Wireless Optical Communication using Silicon-on-Insulator technology

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I. Introduction

As the data rates are increasing, there is an increasing mismatch between wired and wireless communications. While optical fiber communication easily allows Gigabit-per-second (Gbps) communication, the present mainstream wireless communication, based on a radio-frequency (RF) carrier at 2.45GHz does only offer several tens up to hundreds Mbps due to the limited bandwidth available and interference of other users. At RF side, one is therefore looking at the 60GHz band for short range ($\sim$10m) Gbps communication since there is an unlicensed band of 5-7GHz around 60GHz available worldwide. Another option for high-speed wireless communication is wireless optical communication. Optical links are free of FCC regulations resulting in a virtually unlimited bandwidth compared to their RF counterpart. One can then make all-optical networks where only an electro-optic (EO) conversion is necessary at the receiver side [1].

In this paper, the feasibility of on-chip optical wireless components using the Silicon-on-Insulator (SOI) platform is investigated. The SOI platform is CMOS compatible and this allows low-cost, mass-producible optical components to be fabricated. This could be useful in e.g. sensor networks [2]. Link budget calculations demonstrating in which cases an optical on-chip link is useful are presented. Since directive beams are needed, beam steering is desirable. This is enabled by an optical phased array (OPA). An OPA consists of an array of radiating apertures of which the phase can be controlled resulting in beam steering. An OPA on SOI has been demonstrated as well.

II. Feasibility study of optical links

When following an integrated approach, the radiating apertures – which is for example a grating coupler on SOI – are rather small (order of several tens μm). Therefore, link budget calculations are performed to study the feasibility of these links. The link budget of a free-space optical links can be written analog to the well-known Friis formula as:

$$P_r = P_t \eta_t G_t (\frac{\lambda}{4\pi d})^2 Q_{rt} \eta_r G_r \qquad (1)$$

with G_t and G_r the gain of the transmitter and receiver defined as the power-per-unit solid angle radiated in a certain direction (θ, ϕ) compared to the power-per-unit angle radiated by an isotropic radiator, η_t and η_r efficiency factors, d the separation between the antennas and Q_{rt} the polarization mismatch factor, which will not be taken into account further. The wavelength considered is 1550nm.

The main noise contributions are thermal noise and shot noise. In optical wireless links, ambient light shot noise has been recognized to be one of the limiting noise factors although at high data rates, the thermal noise becomes more important. Additionally, the load resistance together with the capacitance of the detector put a limit on the bandwidth of the re-

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ceiver which is detrimental when using large area photodiodes. For a reciprocal OPA link on-chip, the area of the detector can be very small ($A \sim 50\mu\mathrm{m}^2$) since it is the OPA which guides the light into a single mode waveguide for detection. Hence, this method also allows for heterodyne detection which results in up to 20dB extra sensitivity. For a non-reciprocal link with a large area photodiode the received power increases, but so does the ambient light noise contribution and thermal noise due to the smaller load resistor that is needed to comply to our specified bandwidth. When one knows the noise power, the BER can easily be calculated.

The needed received power for a BER of 10^{-9}

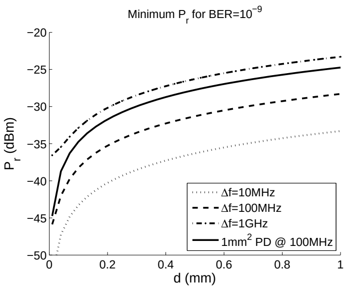

Figure 1. Minimum $P_{r,min}$ in function of aperture diameter.

in function of the total radiating A aperture size for reciprocal links is shown in Figure 1. The case in which the receiver is a large area photodiode is shown as well, clearly showing that an OPA receiver performs better. Some examples of possible links are given in Table 1. Transmit power at 1550nm is limited to 10mW due to eye-safety regulations. It can be concluded that links are possible for small steering ranges, since matrix addressing issues are limiting the number of addressable elements and it is the size of the individual elements which determines the steering range.

III. Optical phased array on SOI

An example of an 1D OPA on SOI is given in Figure 2. Continuous thermo-optic steering

$A(mm^2)$	0.01	0.1	1
$G(dB)$	47.2	57.2	67.2
$P_{r,min}$	-38.2	-28.2	-23.2
$losses(dB)$	137.2	152.6	167.7
$d(m)$	< 1	< 5	< 30
$steering(°)$	8	2.5	0.8

Table 1. Examples of possible links using a 10×10 OPA with $P_{transmit} = 10dBm$

of 2.3° and wavelength steering of 14.1° is reported [3].

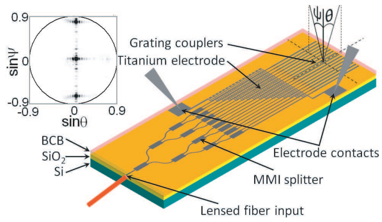

Figure 2. 1D optical phased array on SOI.

IV. Conclusions

The SOI platform offers a promising solution for low-cost, small optical wireless components. Realistic link budgets are possible for short distance (d∼1m) and steering ranges of several degrees. A proof-of-principle 1D optical phased array on SOI has been presented.

Acknowledgments

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References

[1] J. M. Kahn and J. R. Barry, "Wireless infrared communications," *Proceedings of the IEEE*, vol. 85, no. 2, pp. 265–298, 1997.

[2] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless sensor networks: a survey," *Computer Networks*, vol. 38, no. 4, pp. 393–422, 2002.

[3] K. Van Acoleyen, W. Bogaerts, J. Jágerská, N. Le Thomas, R. Houdré, and R. Baets, "Off-chip beam steering with a one-dimensional optical phased array on silicon-on-insulator," *Optics Letters*, vol. 34, no. 9, pp. 1477–1479, 2009.