Backscatter Model for Nanoscale Silicon Waveguides

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Waveguides are the most fundamental building block in photonics, and their behaviour is considered to be well-understood. Usually they are typically considered as simple light guiding channels – with linear phase change and propagation losses. But in high contrast waveguides we have to consider backscattering induced by sidewall roughness, which leads to surprisingly strong fluctuations in the waveguide transmission spectrum. Fig. 1 shows measured transmission spectrum of waveguides of different length. They are ~450 nm x 220 nm air-clad silicon-on-insulator waveguides fabricated by imec's 193 nm deep UV lithography. We observe that fluctuations in the spectrum increase drastically with the waveguide length. The 7-cm-long waveguides produce flucuations above 15 dB.

We attribute the fluctuations to backscattering of light on the rough waveguide sidewalls. This roughness sets up a large number of scattering centers. On each of them, a small portion of light is reflected with a random phase (and amplitude). As shown in Fig. 2, unscattered forward propagating light (solid red line) interferes with many forward contributions that are the result of at least two backscattering/reflection processes (blue lines), and the transmitted light therefore shows sharp interference fringes.

To study the transmission spectrum rigorously, we built a model in the circuit simulator CAPHE, which models waveguides as a series of very short cascaded lumped sections (Fig. 2) of an identical length (50 µm) and a defined loss α. To incorporte backscattering, each section has a defined reflectivity r and a random phase change φ uniformly distributed between 0 and 2π. As shown in Fig. 1, with a reasonable choice of parameters (loss and reflectivity), our model explains and accuractely captures the observed 10 dB fluctuations in 7-cm-long silicon waveguides. This is a first step towards a full understanding and mitigation of such anomalous waveguide behavior.

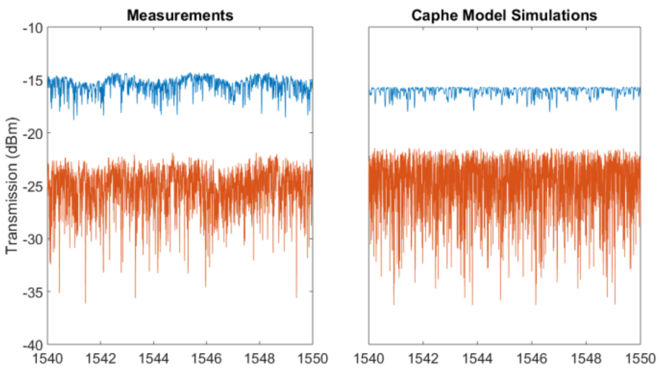

Fig. 1. Measured and simulated transmission spectrum of 1 cm (blue) and 7 cm (orange) SOI strip waveguides.

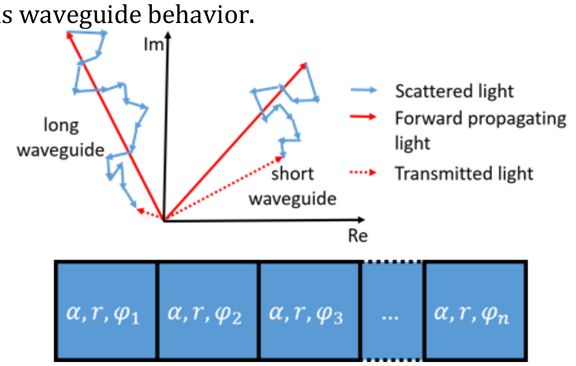

Fig. 2. Upper: Phasor plot of light in waveguides. Lower: Lumped circuit model of waveguides.