Simulation study of propagation losses due to sidewall roughness of GaAs waveguides for single-photon sources in quantum applications

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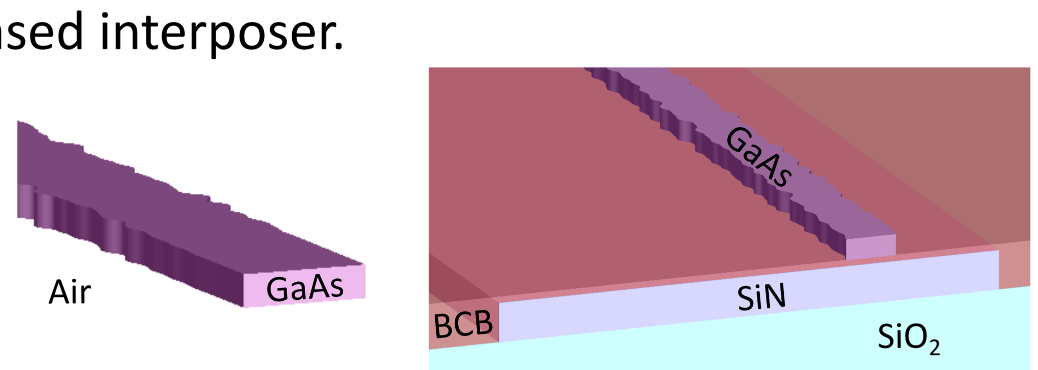
Motivation

- **Quantum photonic integrated circuits** impose stringent requirements on integrated components (e.g., single-photon sources and detectors, modulators, low-loss couplers, and waveguides).
- In this contribution, we utilise numerical simulations to analyse the effects of **sidewall roughness of GaAs waveguides** (WGs) in single-photon sources on (i) WG propagation losses and (ii) coupling efficiency to a low-loss SiN-based interposer.

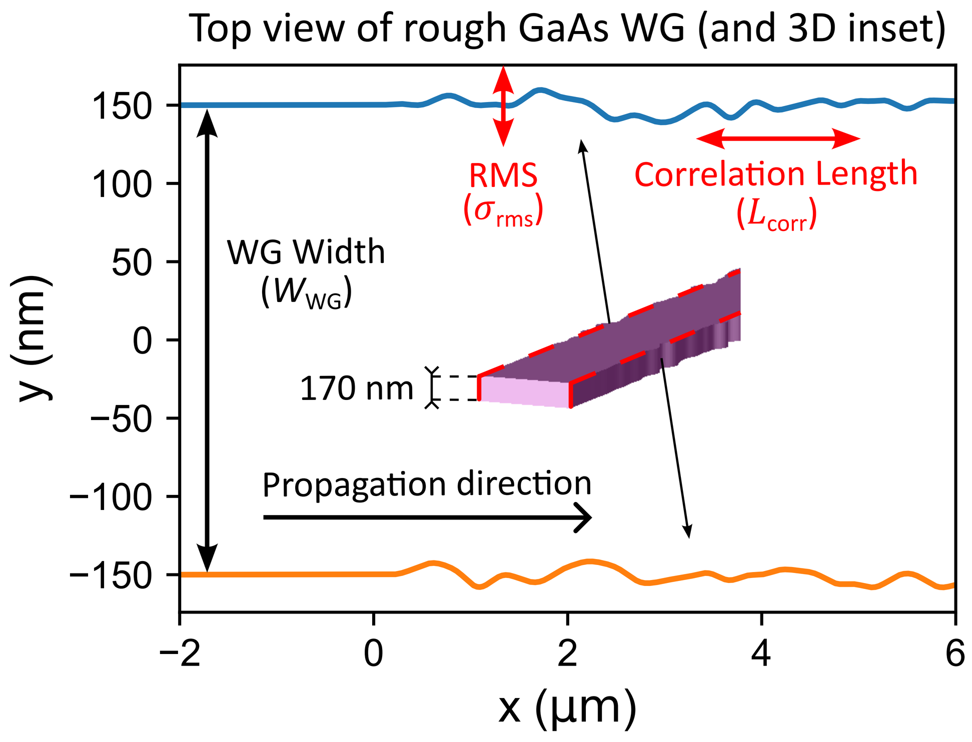


The sidewall roughness of GaAs-based WGs stems from the fabrication process. In our case, we mainly attribute the roughness to e-beam processing of the photoresist. Illustrations of a suspended GaAs WG and an air-cladded SiN-GaAs coupling section with exaggerated roughness are shown above in the left and right image, respectively.

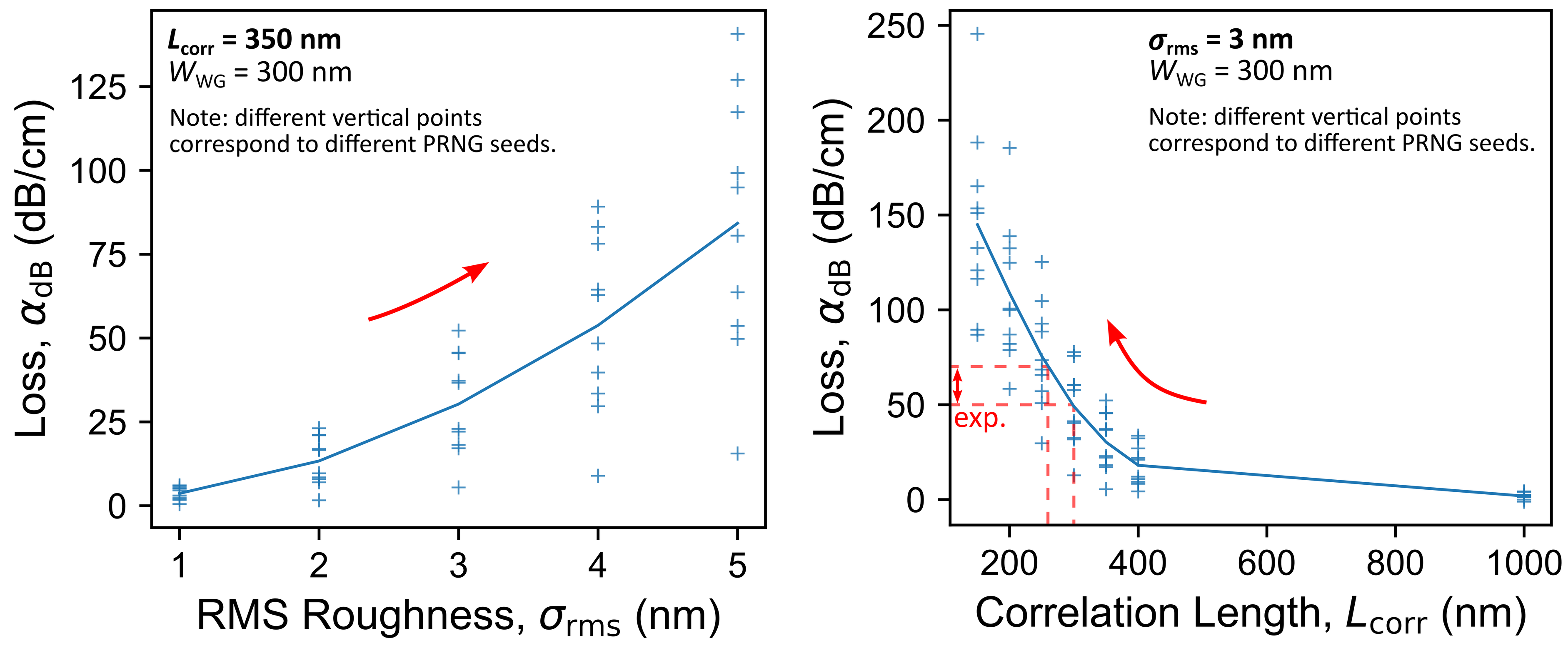
Methods

- We **analyse optical losses due to sidewall roughness** of GaAs WGs and couplers for a 930 nm wavelength by employing 3-D FDTD numerical simulations.
- A pseudo random number generator (PRNG) is used to generate roughness profiles with a gaussian autocorrelation envelope.

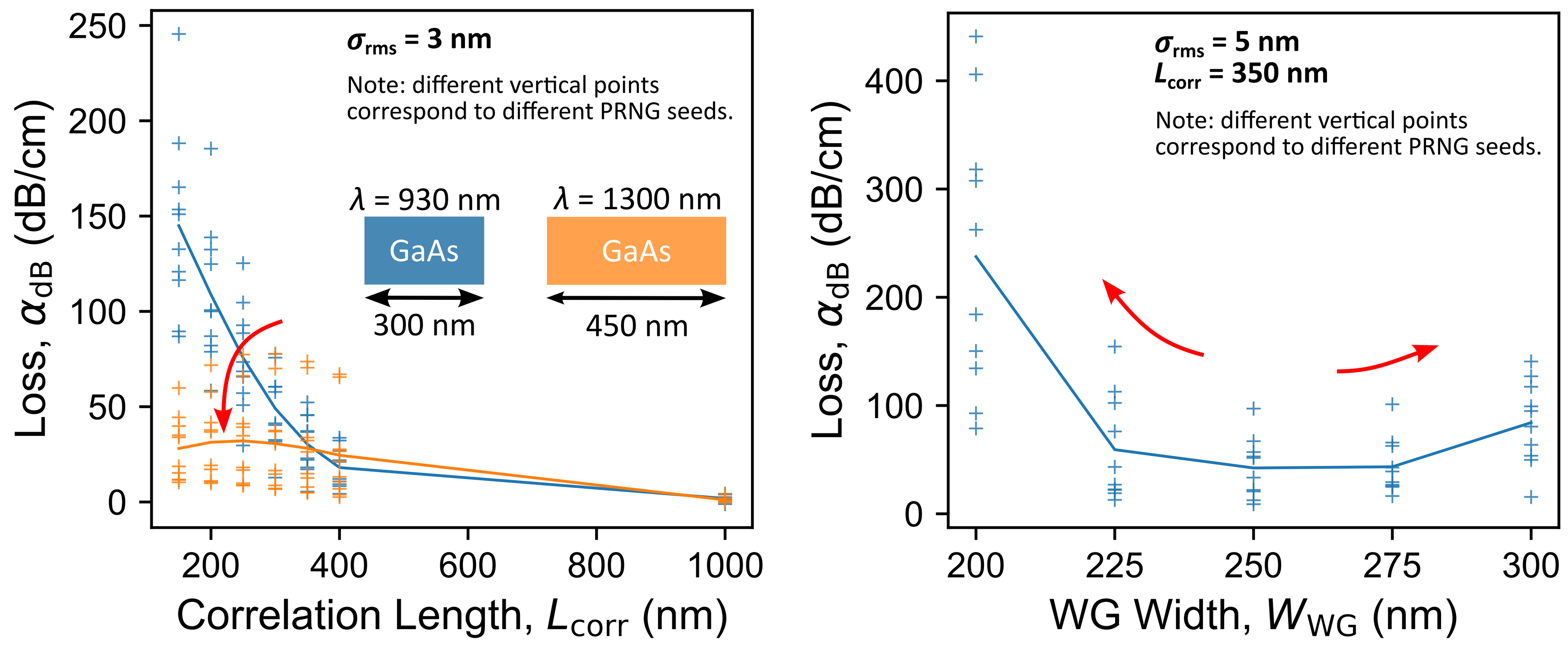
Top view of rough GaAs WG (and 3D inset)



WG Propagation Loss simulation results

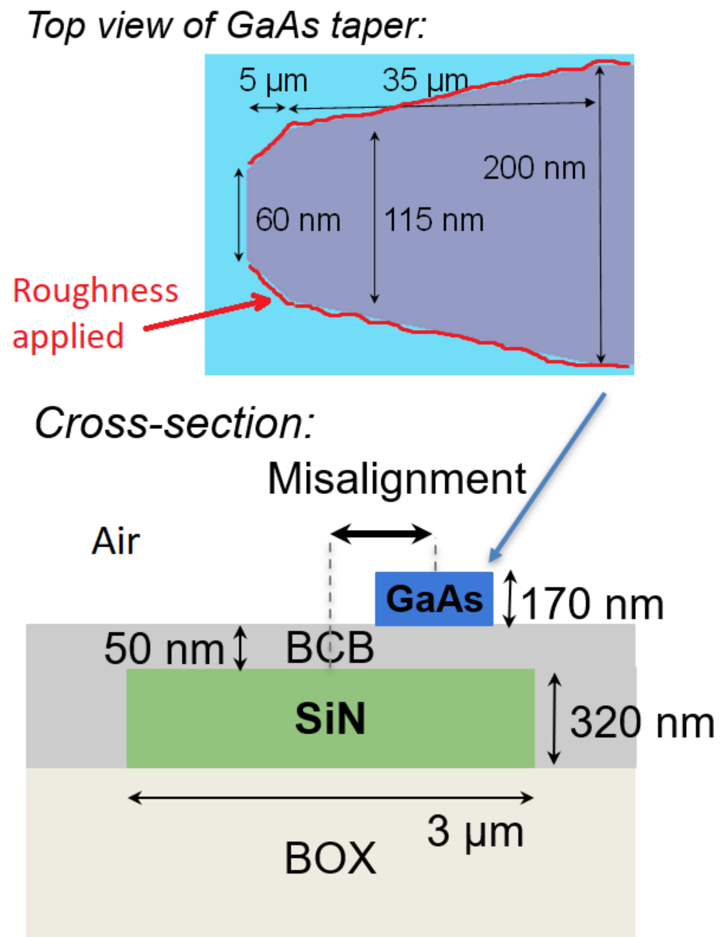


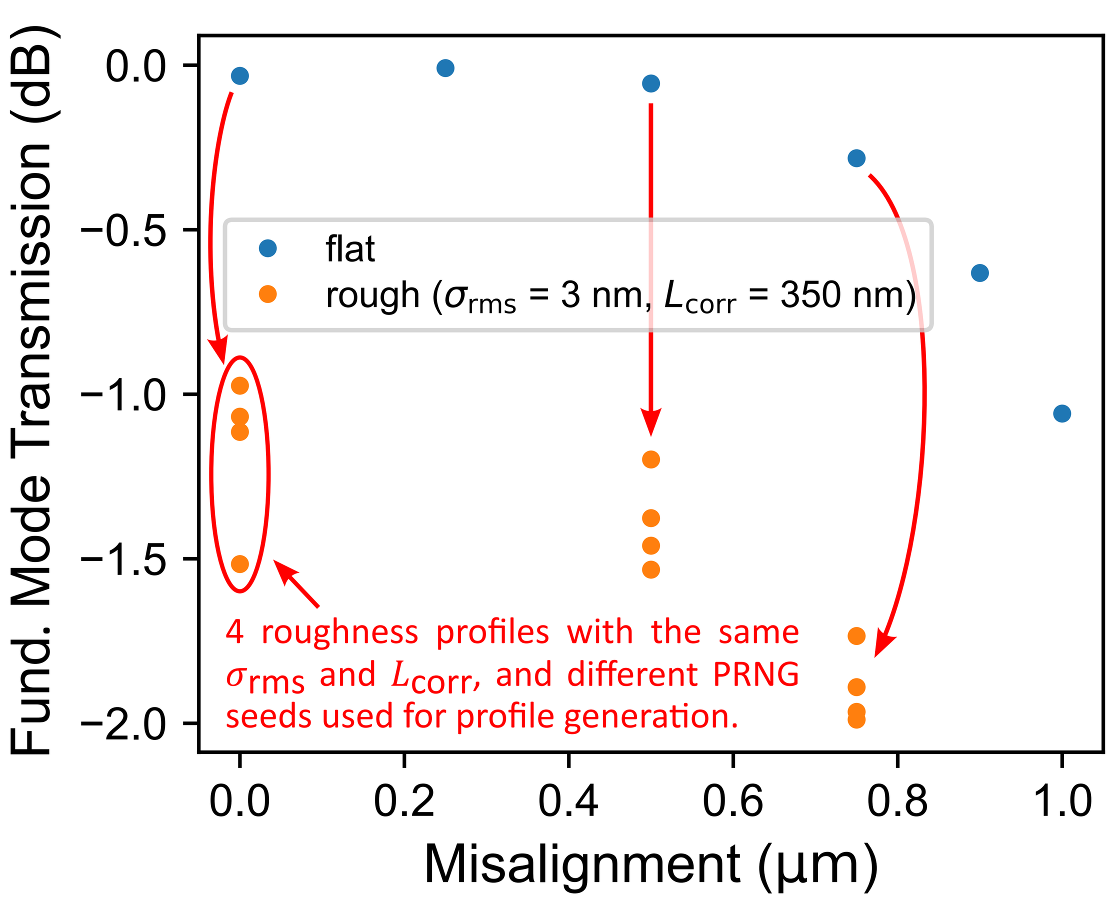
- An increase in roughness RMS value (σ_{rms}) or a decrease in correlation length (L_{corr}) leads to a substantial increase in propagation losses (left and right fig.).
- **A first experimental estimate** of σ_{rms} (~3 nm) and propagation loss (50-70 dB/cm) corresponds to correlation lengths in the range of 260-300 nm in simulations (right fig.).



- **Employing a longer wavelength** (1300 nm) and correspondingly wider WG (450 nm), such that it still remains single-mode, has a significant impact on performance, resulting in lower losses for shorter correlation lengths (left fig.).
- **Wider WGs** exhibit lower losses than narrower WGs, however, simulation results indicate an increase in losses towards the largest WG width considered (right fig.).

GaAs-SiN Coupling Loss simulation results





- **Fundamental mode transmission of an adiabatic SiN-GaAs coupler** drops from nearly 0 dB to around -1.2 dB in case of no micro-transfer-printing-induced misalignment, considering a σ_{rms} of 3 nm and L_{corr} of 350 nm.

Conclusions

- In rough GaAs WGs with σ_{rms} of a few nm and L_{corr} below a few hundred nm very high losses (above 100 dB/cm) are predicted.
- A wider WG and longer operating wavelength can result in substantially lower loss in case of short correlation lengths.
- GaAs WG sidewall roughness can cause significant degradation of the performance of an adiabatic SiN-GaAs coupler.

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