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POSEIDON

NanoPhOtonic devices applying Self-assembled colloIDs for novel ON-chip light

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= Deliverable D1.1 =

Specification table for light source for PIC

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Executive Summary

The requirements of different application fields of integrated on-chip light sources differ significantly. It was therefore chosen to focus on two application fields: 1. information and communication technology (ICT) and 2. sensing.

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1. Introduction

The aim of this deliverable is to set the requirement and define the specification table for the on-chip light source which will be developed within the project. The light sources we are developing in POSEIDON will be integrated on photonic integrated circuits (PIC). In order to increase the outcoupling properties, colloidal emitters will be coupled or directly integrated to on-chip resonators, based on nanophotonic structures.

The major advantage of the light sources developed within this project over the established III-V lasers is possibility to monolithically integrate them with silicon nitride (SiN) or silicon-on-insulator (SOI) photonics, which can significantly lower the cost of the entire system. This can have a major impact on applications where cost is the limiting factor, such as short-range communication, optical interconnects, and optical sensing for IOT (internet of things) applications. Here, the optical losses and required data rates are lower than in long range optical links and the required output power of the sources can be lower than typical tens of mW that can be delivered by established III-V lasers [1]. Another important figure of merit to match is the gain bandwidth, which determines the wavelength range useful for wavelength division multiplexing (WDM), which in case of typical III-V semiconductor heterostructures can reach even 100 nm [2].

2. Results and discussion

The requirements of different application fields of integrated on-chip light sources differ significantly. It was therefore chosen to focus on two application fields: 1. information and communication technology (ICT) and 2. sensing. Separate specification tables were created for them.

Furthermore, for each individual property a "minimum requirement" value and the "optimum" are specified. The reasoning behind this is that compromises are possible to work round certain "non-optimal" aspects of a light source, including limiting its application scope, whereas certain basic specifications have to be fulfilled in order for the solution to be seriously considered.

For some parameters it does not yet make sense to estimate or demand precise values this early in the project. These will be marked with "*" in the specification table and are meant to specify only the target order of magnitude.

2.1. Colloidal on-chip light source for information and communication technology applications

Parameter	Minimum requirement	Optimum
Wavelength	1550 nm	1300 – 1600 nm
Output power*	0.1 mW	1 mW
Internal quantum efficiency*	10 %	90 %
Coupling to waveguide*	10 %	90 %
Coherent emission	no	yes
Gain bandwidth*	5 nm	100 nm
Quality (Q) factor of loaded nanophotonic resonator*	500	100,000
Process compatibility	Light source last	Full
Integration with waveguide material	Si3N4	Si3N4 and SOI
Wafer-scale processes	no	yes

The target **wavelength** has been chosen to match the classical telecommunication wavelengths to achieve best compatibility with existing equipment. However, these targets do not exclude other wavelengths from being potentially useful for short range communication, i.e. on-chip. The silicon nitride platform has a broad transparent wavelength range, whereas the SOI platform is limited to wavelengths above 1.1 µm. Within this project, we concentrate on the communication bands for the O-band (1260 nm -1360 nm) and C-band (1530 nm - 1565 nm).

The **optimal output power** target is set to a value typically employed in current systems, where losses on the order of 20 dB can be handled. The minimum specification builds upon this lossy case and assumes applications with low additional loss, i.e. for short range communication. Single nano emitters are predicted to provide output powers of 0.1 µW be means of spontaneous emission. Here, multiple emitters will be combined with high quality optical resonators to achieve targeted output power of 1 mW by means of efficient light amplification.

The output power should not be generated by inefficient means, though. This is specified by the **internal quantum efficiency** of the emitters and the efficiency of their coupling to the photonic waveguides. For both values the minimum target is set to approximately 10 %, as below this value the emitters will probably never be used in real devices.

Ideally the emission would be coherent, i.e. from an optically or electrically pumped laser. However, slower transmissions using incoherent light may still be useful, especially for characterization purposes.

The **gain bandwidth** of the material determines the bandwidth maximally available for wavelength division multiplexing (WDM). Any single light source will need to have a smaller bandwidth than this. This is specified in terms of the **Q factor** of the on chip microring resonators to which the emitter is coupled, with higher values allowing finer/more WDM. For a resonator this means, that the light can be stored in the resonator for longer time, thus by coupling the emitter to a resonator, more output power can be achieved.

The **process compatibility** of the light source has to allow fabrication on top of otherwise finished AMO photonic integrated circuits (PICs). Optimally the active material like quantum dots would be encapsulated by e.g. SiO2 so that after their deposition and encapsulation all fabrication steps could be performed as usual.

The light source is targeted for integration with silicon nitride waveguides, but **compatibility** with silicon on insulator (SOI) would be a strategic advantage. This is of high importance to demonstrate feasibility of the colloidal light source approach via integration of lasers into silicon based photonic and electronic chips.

Wafer-scale processes are necessary for cost-effective production of the light sources and are aimed to be reached for the communication light source. Our research within the POSEIDON especially targets approaches which are compatible for mass production.

2.2. Colloidal on-chip light source for sensing applications

Parameter	Minimum requirement	Optimum
Wavelength	650 nm	400 – 900 nm
Output power*	0.5-1 µW	1 mW
Internal quantum efficiency*	10 %	90 %
Coupling to waveguide*	10 %	90 %
Coherent emission	no	yes
Gain bandwidth*	1 nm	100 nm
Quality (Q) factor of loaded nanophotonic resonator*	1,000	100,000
Process compatibility	Light source last	Full
Integration with waveguide material	Si3N4	Si3N4
Wafer-scale processes	no	yes

The minimum **wavelength** requirement has been chosen to match readily available CdSe quantum dots, whereas the optimum has been chosen as the complete visible spectrum together with the near-infrared IR) to allow a broad range of potential applications. However, these targets do not exclude other wavelengths from being potentially useful for sensing. We chose the wavelength range 400-900 nm to be reasonable for the fabrication and at the same time useful to many applications for future sensing devices.

The **optimal output power** target is set to a value readily available from commercial laser diodes. The minimum specification is set significantly lower, targeting applications which prefer lower cost over maximum sensor performance. The output power should not be generated by inefficient means, though. This is specified by the **internal quantum efficiency** of the emitters and the efficiency of their coupling to the photonic waveguides. For both values the minimum target is set to approximately 10 %, as below this value the emitters will probably never be used in real devices.

Ideally the emission would be **coherent,** i.e. from an optically or electrically pumped laser. However, simple measurement schemes like absorption spectroscopy do not require this.

The **gain bandwidth** of the material determines the flexibility to cover different wavelength with the same material

The **process compatibility** of the light source has to allow fabrication on top of otherwise finished AMO photonic integrated circuits (PICs). Optimally the active material like quantum dots would be encapsulated by e.g. SiO2 so that after their deposition and encapsulation all fabrication steps could be performed as usual.

Wafer-scale processes are necessary for cost-effective production of the light sources and are aimed to be reached for the sensing light source.

3. Conclusions

This deliverable sums up the specifications which have been set in the POSEIDON project for the integrated colloidal light source.

Two main fields of application were identified: communication technologies and sensing. Both of them require different parameters from the light source. For both, a monolithically integrated light source, which can be fabricated in scalable wafer-based processes would boost the state of the art tremendously. The two spec sheet tables summarize the minimum and optimal requirement for each light source. Certain sensing applications can work with light sources which are incoherent and require less output power, whereas ICT require coherent light at higher output power levels.

4. Degree of progress

The development of “Specification table for light source for PIC” is 100% fulfilled.

5. Dissemination level

The Deliverable D1.1 “Specification table for light source for PIC” is public and therefore it will be available to download on the project’s website and on demand.

6. References

[1] M. Theurer *et al.*:*IEEE Photonics Technol. Lett.*, vol. 31, no. 3, pp. 273–276, 2019.
[2] B. Chen:*Opt. Express*, vol. 25, no. 21, p. 25183, 2017.