNA sequencing [3].

The present prototype was close to laser operation and a redesign has been made for which we are confident that it will bring us the first metallo-dielectric lasers coupled to silicon-based photonic wire waveguides.

1.2.NAVOLCHI Plasmonic amplifier

The advantage of using colloidal quantum dots as the active medium is the extremely broad optical wavelength range over which they are applicable, and there ease of integration and processing, e.g. compared to epitaxially grown materials.
The electrically pumped QD-device developed in NAVOLCHI could serve as an on-chip light source generating broad band light. Given the relatively low efficiency of the system, the target thereby is mainly applications whereby power consumption is less relevant but where low cost of the chip is essential. This could e.g. be a disposable bio-sensor chip which can be used in a laboratory setup for testing. Such systems are now being developed in several EU-projects, without integrating the source on the chip (e.g.ICT Pocket for Tuberculosis detection, RAPP-ID for detection of infectious diseases). The latter could make the overall system cheaper (avoiding the difficult coupling from external source to the chip).

The QD-embedded SiN platform allows to realize more complicated and more efficient sources (e.g. disk lasers coupled to waveguides), albeit optically pumped. This platform is especially relevant in combination with QDs operating in the visible wavelength range. Again, a disposable chip for sensing could be a meaningful application, certainly when exploiting the properties of the more complex source: e.g. one could envision a disk based comb source in combination with a ring based sensor, in a Vernier configuration. If the ring sensor has a FSR

slightly differing from that of the ring, a small change in the resonator response will lead to an abrupt change in the overall response formed by the product of both devices.
An alternative application of the QD-embedded SiN platform lies in quantum optics. Imec and UGent are actively developing single photon sources based on this technology. Instead of embedding a full film of QDs we developed a technology (outside of NAVOLCHI) to deterministically place single QDs at given locations in an optical cavity or waveguide. Combining this with a high beta factor for the highly confined optical waveguides should allow us to realize sources with large coupling fraction and large degree of polarization.

Finally, we also investigated use of PbS based devices for wavelength conversion. We showed that the interplay between intraband and bandgap absorption in colloidal quantum dots (QDs) leads to a very strong and ultrafast modulation of the light absorption after photoexcitation in which slow components linked to exciton recombination are eliminated. This approach enables all-optical wavelength conversion at rates matching state-of-the-art convertors in speed, yet with significantly cheaper materials. Moreover, the stronger light-matter interaction allows for implementation in small- footprint devices with low switching energies. Being a generic QD property, the demonstrated effect opens a pathway towards low-power integrated photonics based on colloidal QDs as the enabling material. Fig. 2.4.1 shows preliminary results.

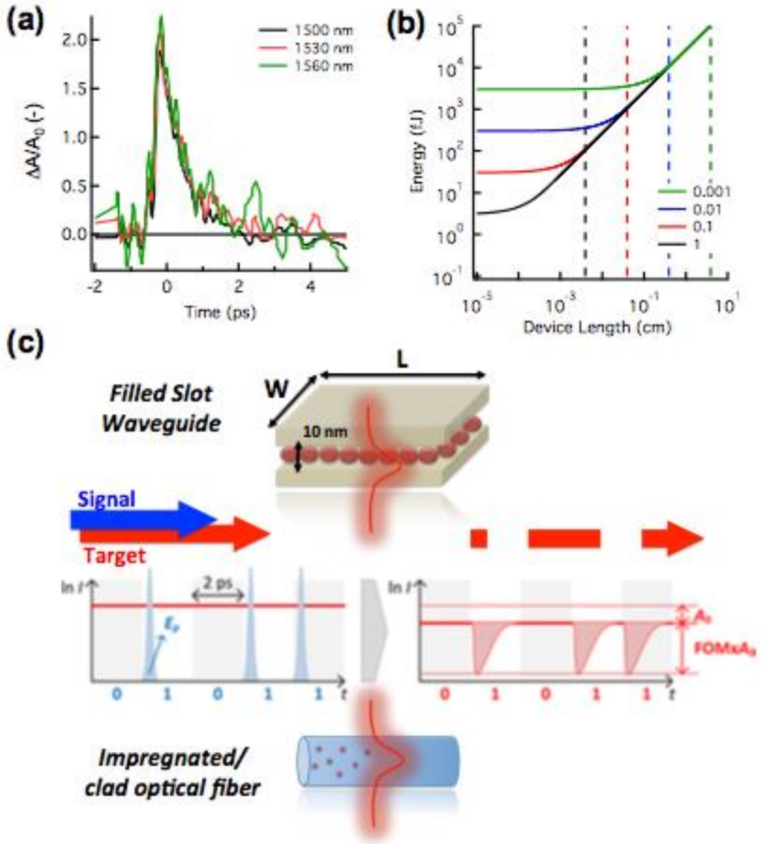

Figure 2.4.1 (a) Demonstration of wavelength conversion in thin (75 nm) spincoated film of QDs on a glass substrate, (b) evaluation of switching energy per bit (in femtojoule) and device interaction length (in cm) for a variety of optical confinement factors with 3 dB exctinction (vertical dashed lines) of the target wave without pump pulse present. (c) Wavelength conversion scheme with incident pump (solid red)/probe (blue) sequence and corresponding output indicating the meaning of the FOM, using either a typical integrated SOI design with slot

waveguide (Γ = 0.1) containing nanocrystals or a impregnated or QD covered glass fiber(Γ = 0.001). Additional calculations are added in the Supporting Information.

References

[1] Kevin C. Y. Huang, Ming-Kyo Seo, Tomas Sarmiento, Yije Huo, James S. Harris, and Mark L. Brongersma, “Electrically driven subwavelength optical nanocircuits”, Nature Photonics 8, 2014.
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[3] Martin T. Hill and Malte C. Gather, Advances in small lasers, Nature Photonics 8, 2014.