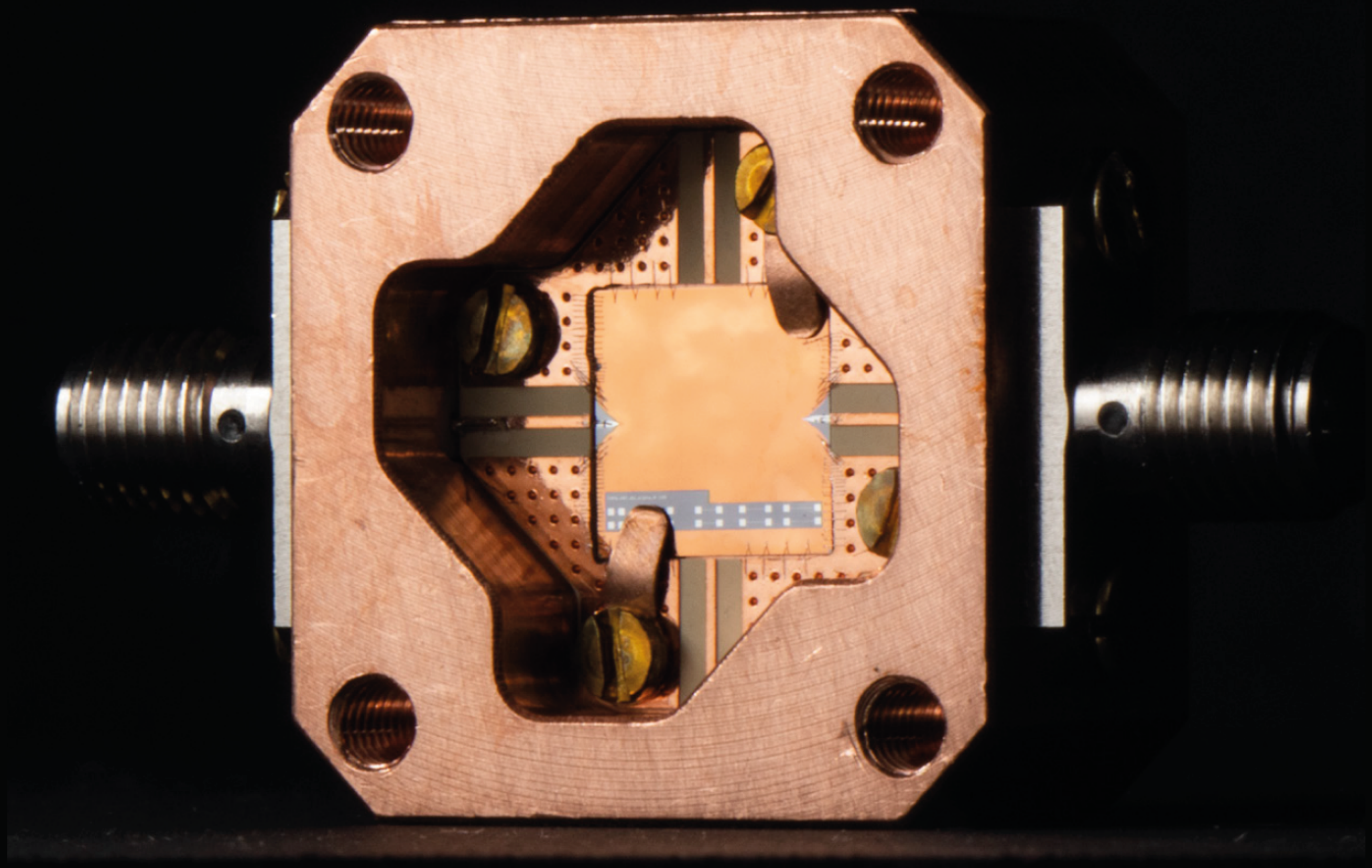
Introduction to
Traveling Wave Parametric Amplifiers (TWPA)



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NÉEL institut

UGA

Quantum Engineering
Univ. Grenoble Alpes

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MARIE CURIE ACTIONS

erc
European Research Council
Established by the European Commission

PROGRAMME ET
EQUIPEMENTS
PRIORITAIRES
DE RECHERCHE
QUANTIQUE

ROBUST
SUPERQ

TruePA

AVaQus

anr

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Outline

Introduction

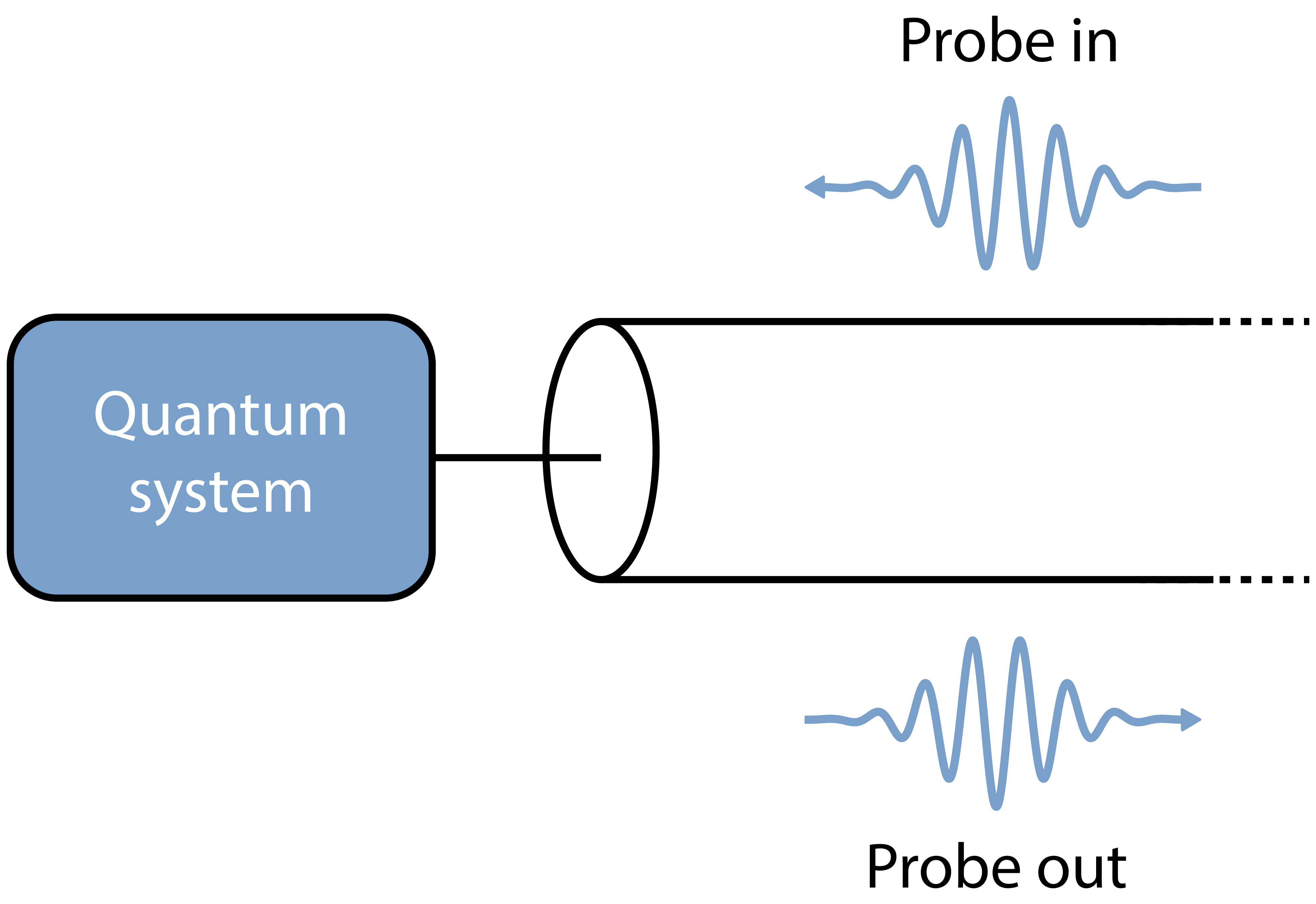
TWPA: microscopic derivation

TWPA: gain and phase matching

TWPA: noise performances

TWPA Fabrication

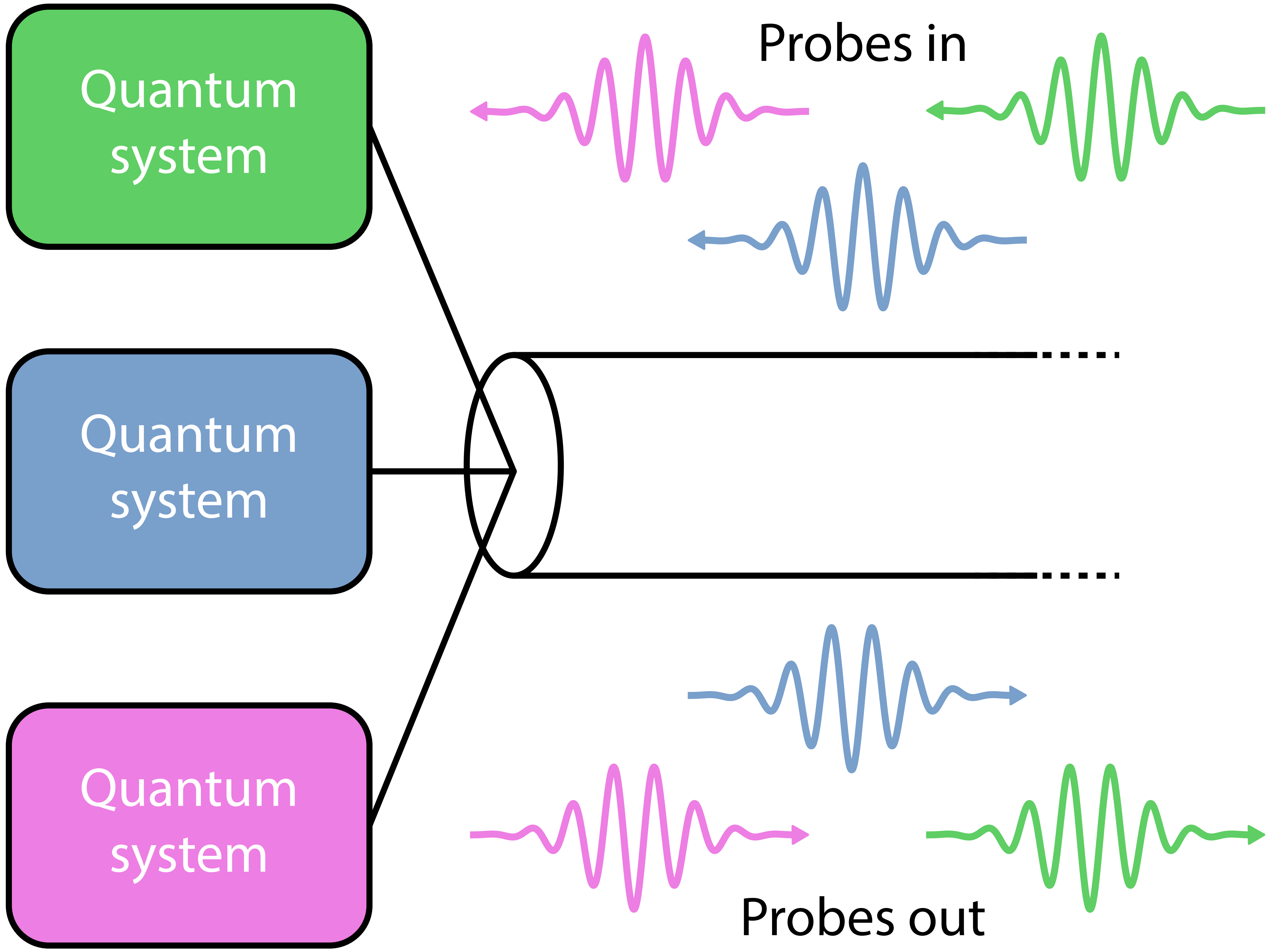
Use-case: ultra low noise amplification



Very low energy (quantum) systems

Probe: few photons

Use-case: ultra low noise amplification



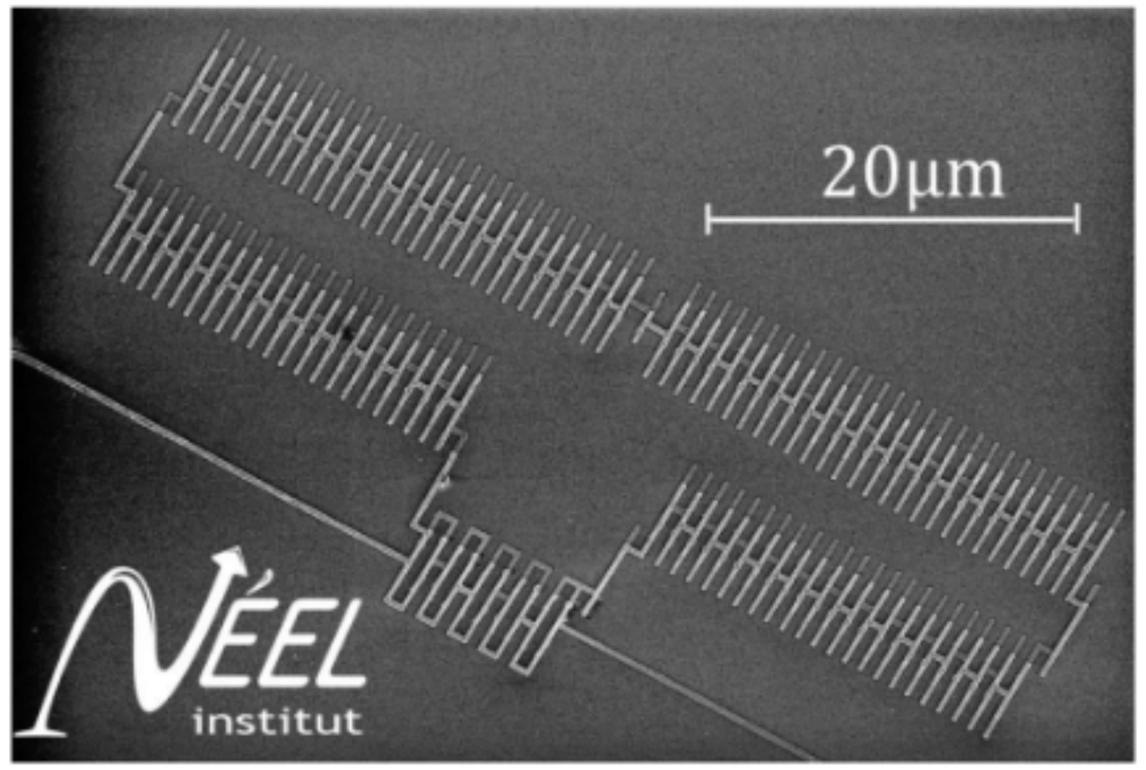
Very low energy (quantum) systems

Probe: few photons

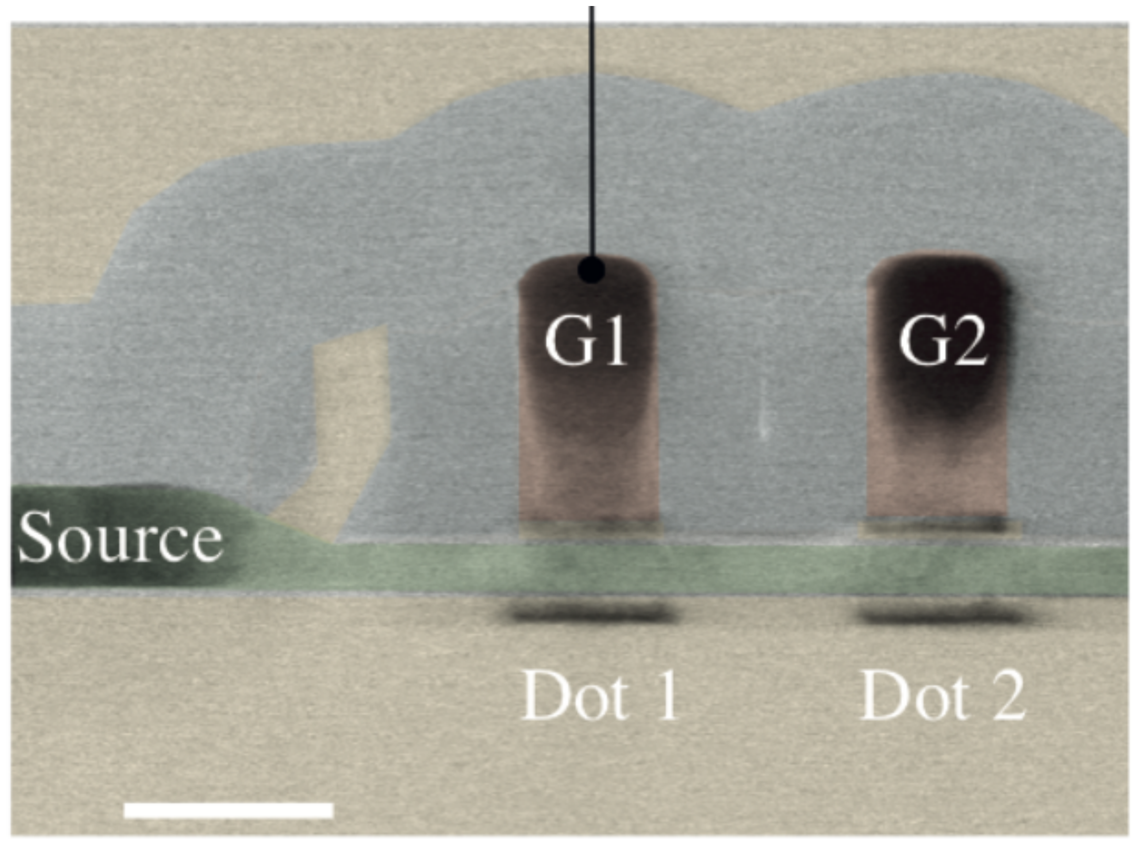
Several quantum systems
or frequency difficult to predict

Need high amplification, low noise AND large bandwidth

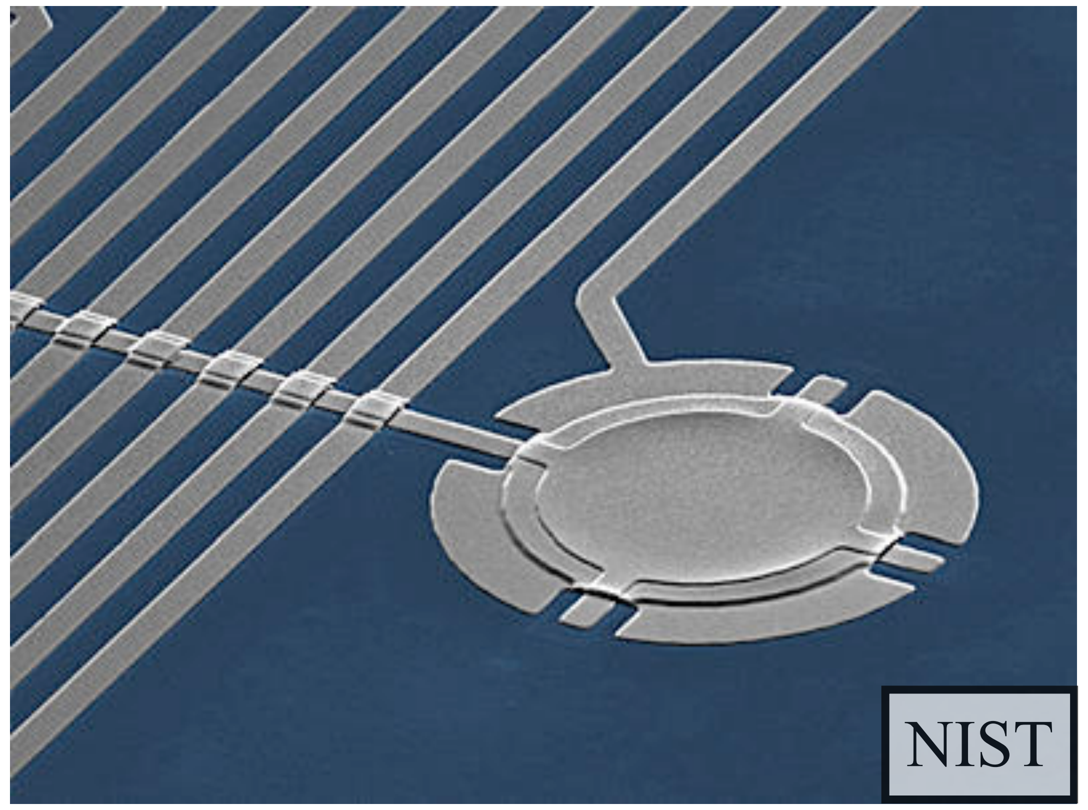
Ultra low noise amplification: applications



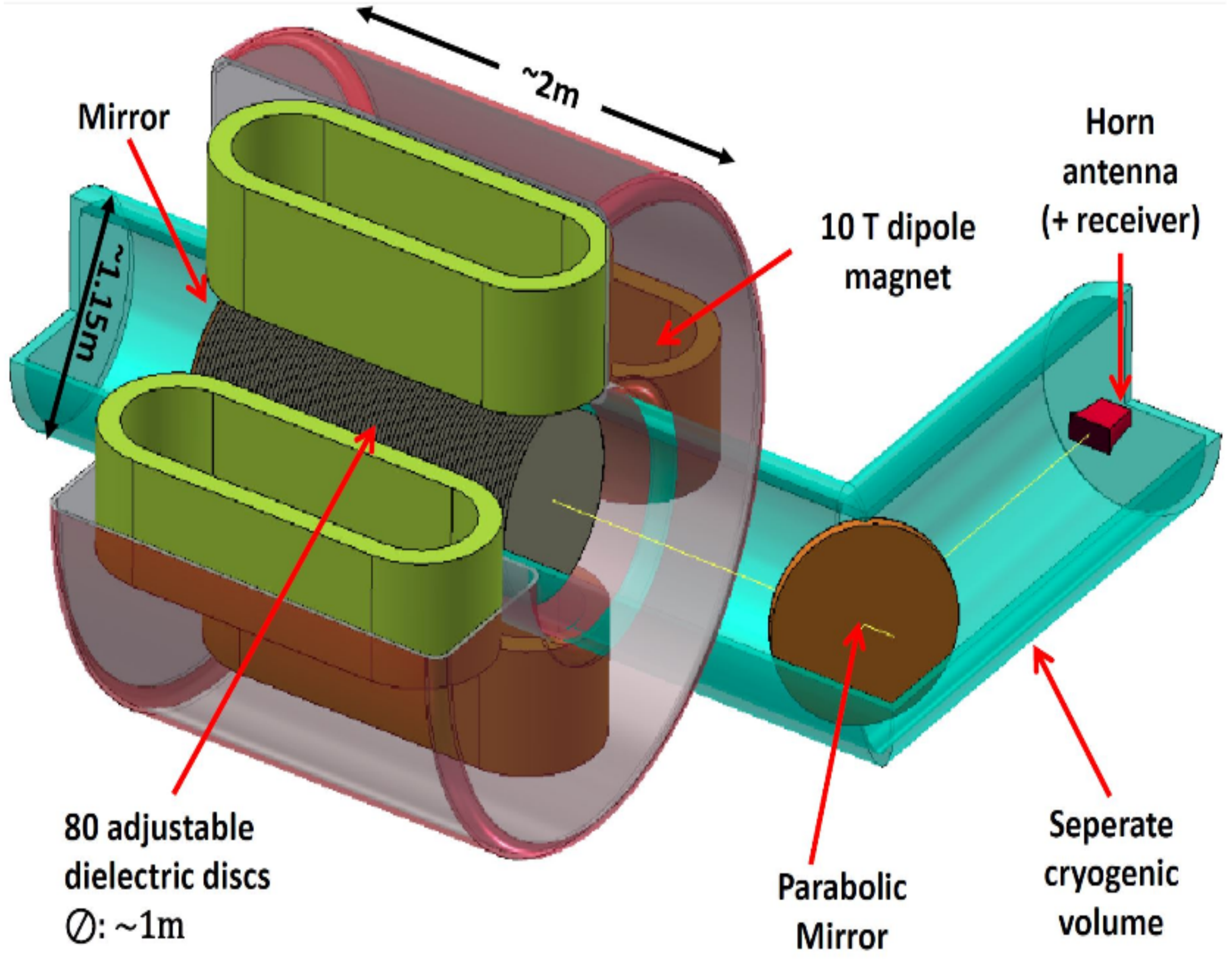
Superconducting Qubits



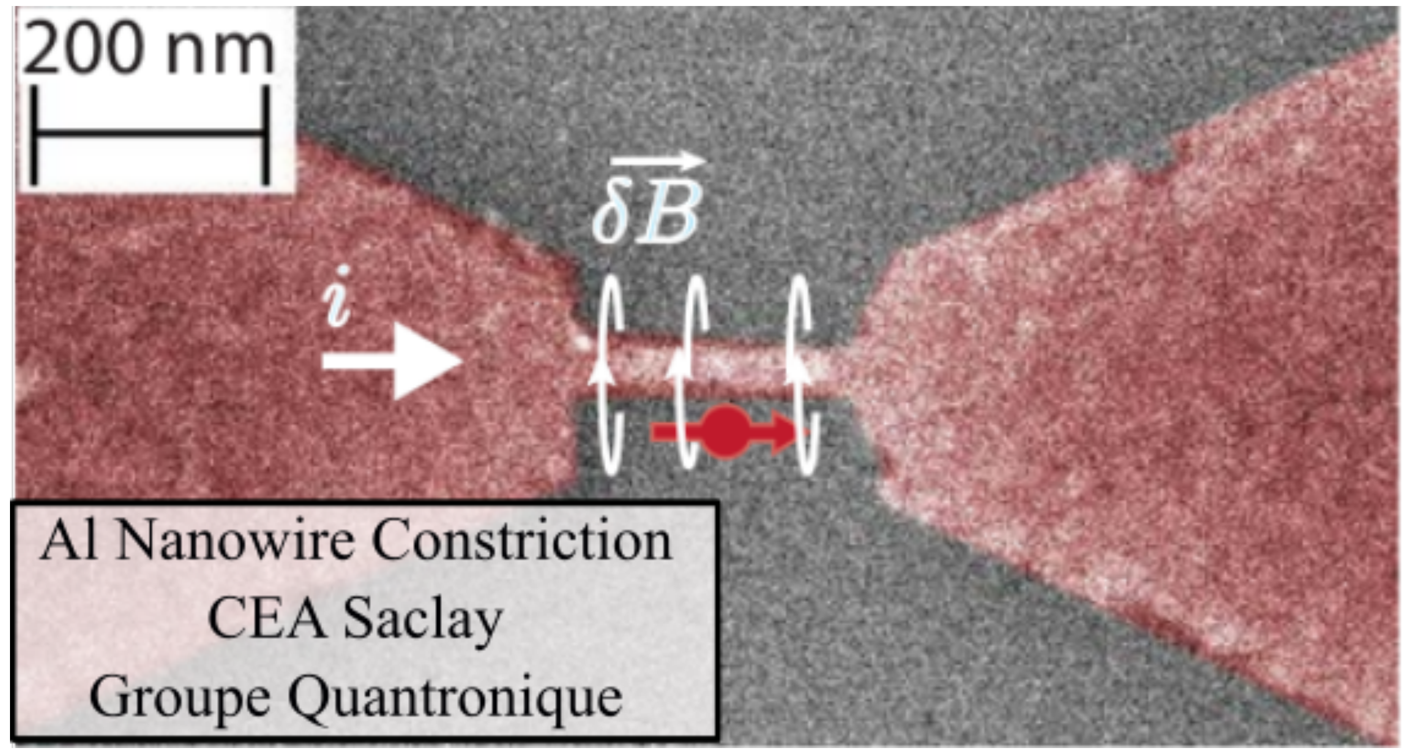
Spin Qubits



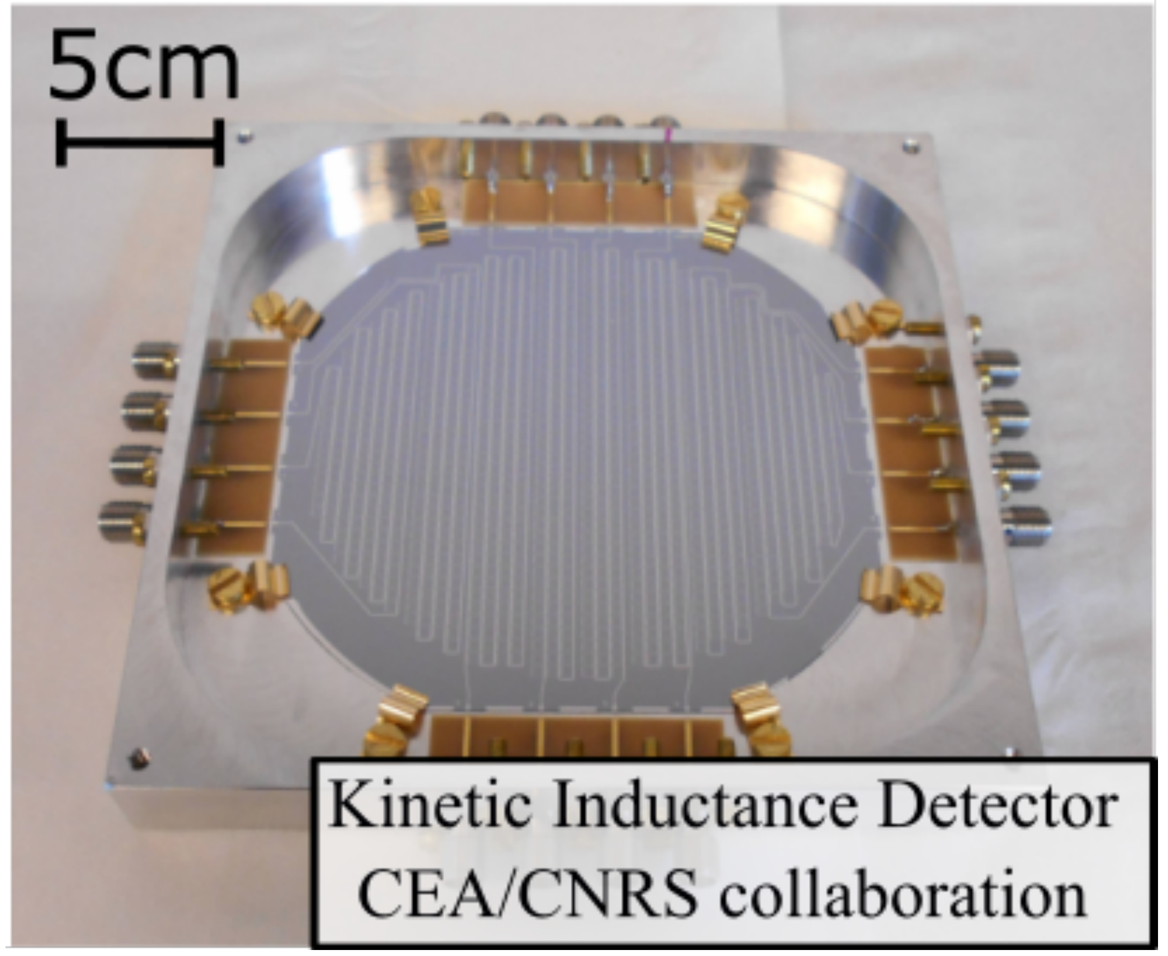
Electromechanical Circuits



Dark matter detection

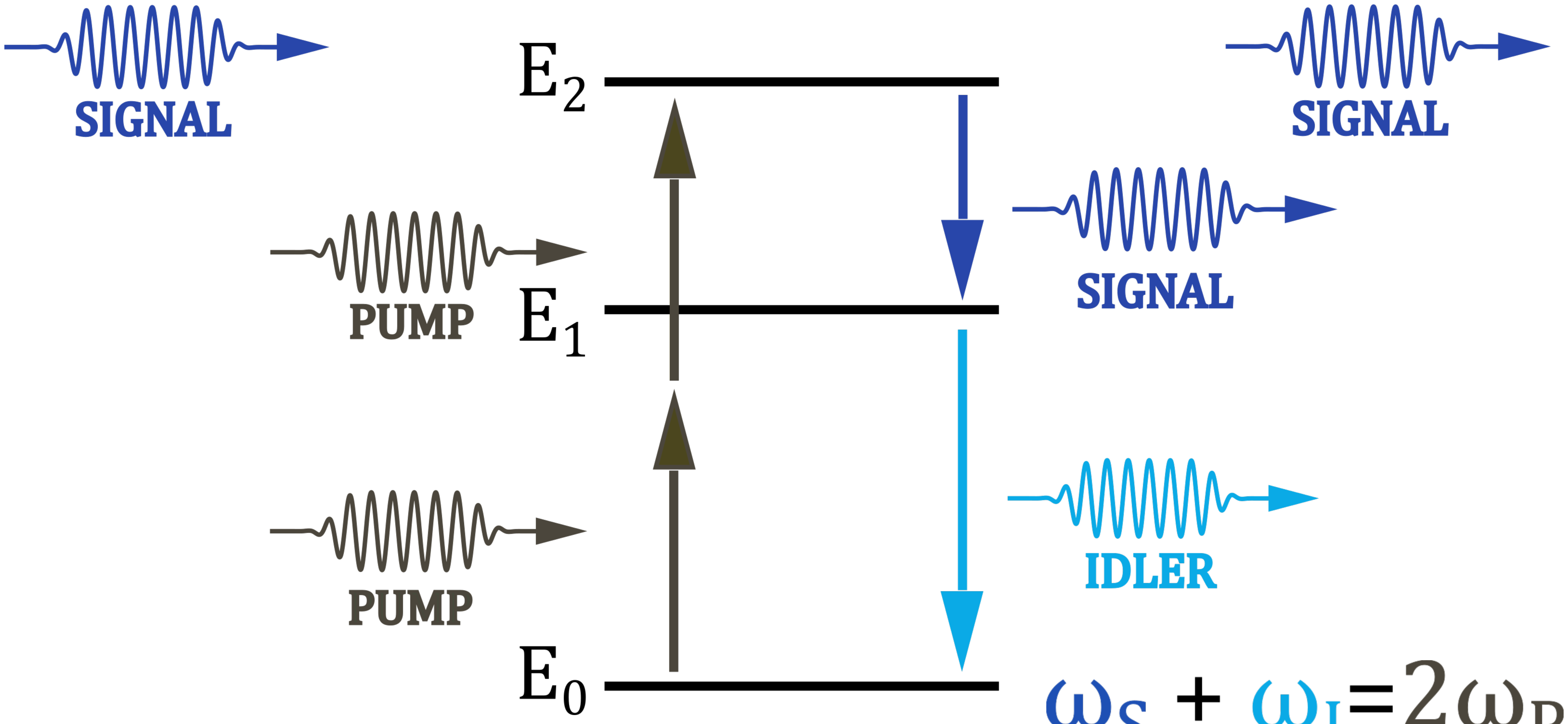


Q-limited ESR



Astrophysics detectors

Parametric amplifiers:
quantum optics point of view

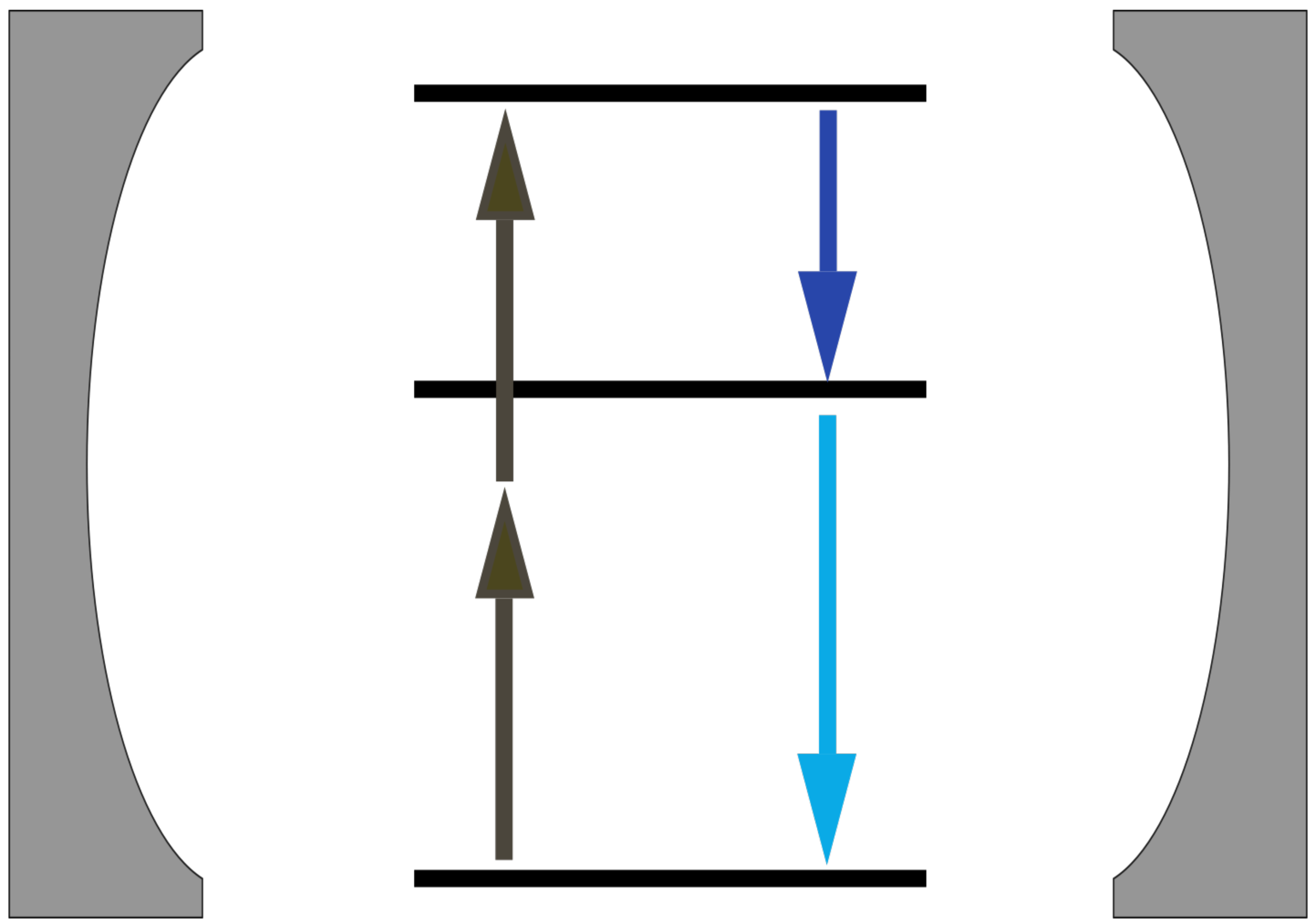


$$\omega_S + \omega_I = 2\omega_P$$

Four wave mixing

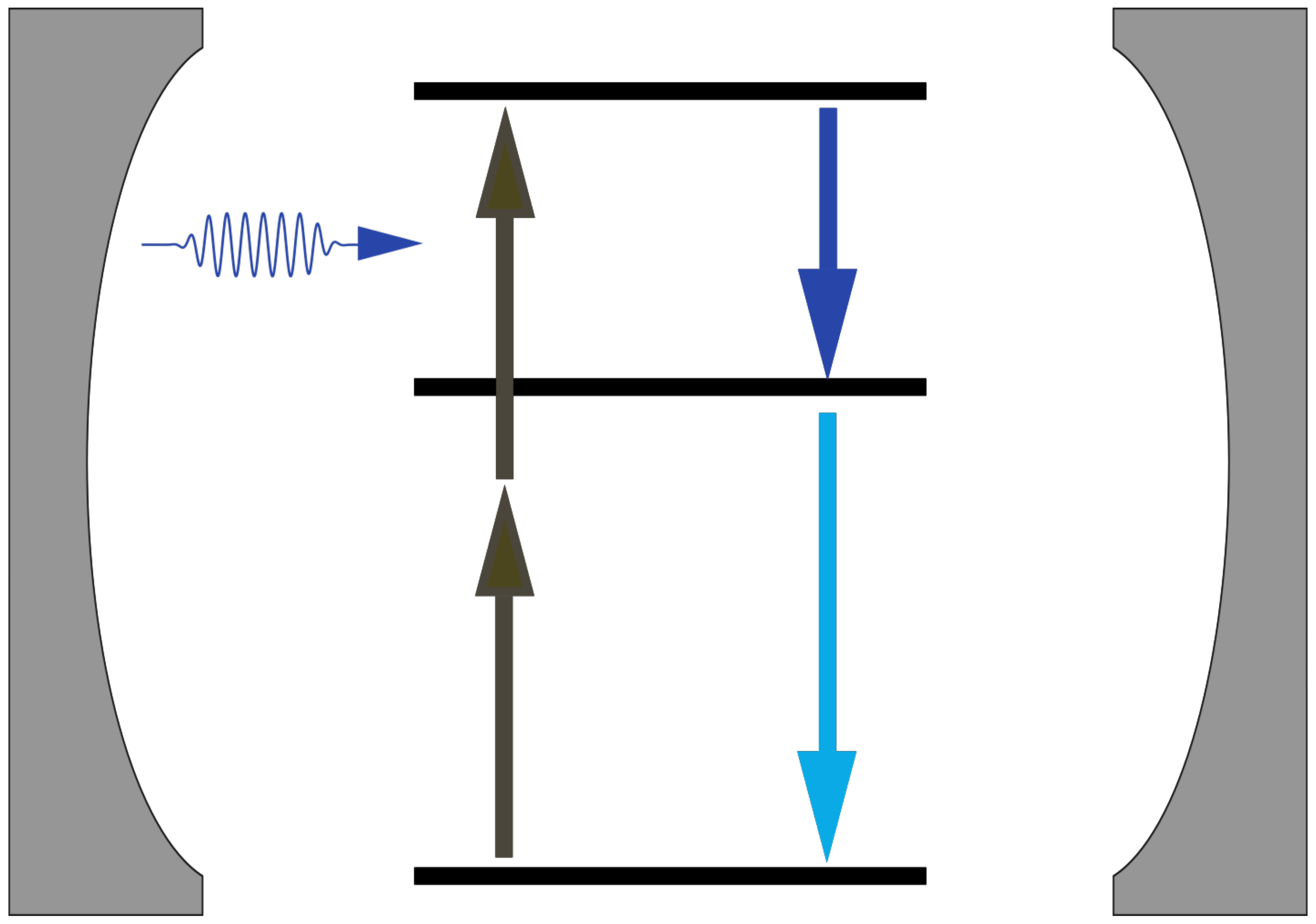
Resonant parametric amplification

Interaction time $\propto$ 1/cavity bandwidth



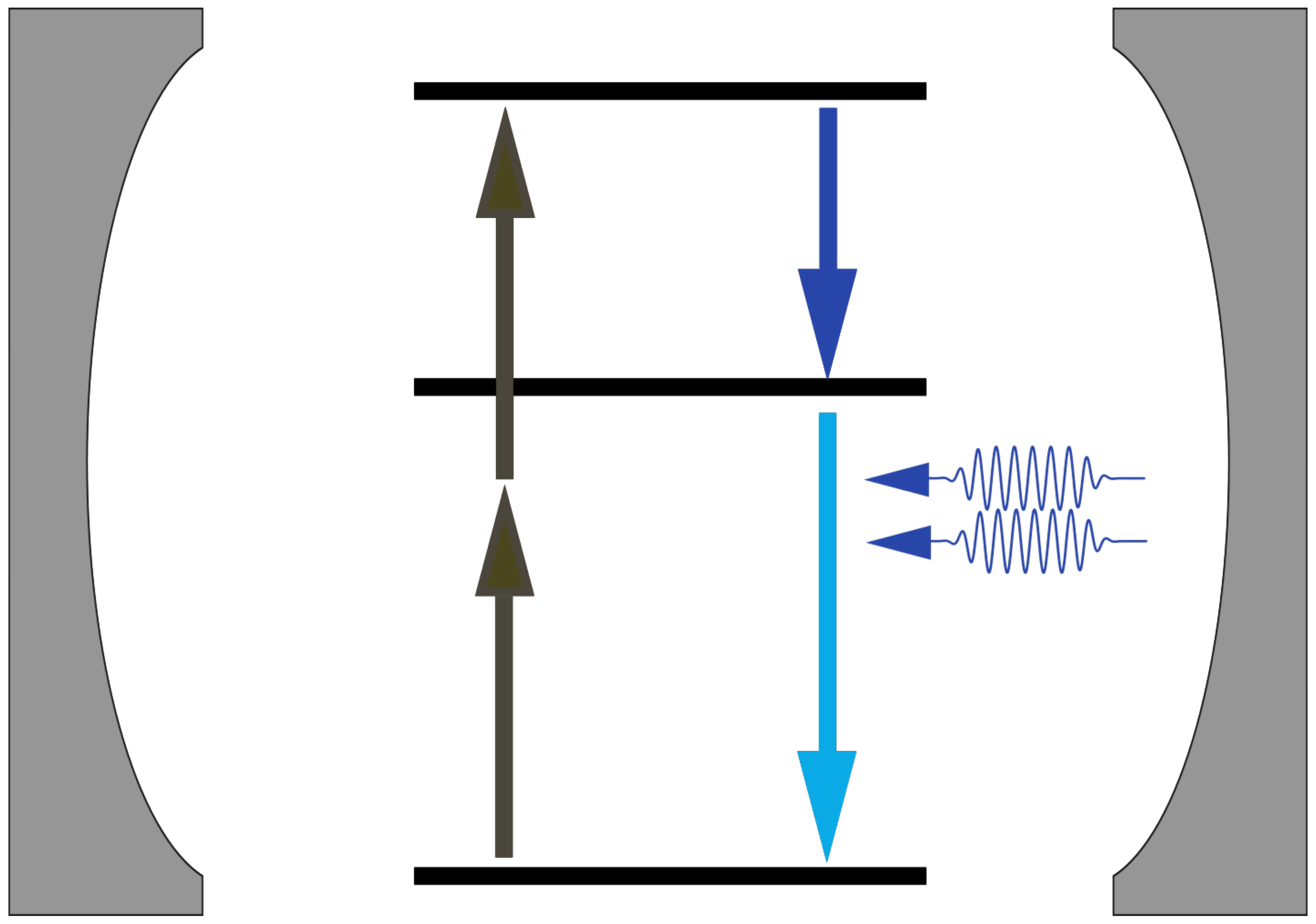
Resonant parametric amplification

Interaction time $\propto$ 1/cavity bandwidth



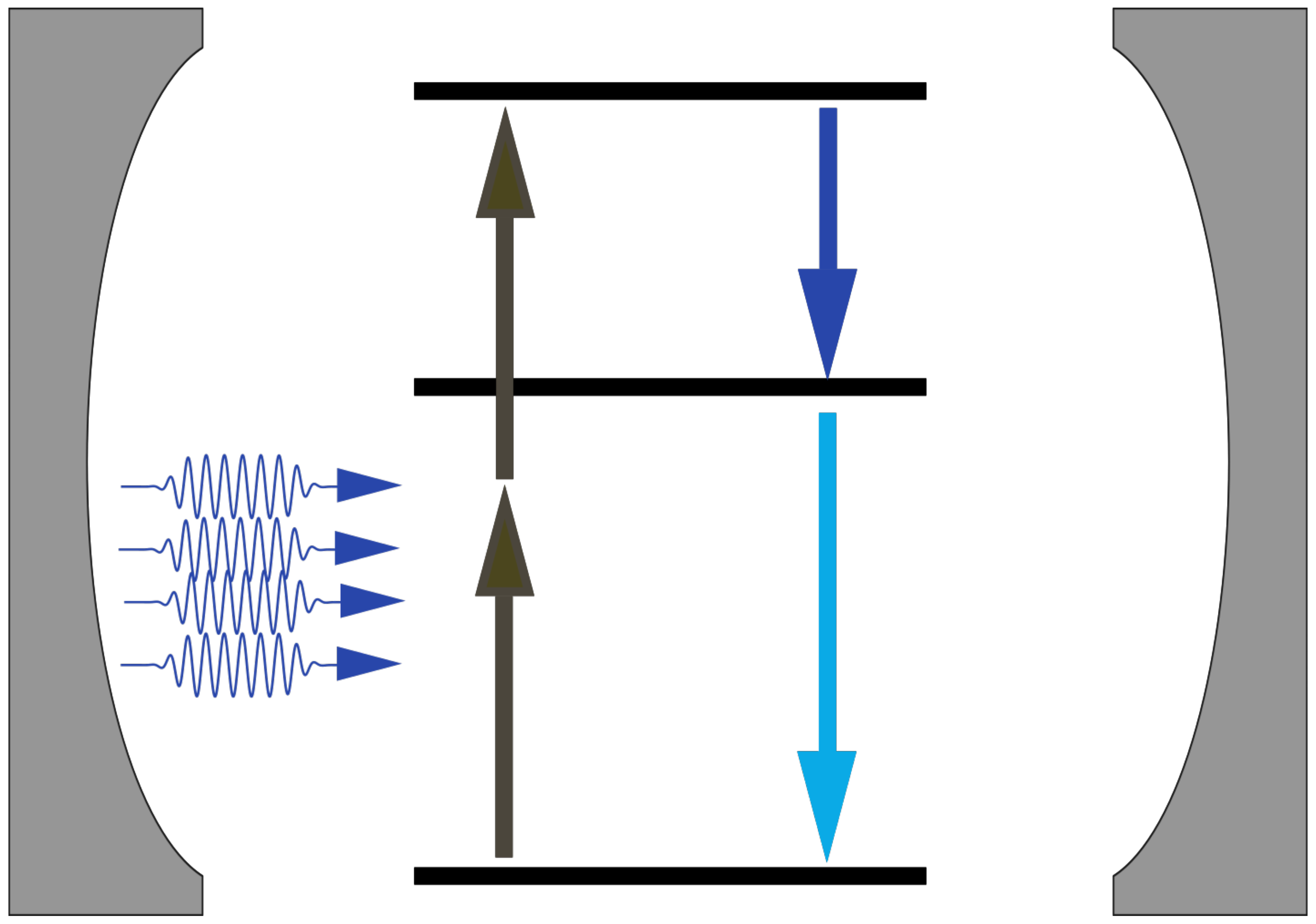
Resonant parametric amplification

Interaction time $\propto$ 1/cavity bandwidth



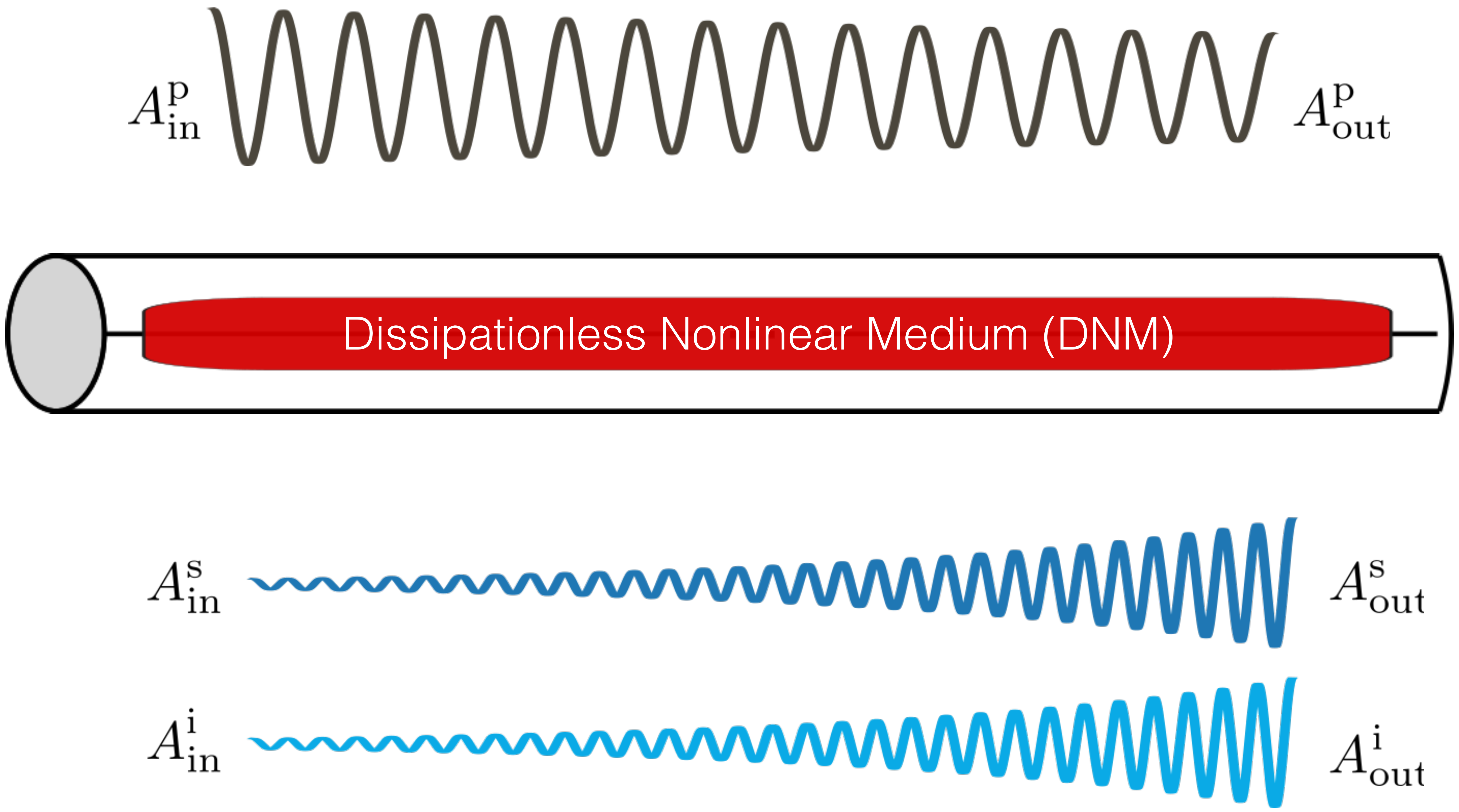
Resonant parametric amplification

Interaction time $\propto$ 1/cavity bandwidth

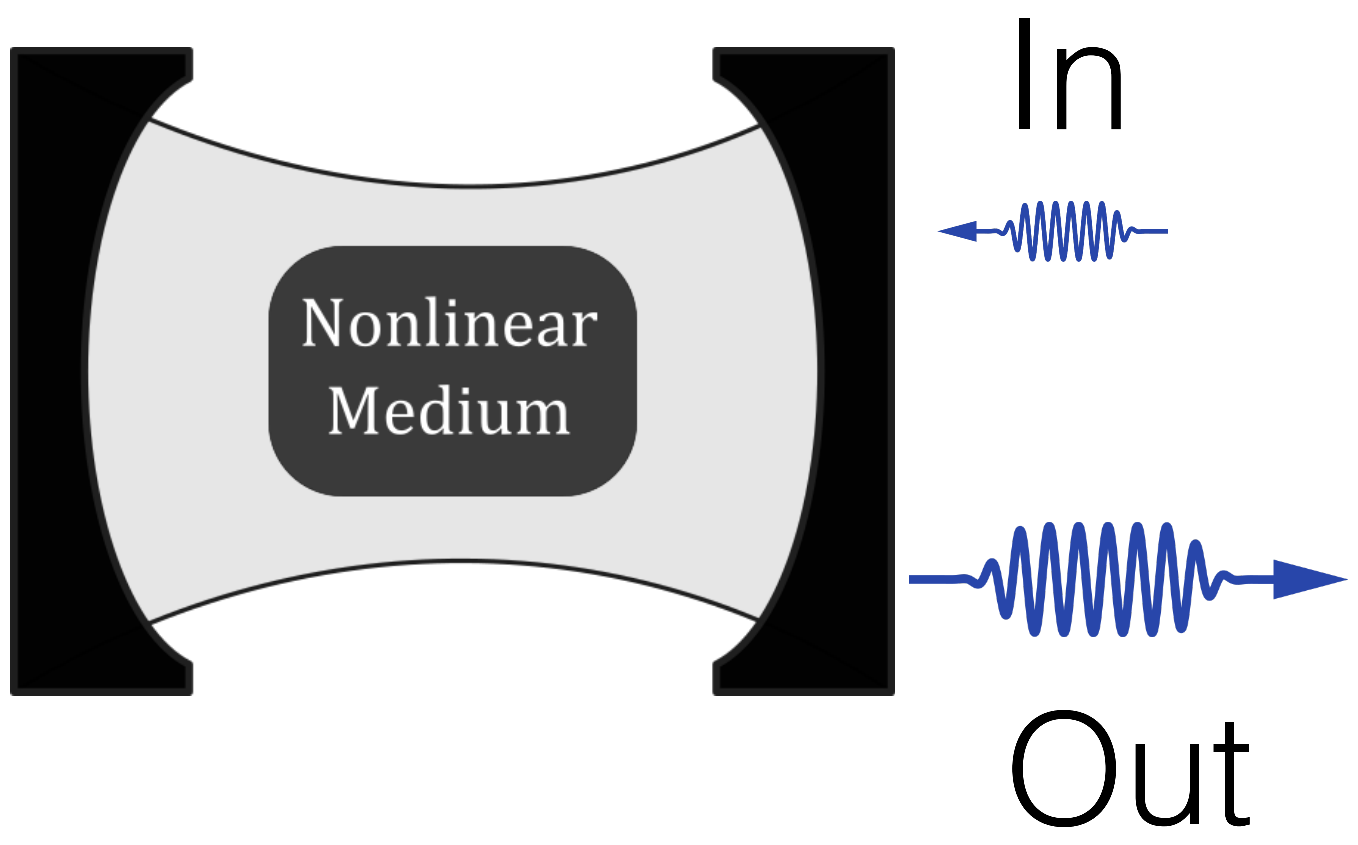


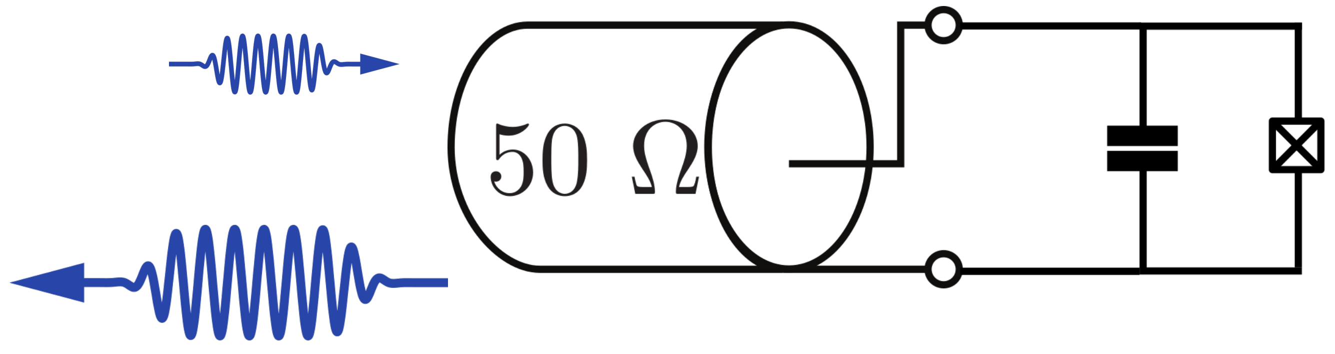
Traveling wave parametric amplification

$$\text{Interaction time} \propto \frac{\text{Medium length}}{\text{Wave velocity}}$$

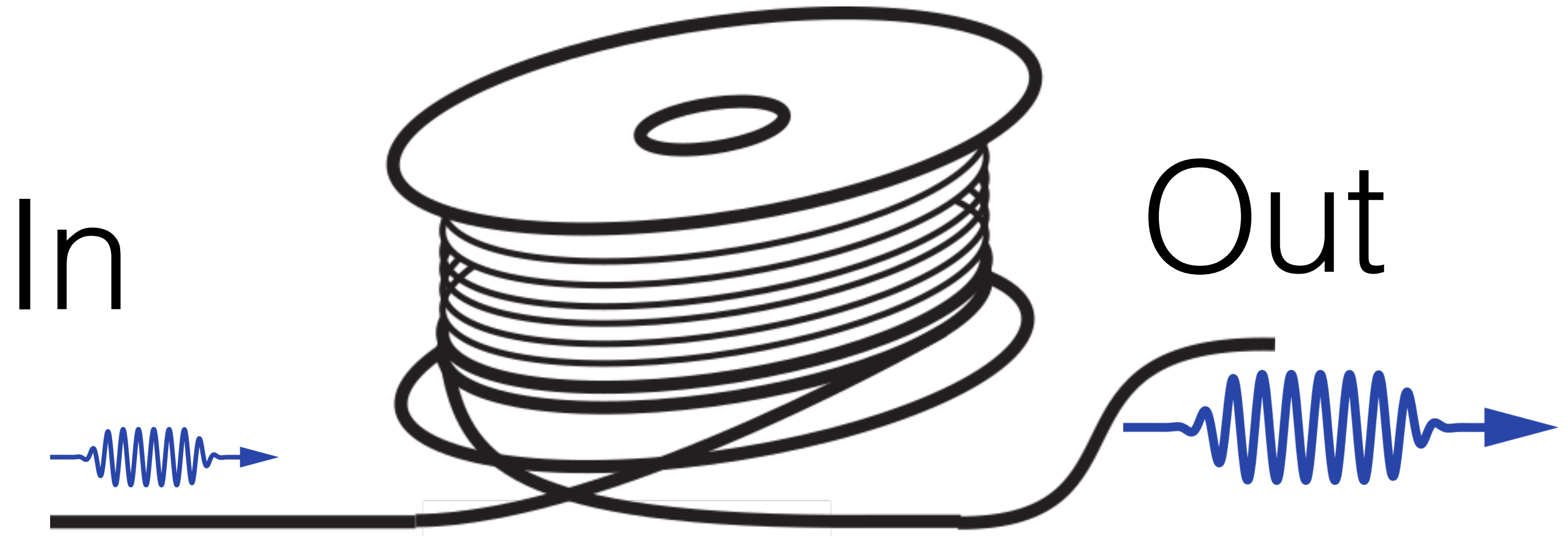


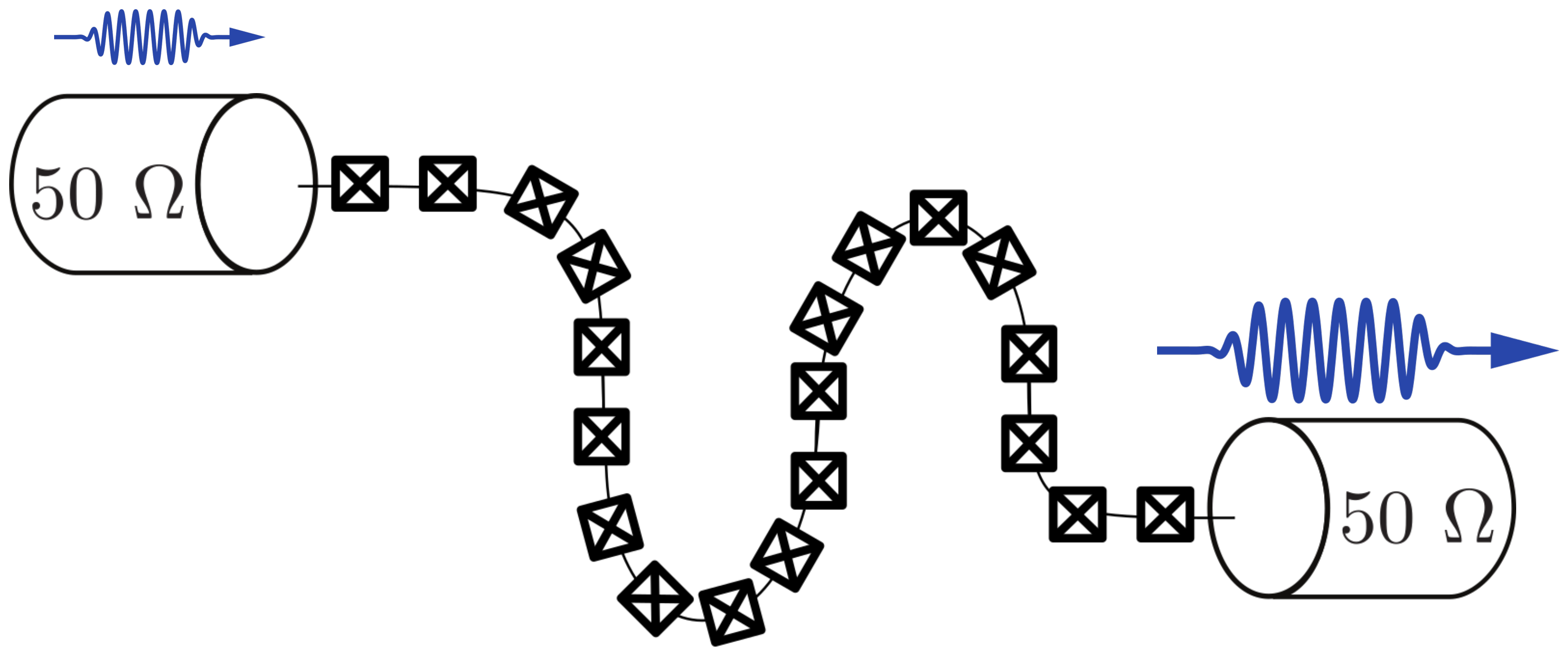
Resonant vs Traveling-wave





✓ Low Noise x Narrow bandwidth





✓ Low Noise ✓ Broadband

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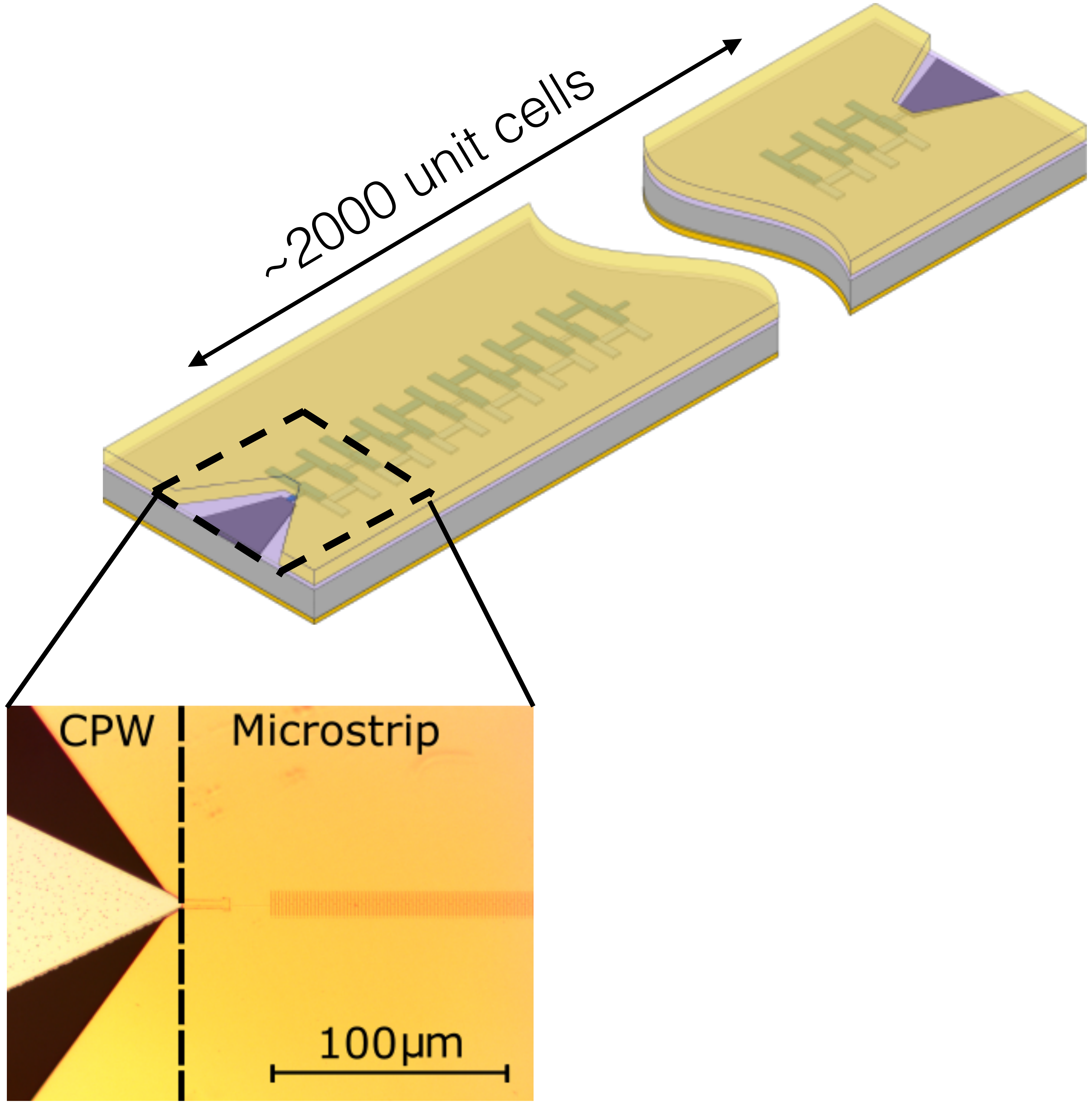
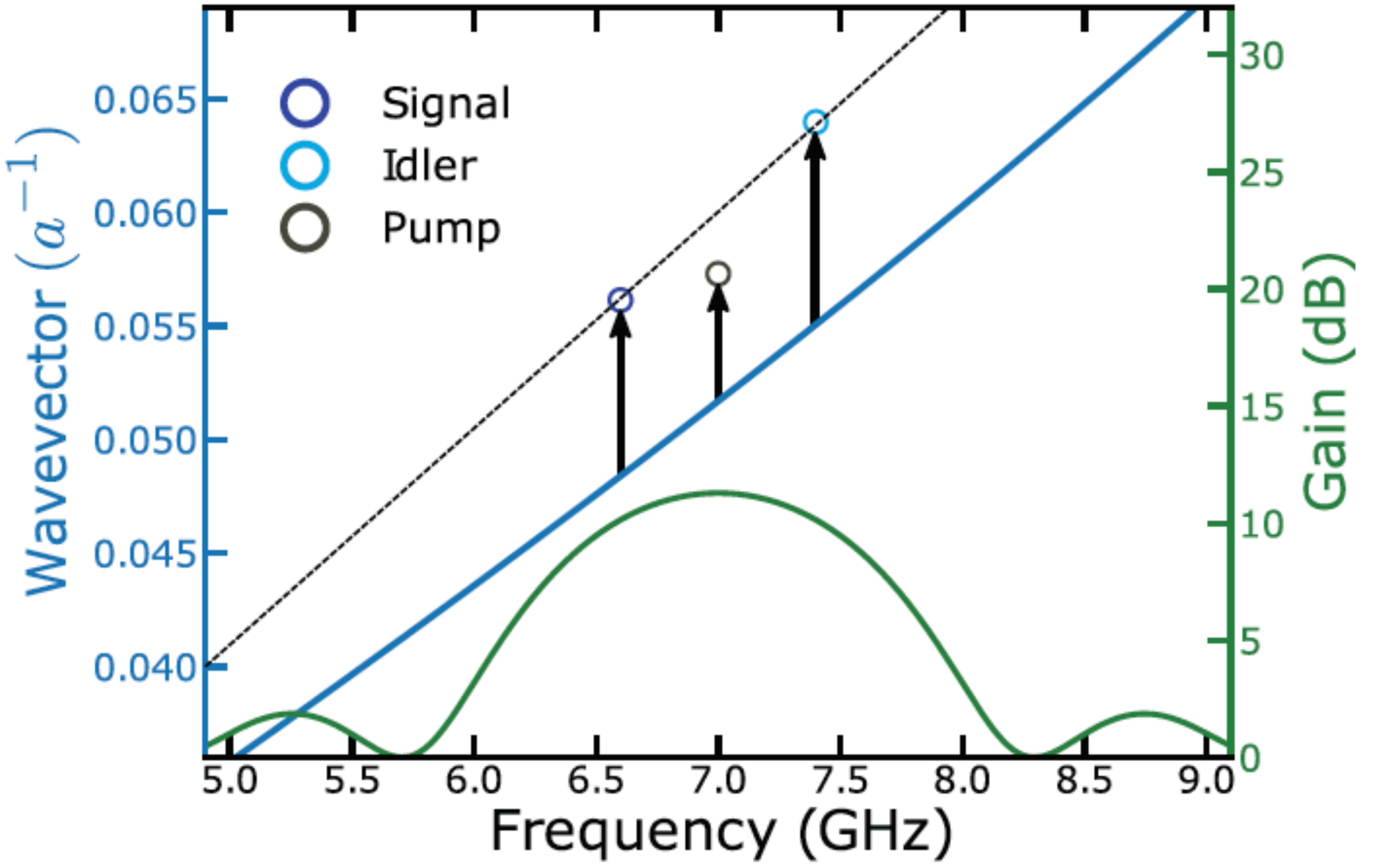
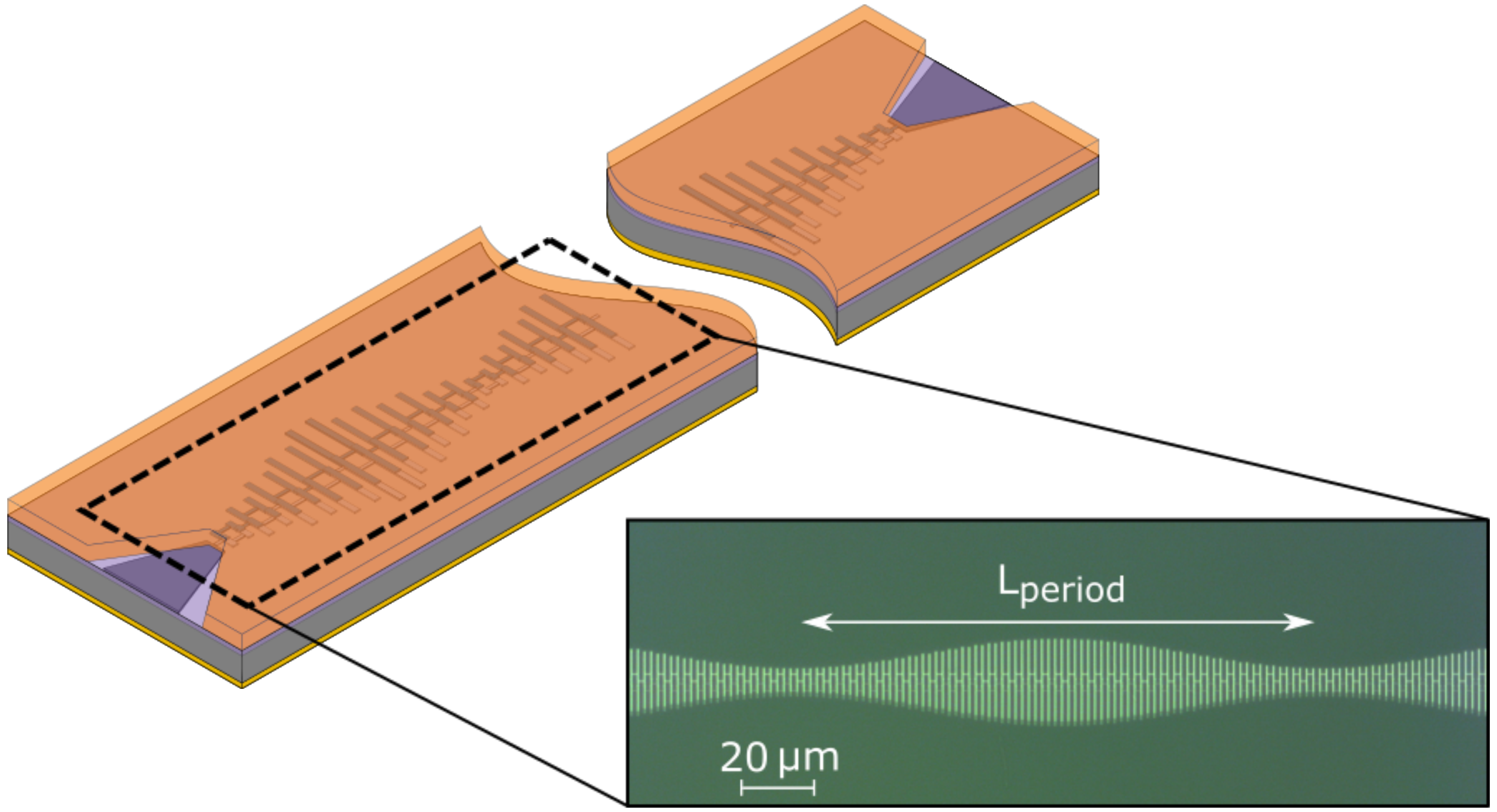
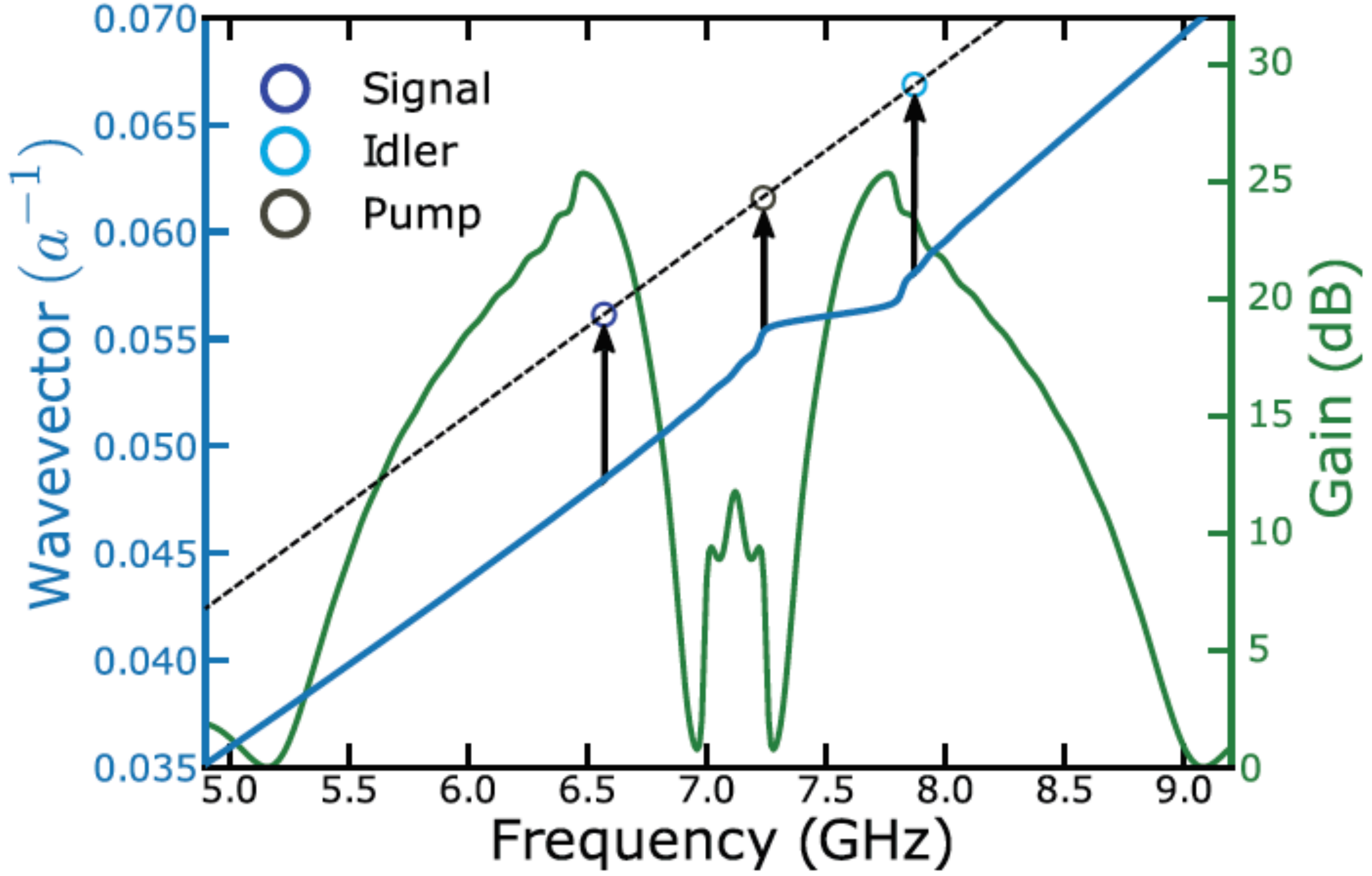




Poor phase matching: limited gain

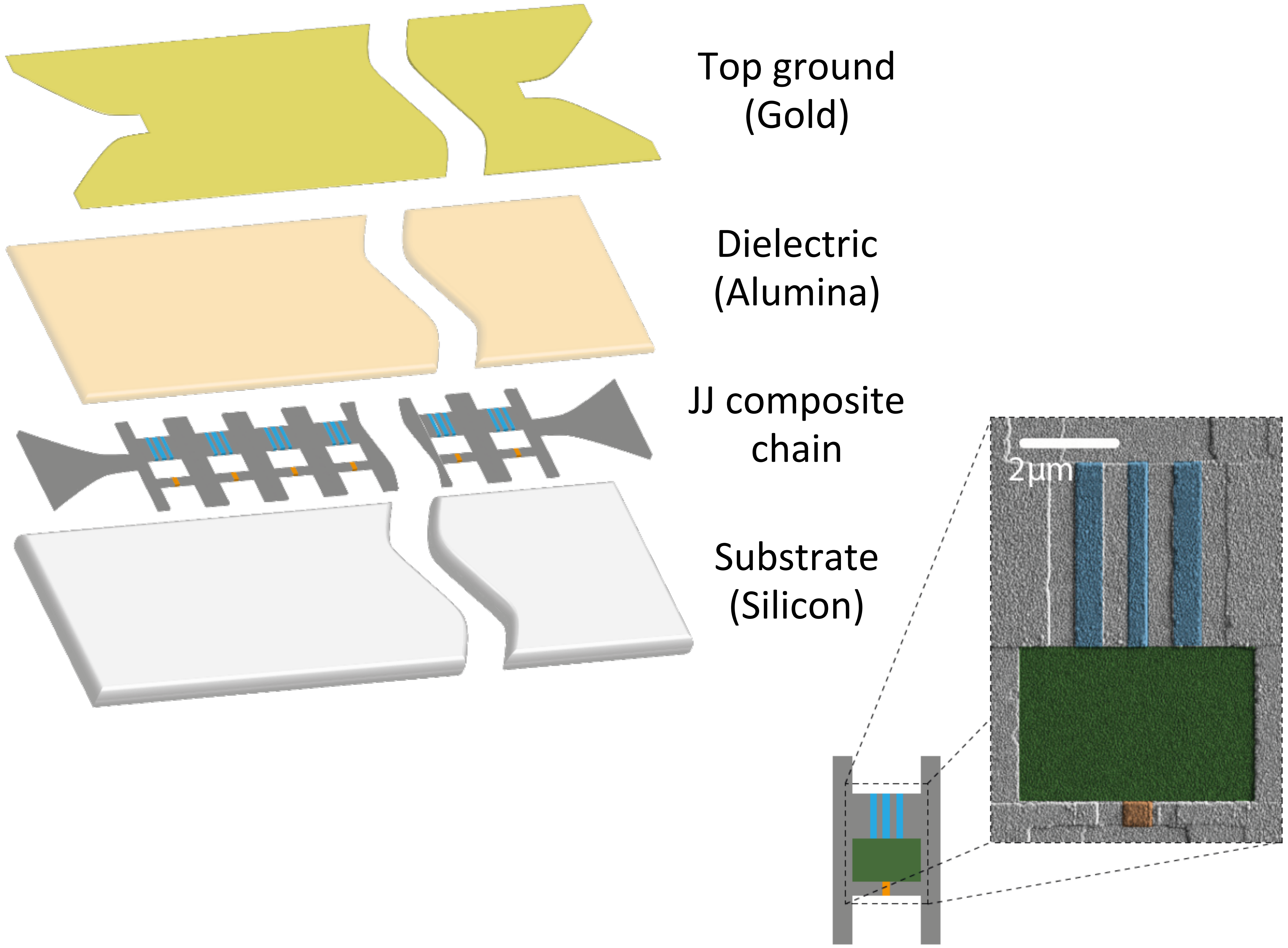
TWPA: gain and phase matching

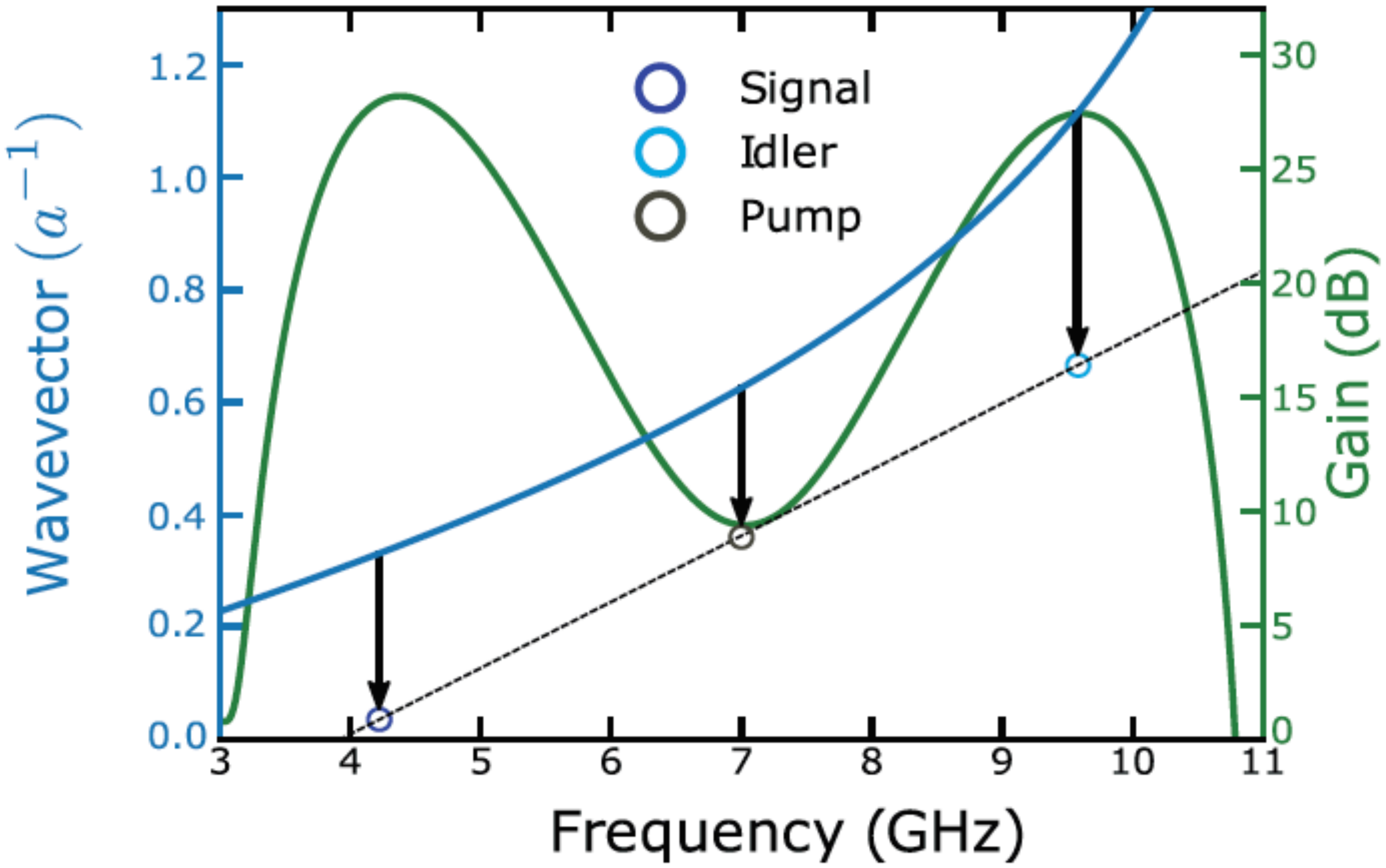




Phase matching using band engineering

TWPA: gain and phase matching





Phase matching using engineered non-linearity: SNAIL TWPA

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Quantum limited amplifiers: noise performances

Standard Quantum Limit (SQL)

$$T_N \geq \frac{\hbar\omega}{2k_B} = T_{SQL}$$

C. M. Caves, Phys. Rev. D (1982)

Quantum limited amplifiers: noise performances

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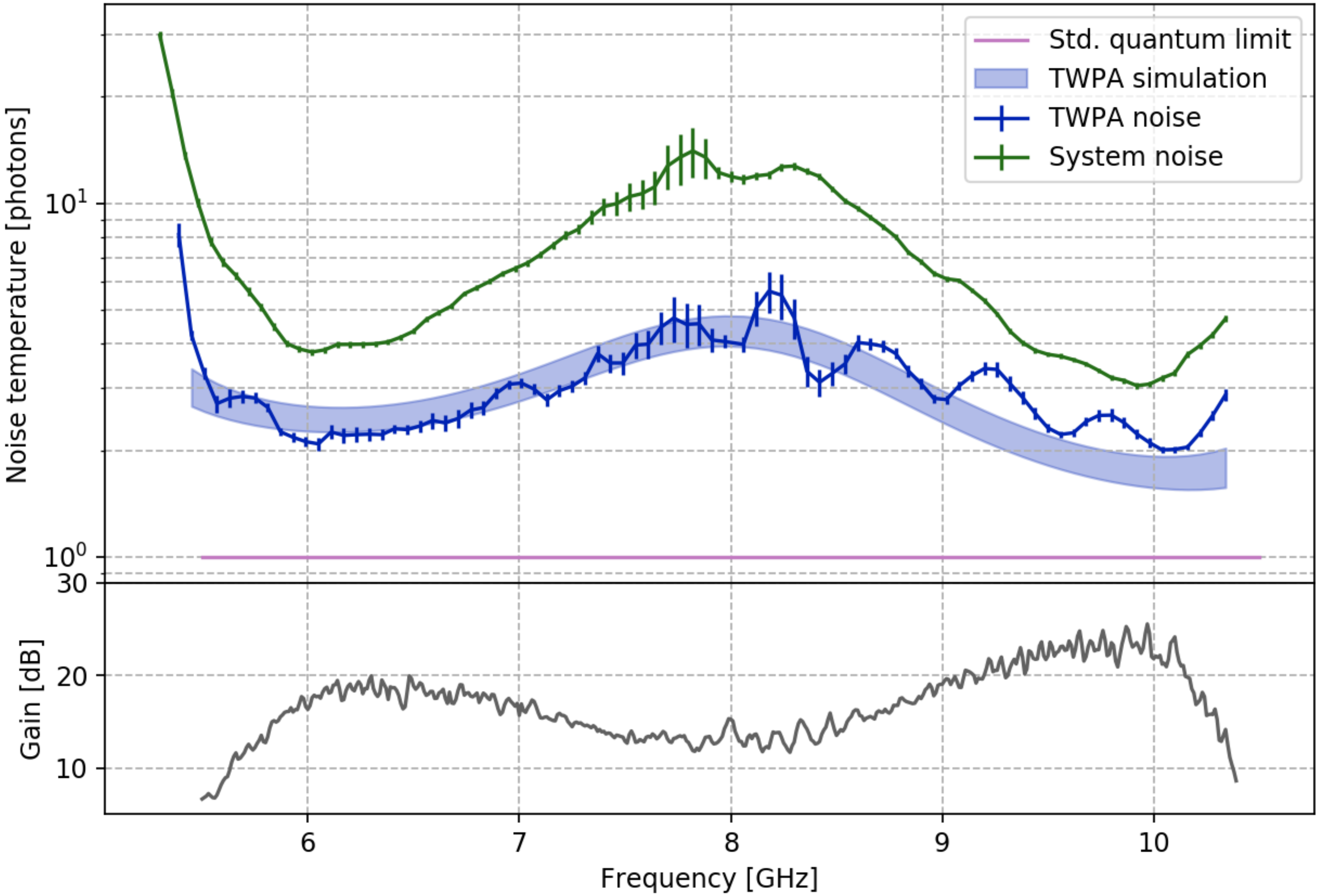

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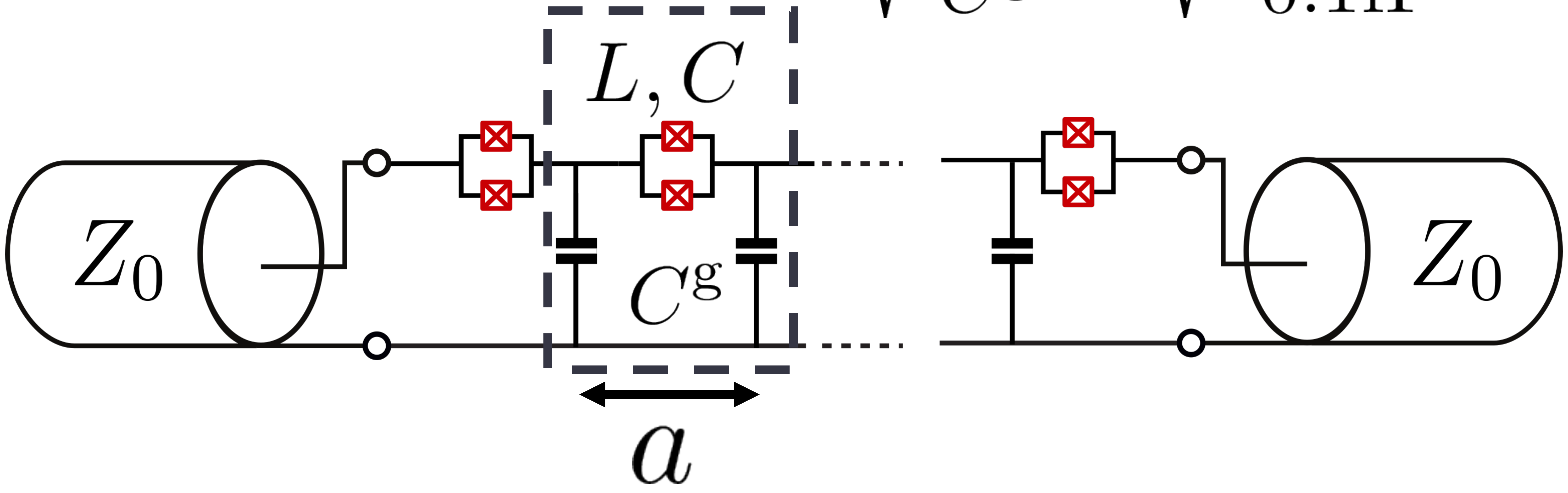
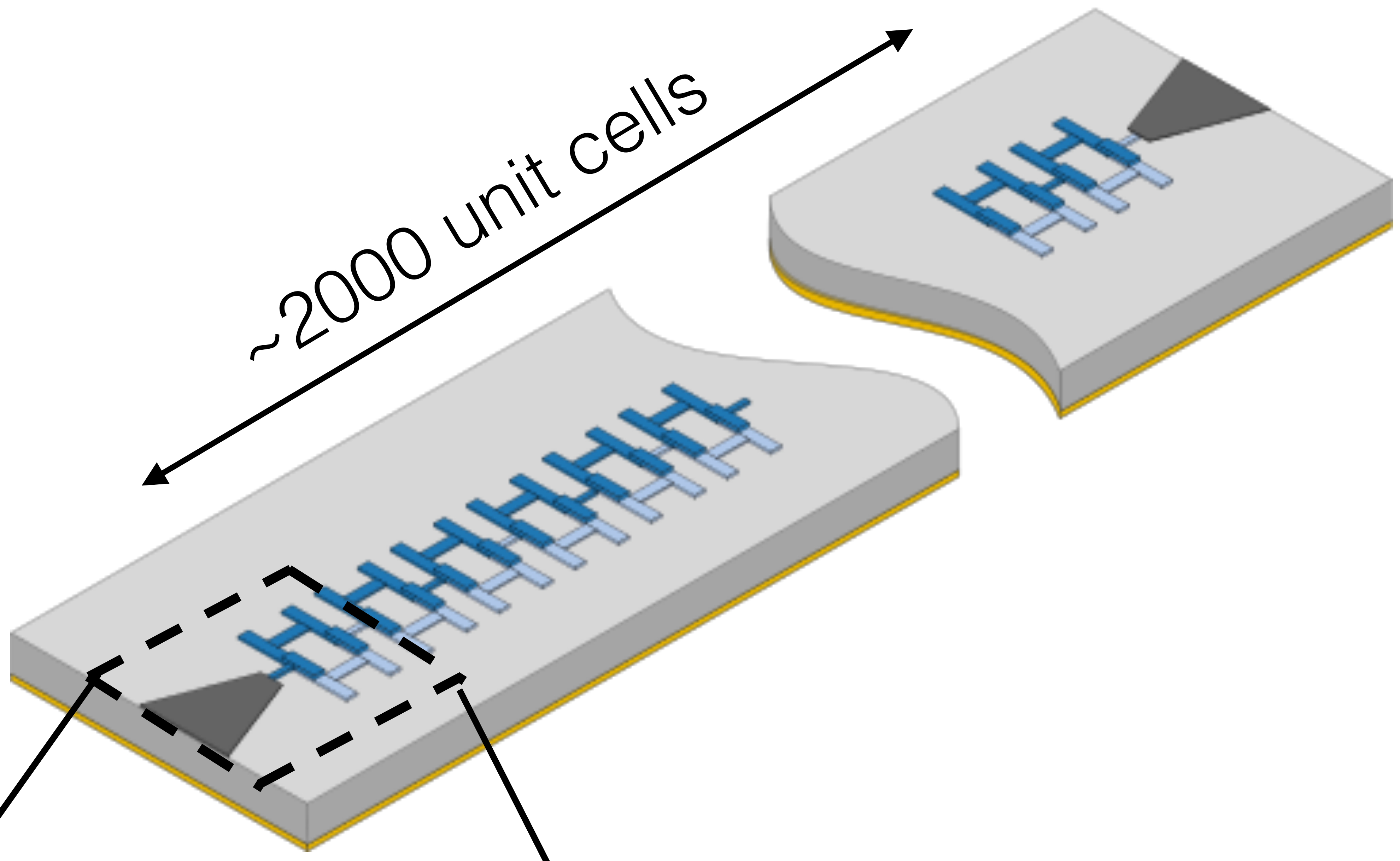
Josephson transmission line: challenge

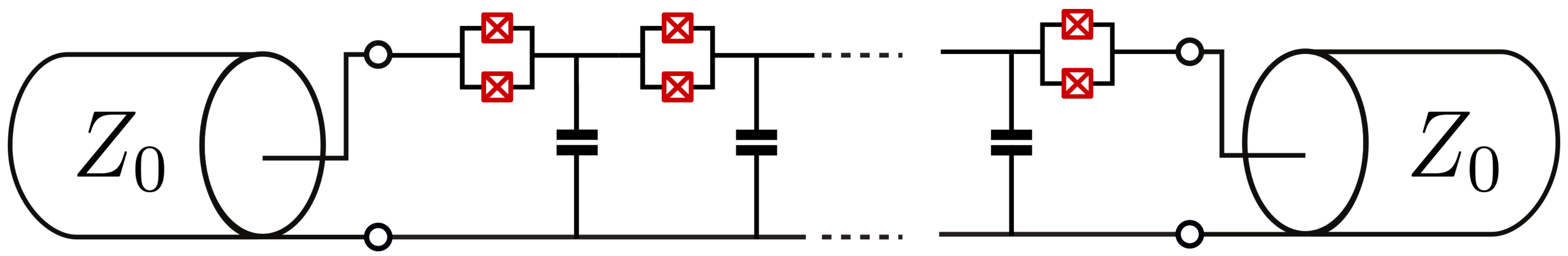
Far from 50 Ohms

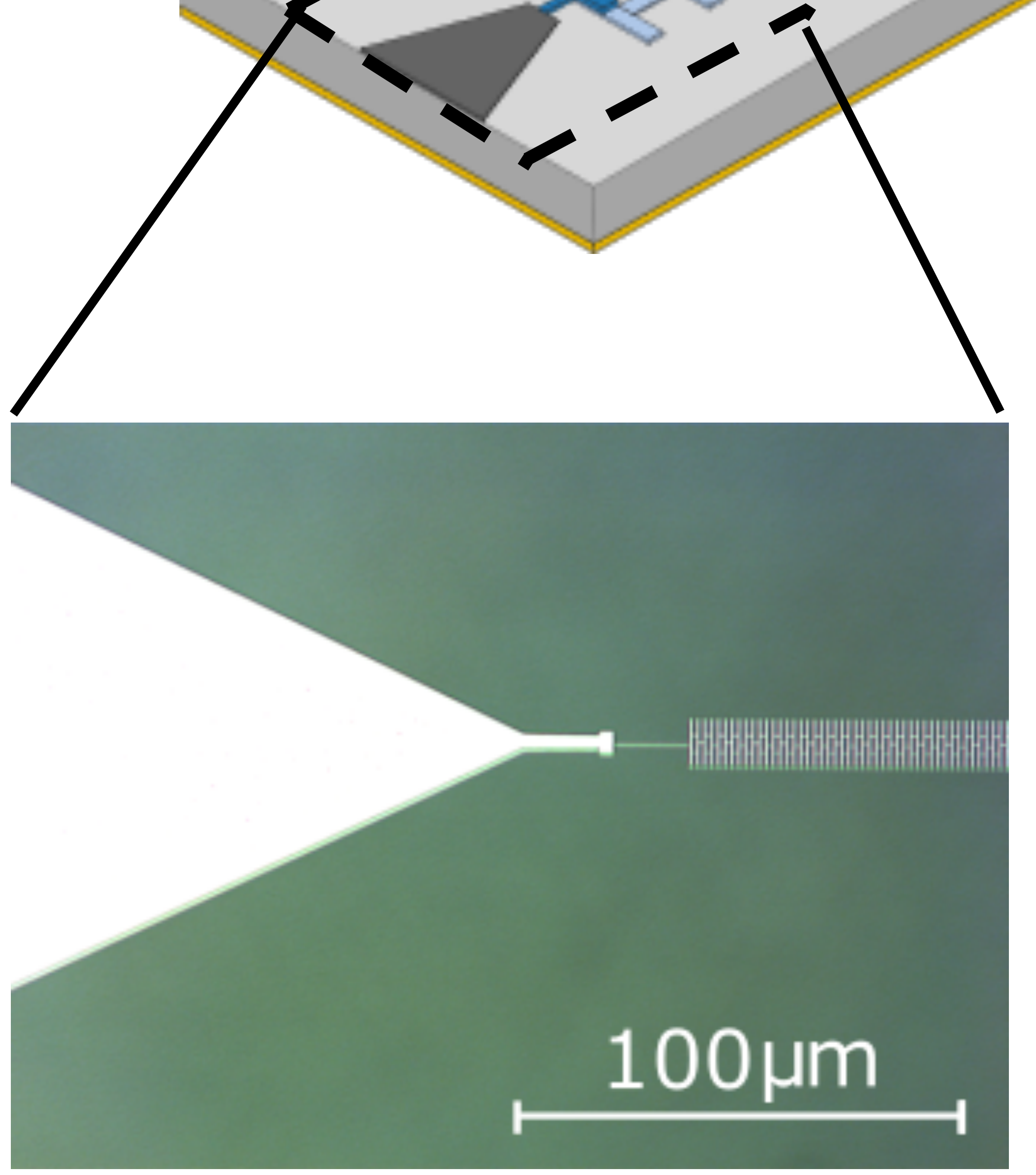
$$Z_c = \sqrt{\frac{L}{C^g}} = \sqrt{\frac{100\text{pH}}{0.1\text{fF}}} \approx \boxed{1\text{k}\Omega}$$



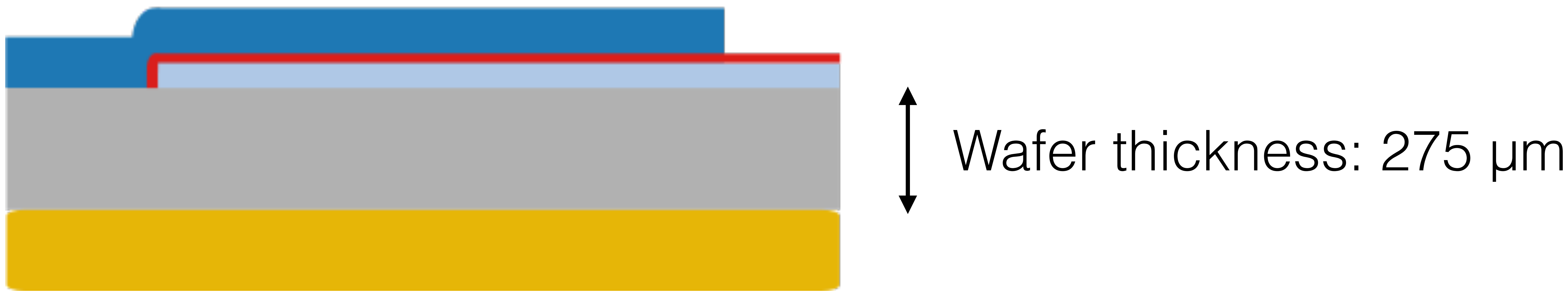
Josephson transmission line: fabrication recipe



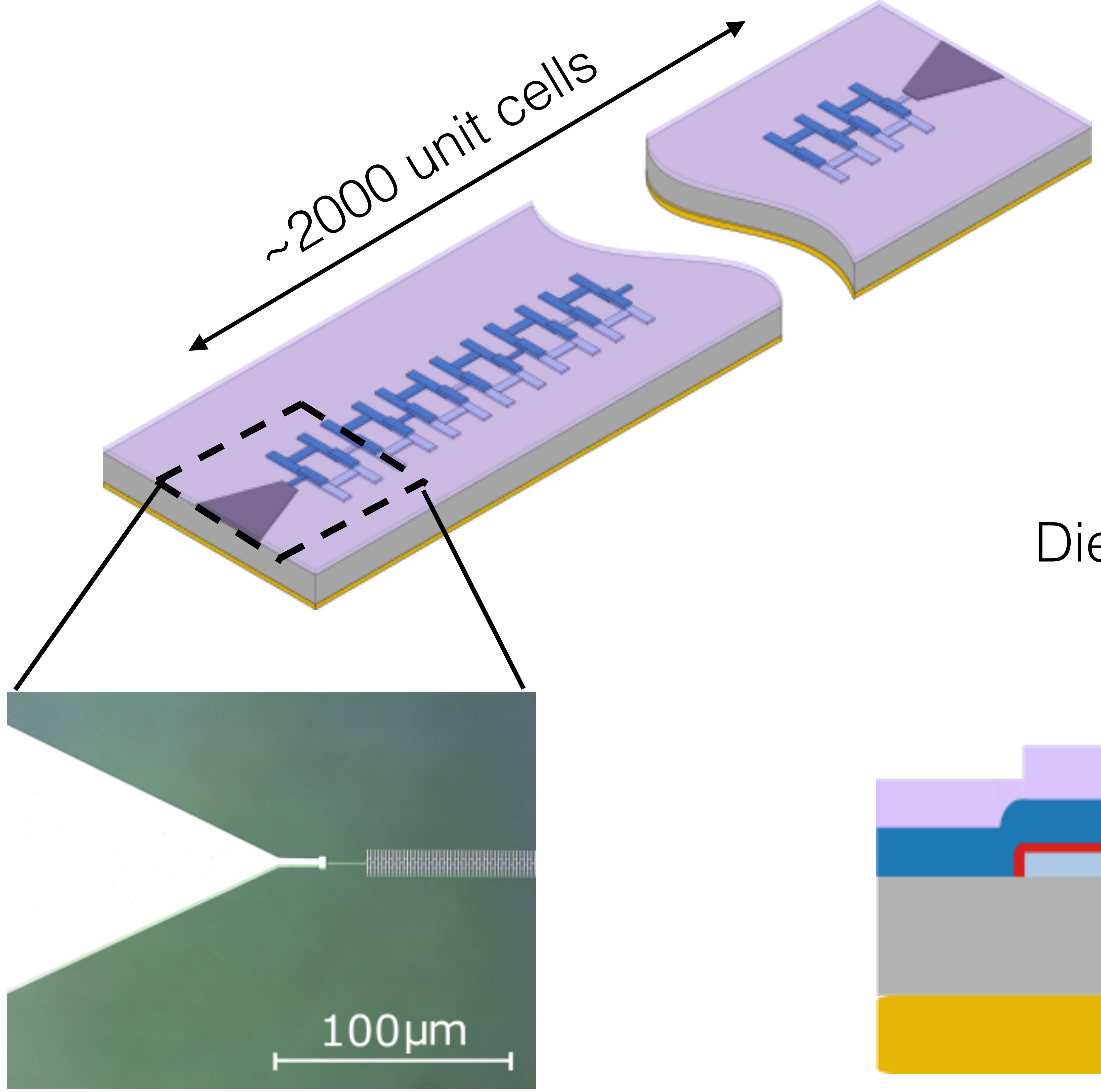


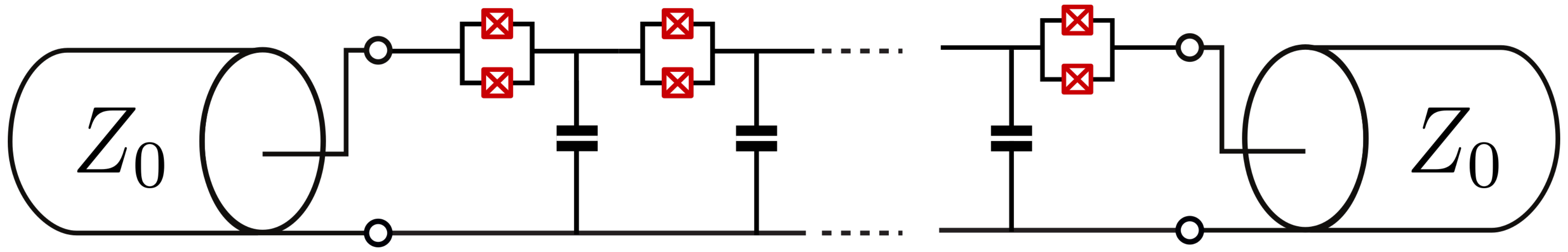


Josephson junction fabrication



Josephson transmission line: fabrication recipe



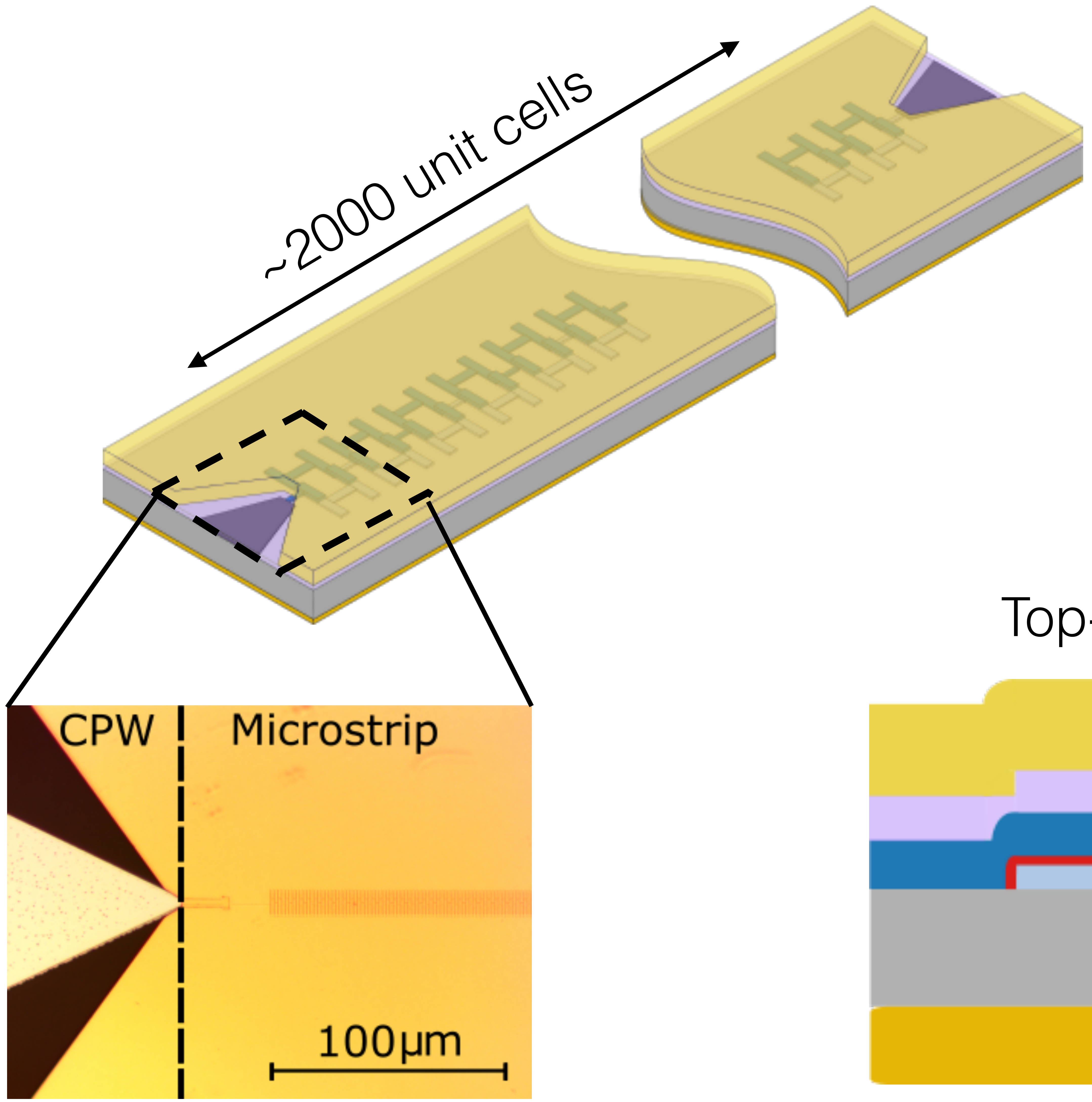


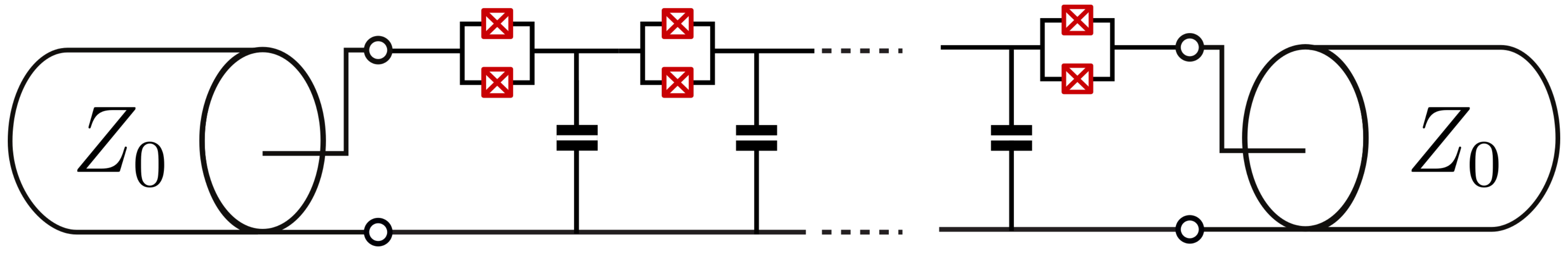
Dielectric deposition
(Al_2O_3, ALD)

Dielectric thickness: 30 nm

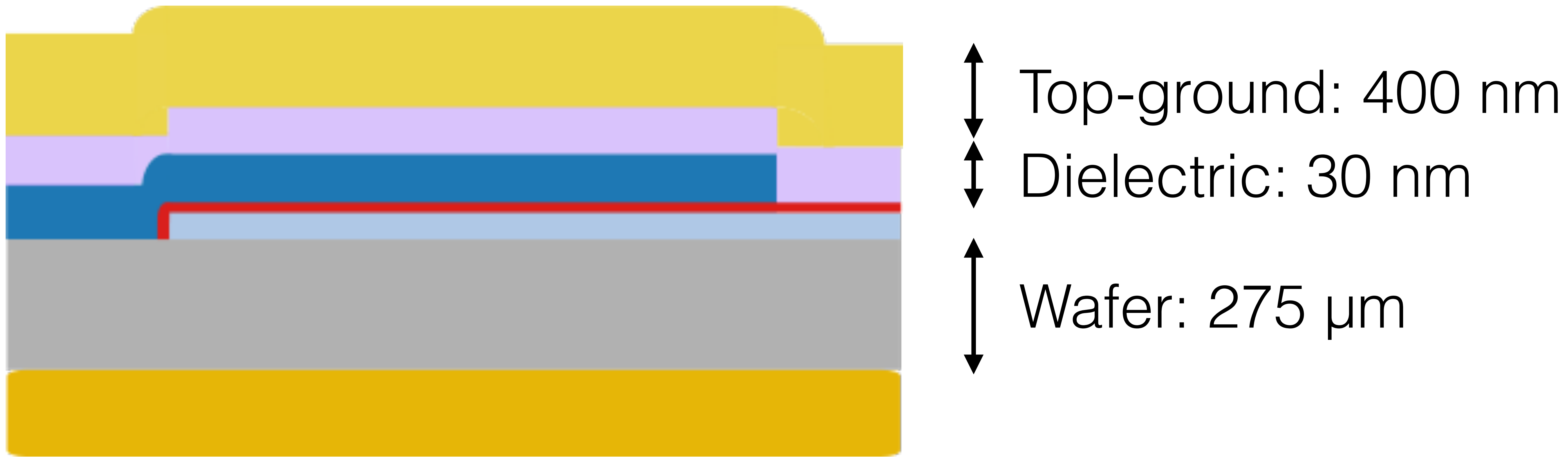
Wafer thickness: 275 µm

Josephson transmission line: fabrication recipe

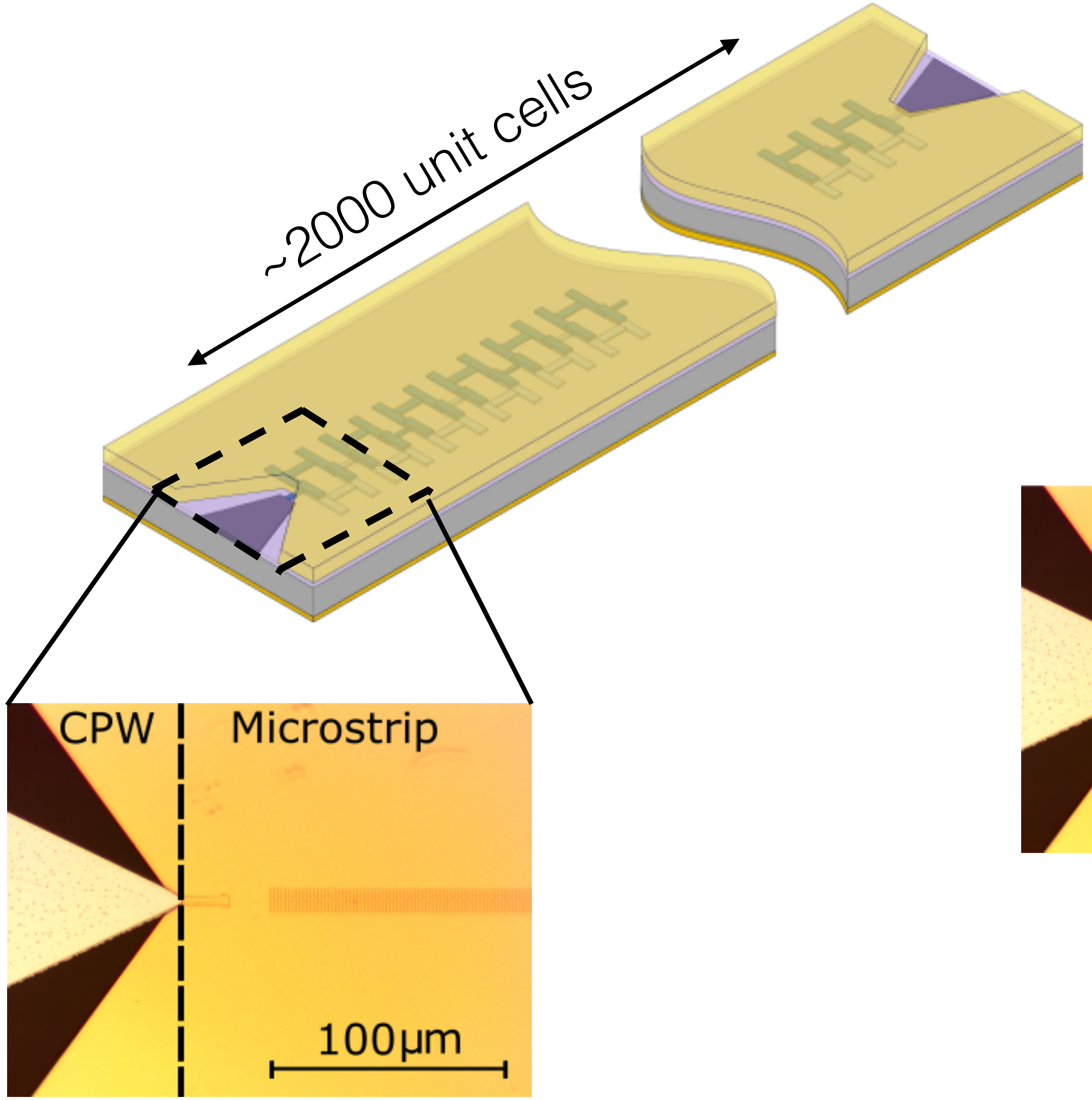


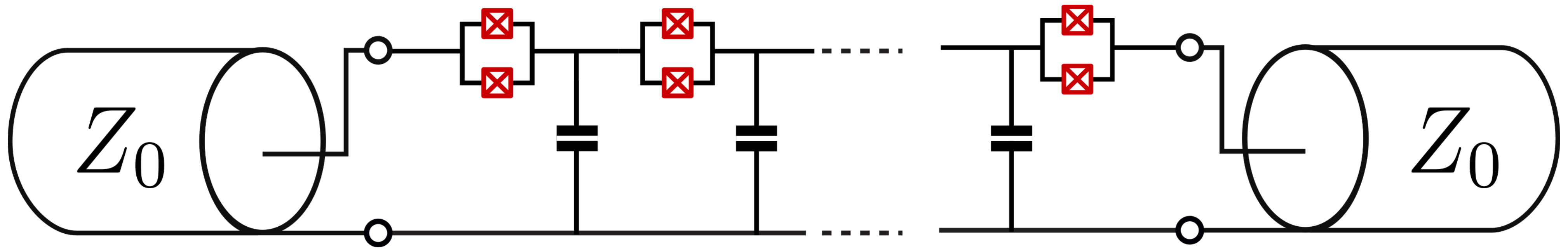


Top-ground deposition



Josephson transmission line: fabrication recipe





C^g 0.1 fF to 40 fF

Z_c 1kOhms to 50 Ohms

Superconducting Quantum Circuits

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