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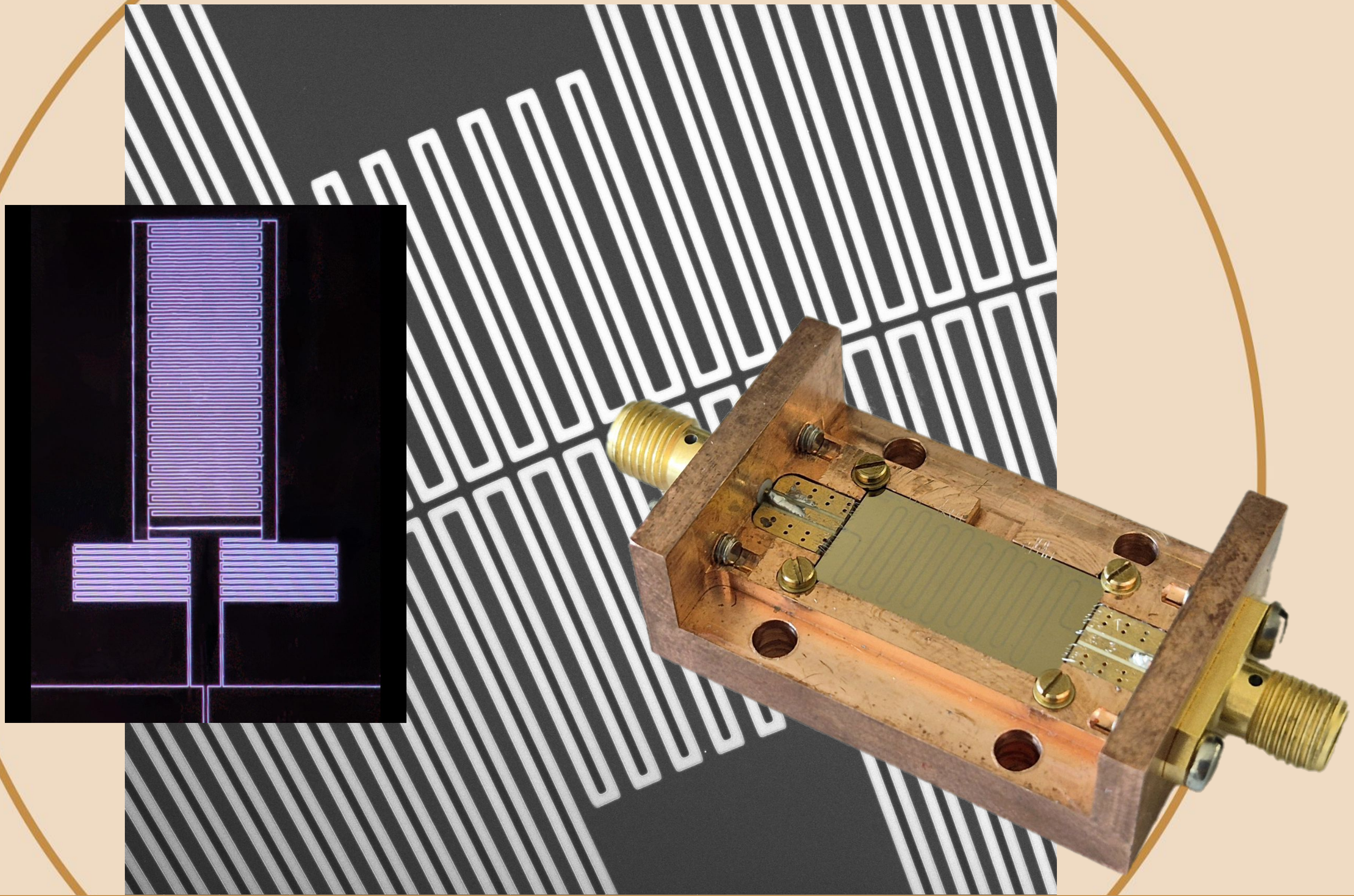
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
NQSTI National Quantum Science and Technology Institute

Development of superconducting **high kinetic inductance** devices



Felix Klaus Ahrens

Fondazione Bruno Kessler (Trento)
Centre for Sensors and Devices

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FONDAZIONE BRUNO KESSLER SENSORS AND DEVICES

Second NQSTI Congress, 5-7 February 2025, Rome

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The FBK team

FONDAZIONE BRUNO KESSLER SENSORS AND DEVICES

From left to right:

Enrico Bogoni	-	PhD student
Marcello Faggionato	-	Master's student
Benno Margesin	-	Senior fellow
Federica Mantegazzini	-	Researcher & Team leader
Nicolò Crescini	-	Researcher
Alessandro Irace	-	PhD student
Felix Ahrens	-	Researcher

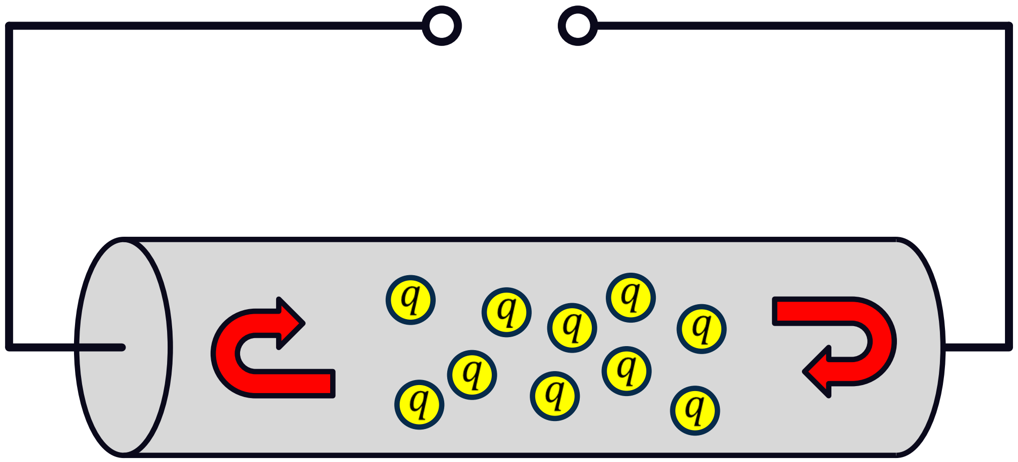
External collaborators in Trento:
Experimentalists: Paolo Falferi, Renato Mezzena, Andrea Vinante
Theoreticians: Iacopo Carusotto, Gianluca Rastelli, Stephanie Matern

Collaboration with Milano Bicocca:
Andrea Giachero, Angelo Nucciotti, Marco Faverzani and colleagues

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

High kinetic inductance films

$$U = U_0 e^{i\omega t}$$



$$\sigma = \frac{nq^2\tau}{m(1 + i\omega\tau)}$$

Kinetic inductance:
- large collision time τ
- high frequency ω

Superconductor:

$$\tau \to \infty, \quad m = 2m_e, \quad q = 2e$$

Cooper pair density $n = n(I)$

$$\Rightarrow \quad L(I) \approx L_0 \cdot \left(1 + \frac{I^2}{I_*^2}\right)$$

$$L_0 = \frac{R_S\,\hbar}{\pi\,\Delta} \qquad I_* \propto 1/\sqrt{R_n}$$

High kinetic inductance films

- Interesting materials:
  high-resistivity superconductors

- Our choice: **NbTiN**
  → high resistivity (~100−200 mΩcm)
  → high critical temperature (~12-13 K)

Superconductor:

$$\tau \to \infty, \quad m = 2m_e, \quad q = 2e$$

Cooper pair density $n = n(I)$

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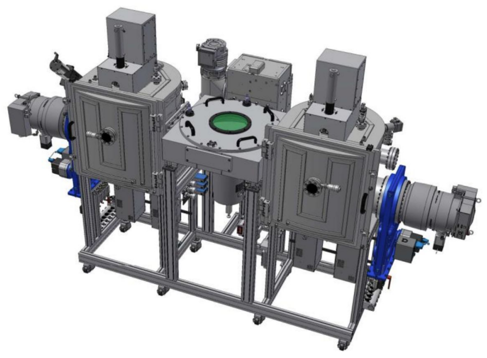
$$L_0 = \frac{R_S\,\hbar}{\pi\,\Delta} \qquad I_* \propto 1/\sqrt{R_n}$$

Optimisation of NbTiN thin films: parameter exploration

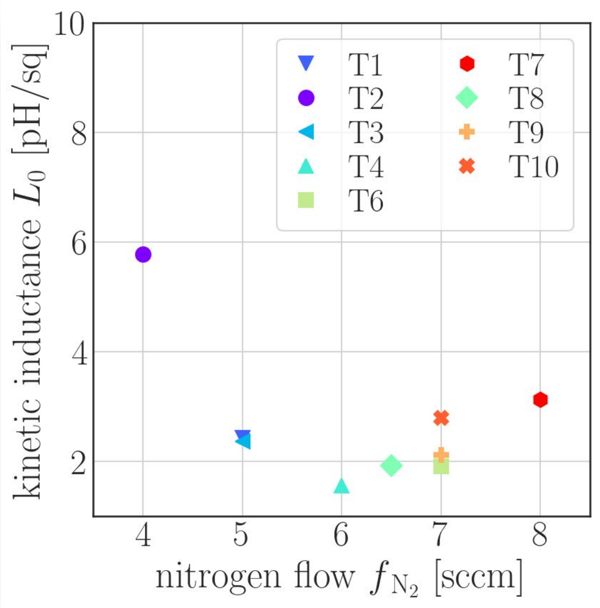
Sputter target:

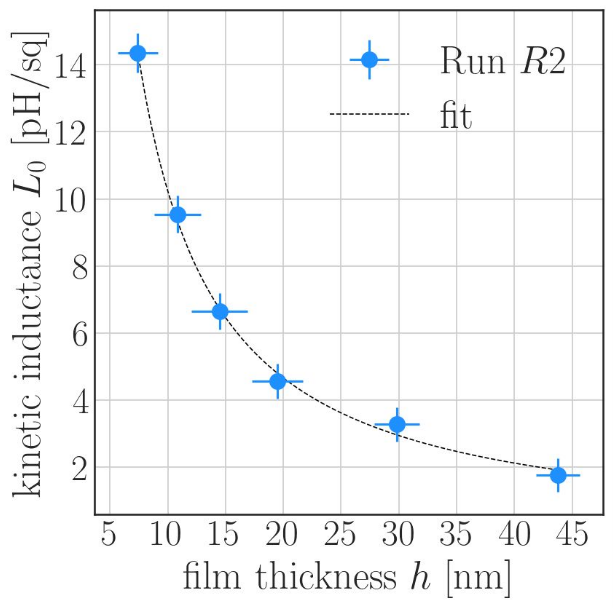
$Nb_{80\%}Ti_{20\%}$

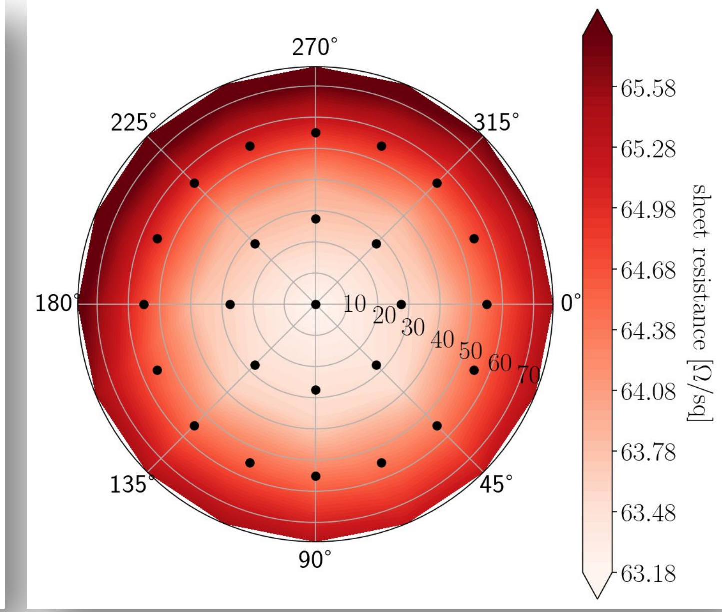


$$L_0 = \frac{R_S \cdot \hbar}{\pi \cdot T_C \cdot k_B \cdot 1.762}$$

✖ T10





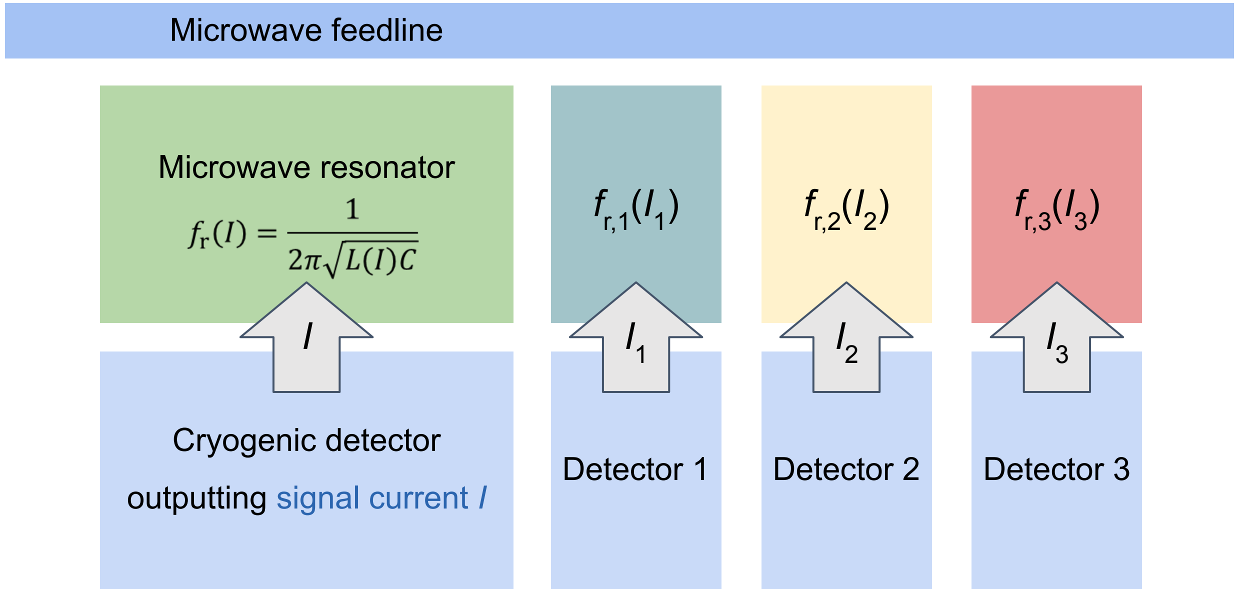


Kinetic inductance devices:

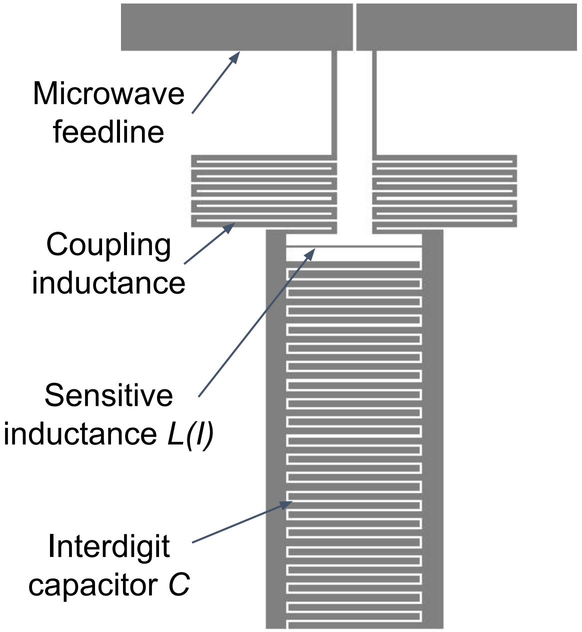
- Kinetic Inductance **Current Sensor** (KICS)
- Travelling Wave Parametric **Amplifier** (KI-TWPA)
- Travelling Wave Microwave **Photon Energy Lifter** (KI-TWPEL)

Kinetic Inductance Current Sensor (KICS)

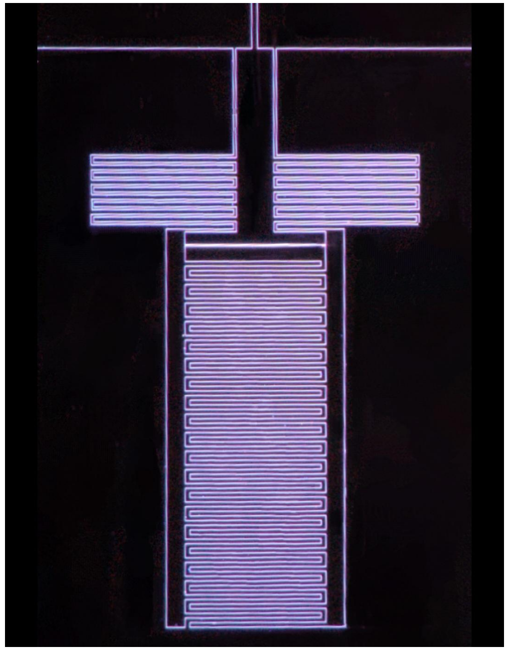
Concept:



Prototype design:



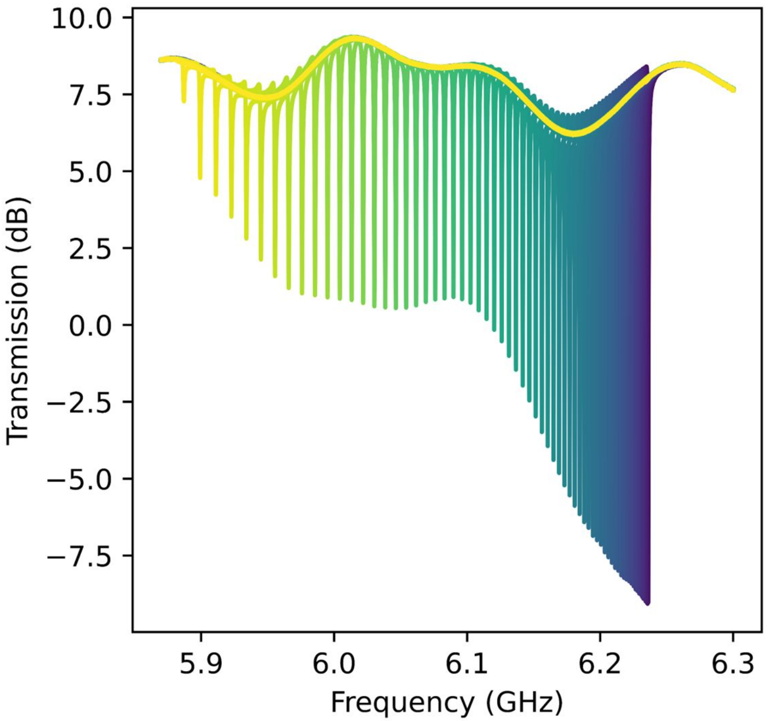
Microfabricated device:

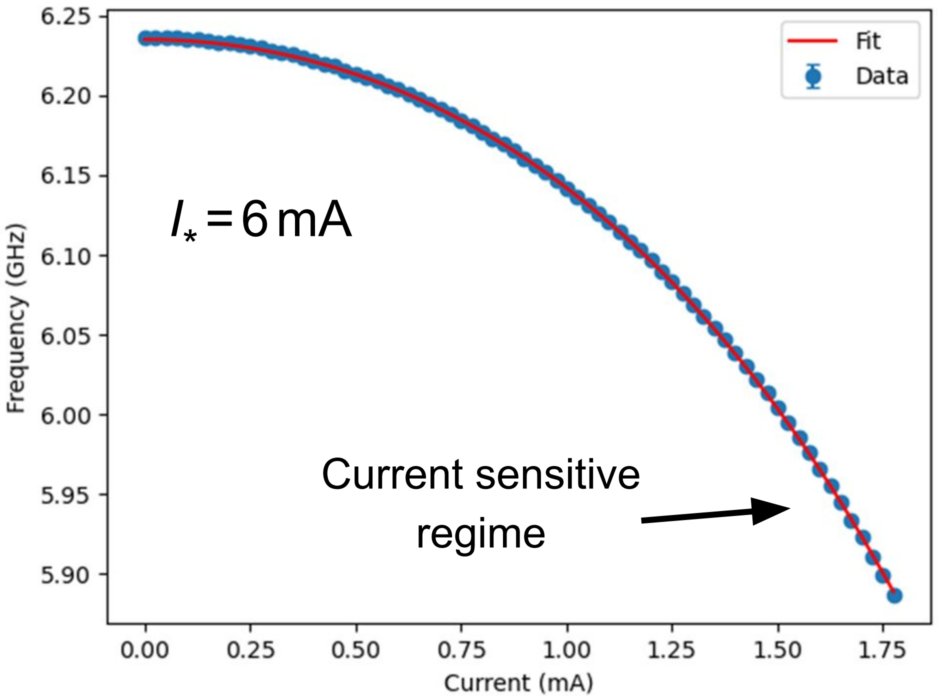


Idea: P. Szypryt *et al.*, *Commun Eng* **3**, 160 (2024)

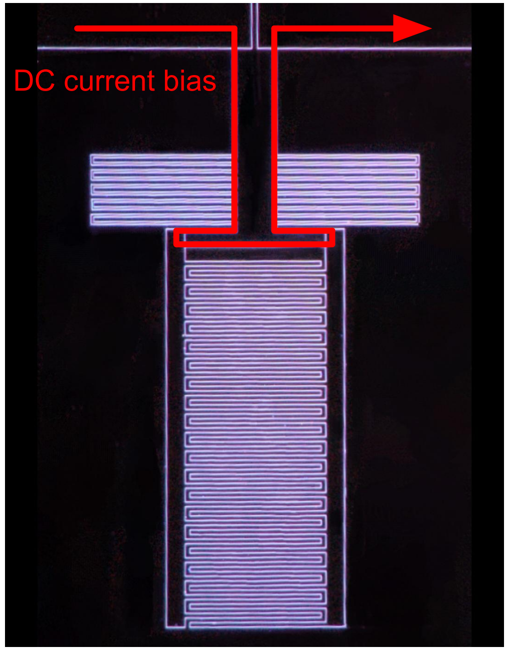
Kinetic Inductance Current Sensor (KICS)

Tunability of the resonance frequency:



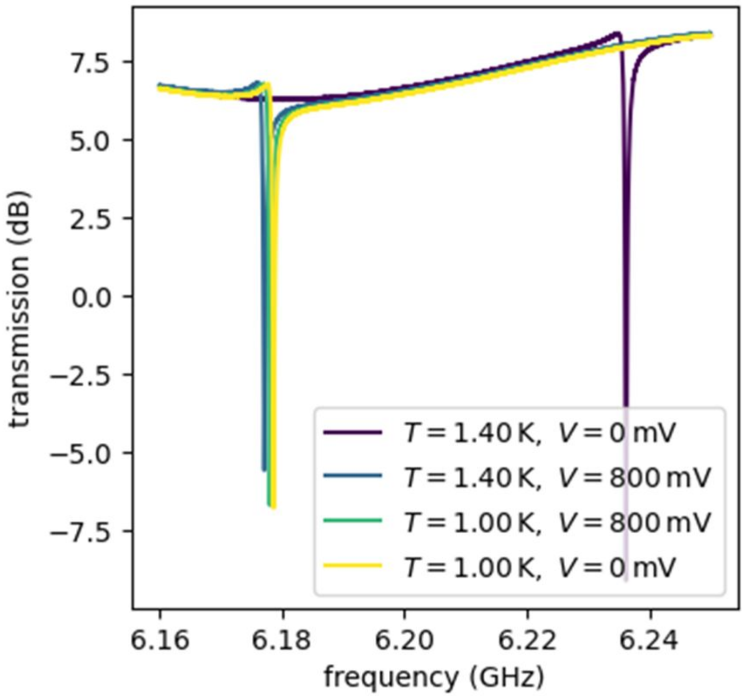


Microfabricated device:

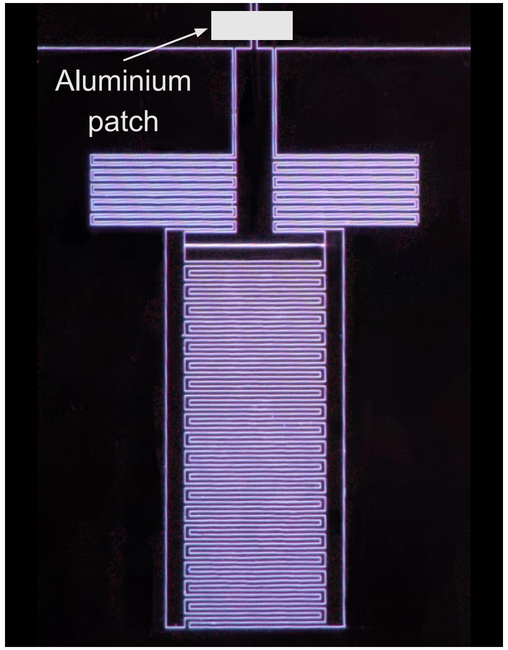


Kinetic Inductance Current Sensor (KICS)

Preparation of persistent supercurrent bias:

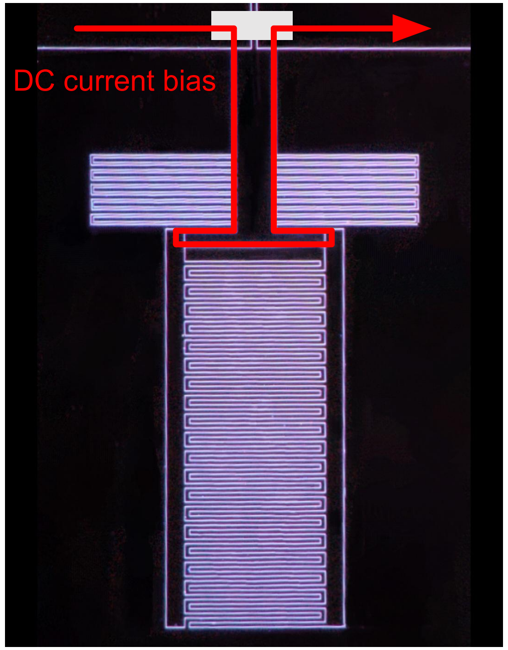


Step 1:



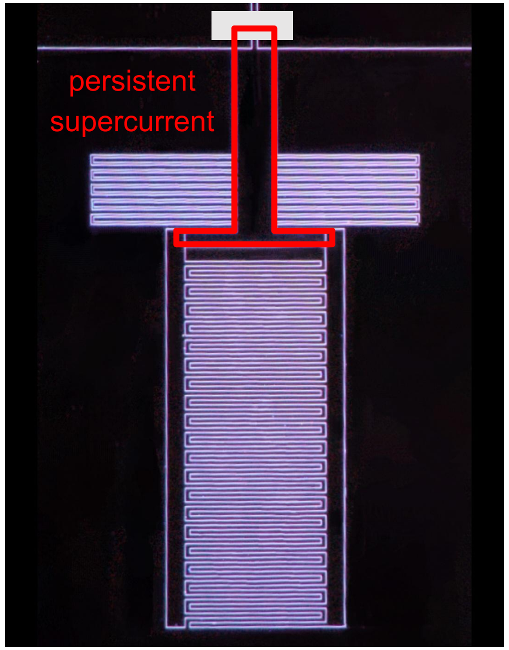
$T_{NbTiN} > T > T_{Al}$

***Step 2* & *step 3*:**



Apply bias, cool to $T < T_{Al}$

Step 4:



Remove external bias, $T < T_{Al}$

Kinetic Inductance Travelling Wave Parametric Amplifier (KI-TWPA)

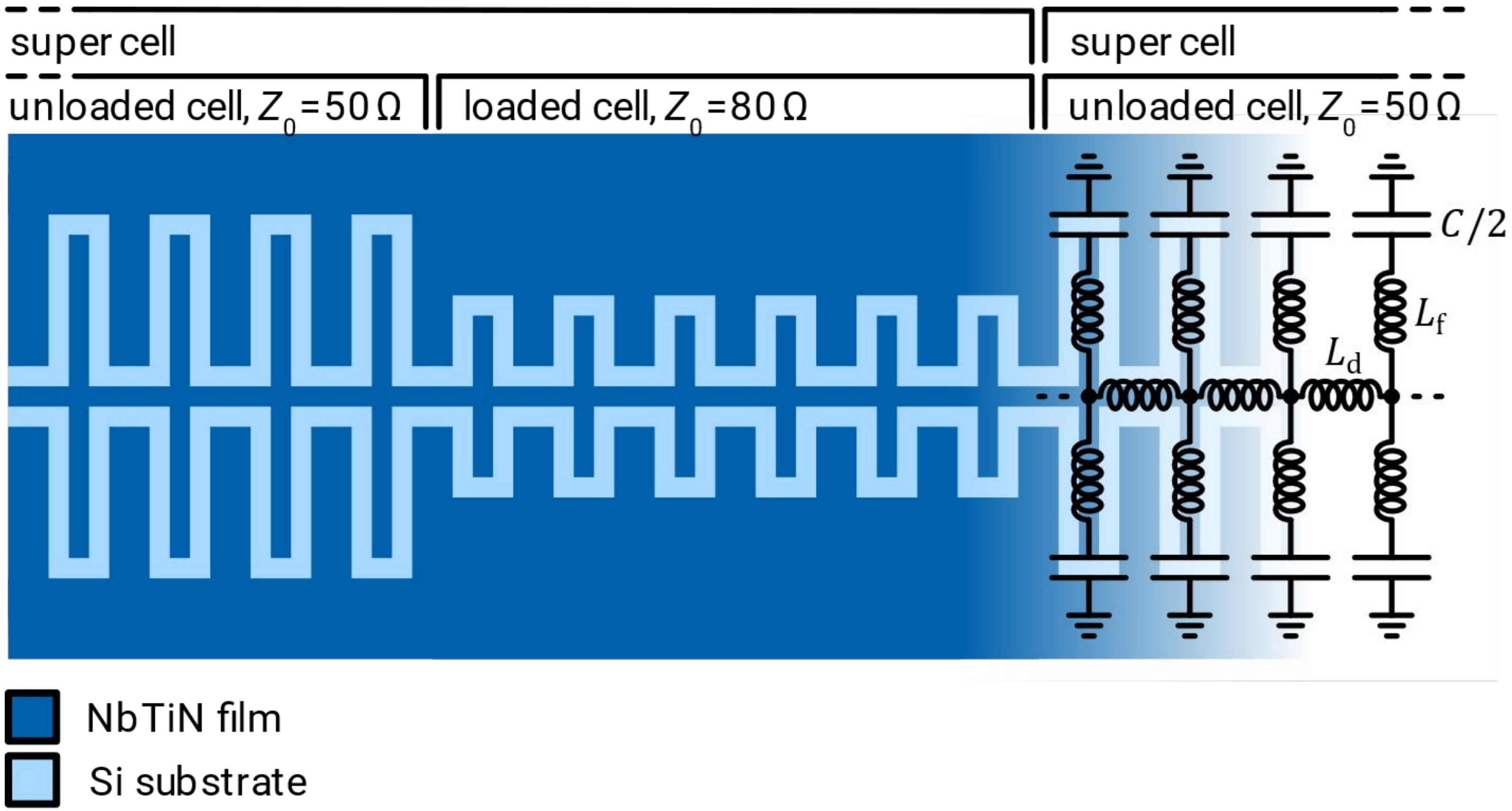
Weakly dispersive artificial transmission line:

Series of CPW sections (*cells*) flanked by IDC fingers

⇒ *decrease phase velocity*

Phase-matching: periodic increasing of the line impedance (*loading*)

⇒ *stopband*



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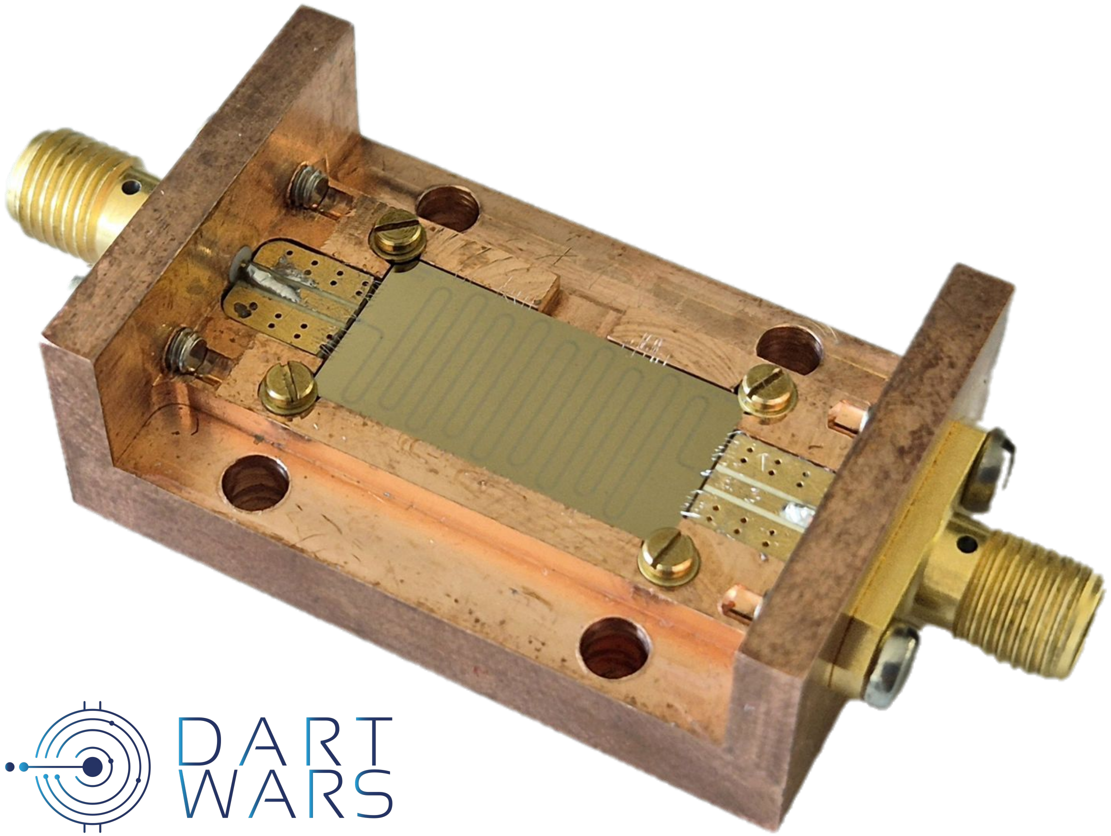
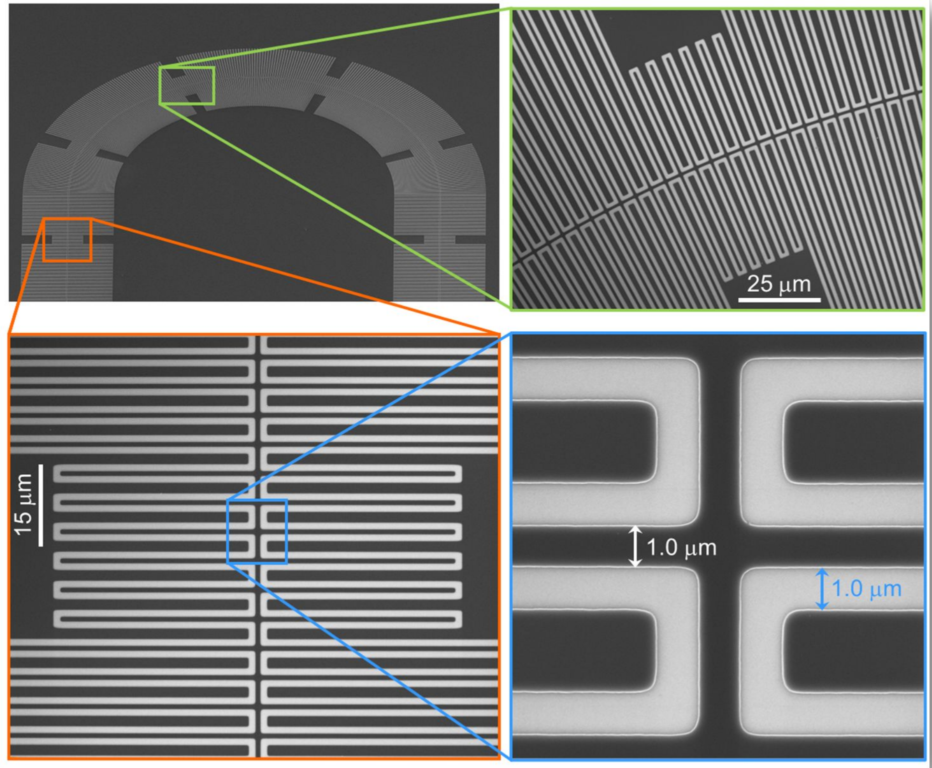
Kinetic Inductance Travelling Wave Parametric Amplifier (KI-TWPA)



DART WARS



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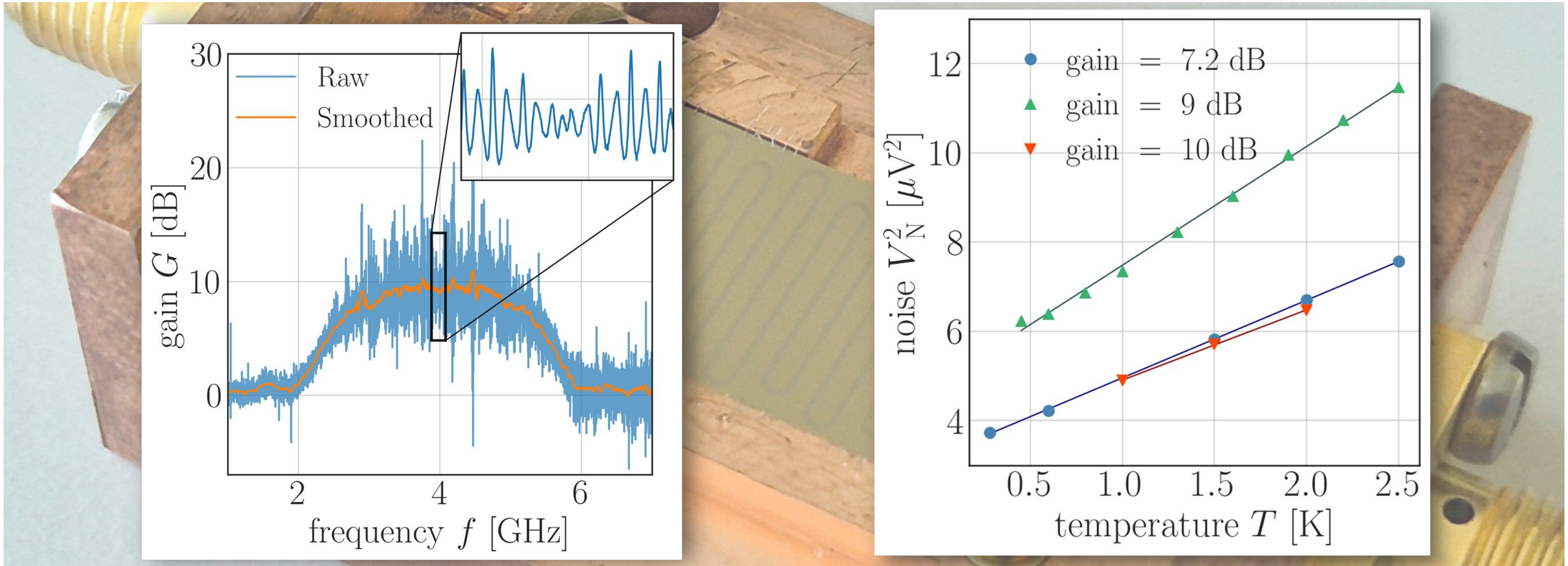
Kinetic Inductance Travelling Wave Parametric Amplifier (KI-TWPA)

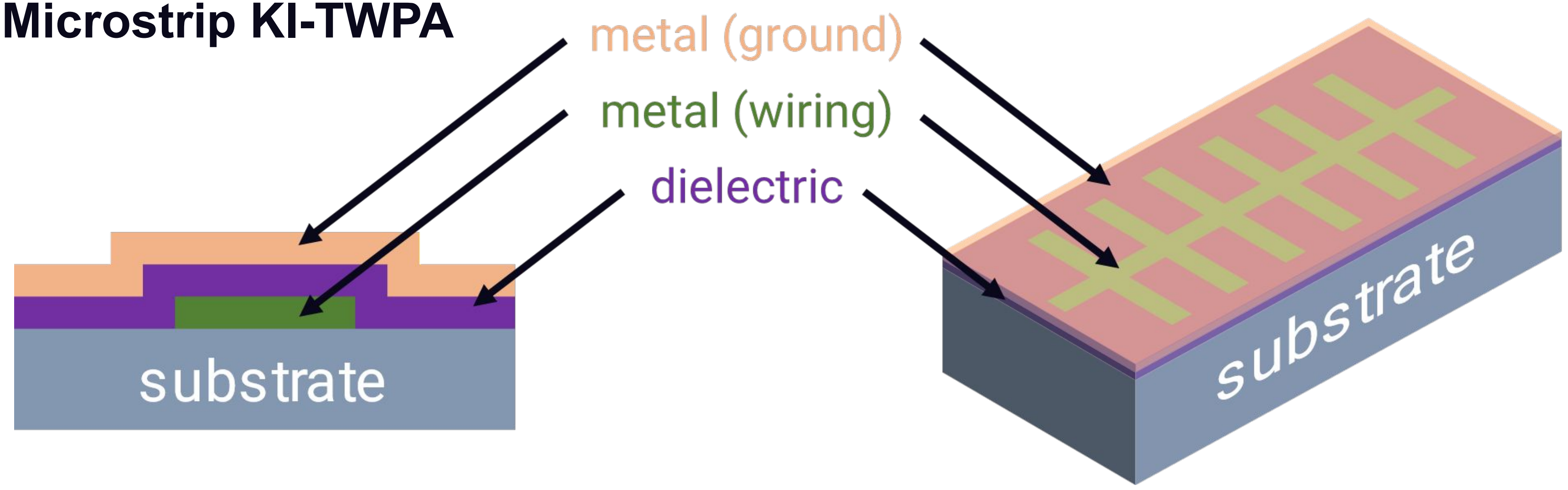


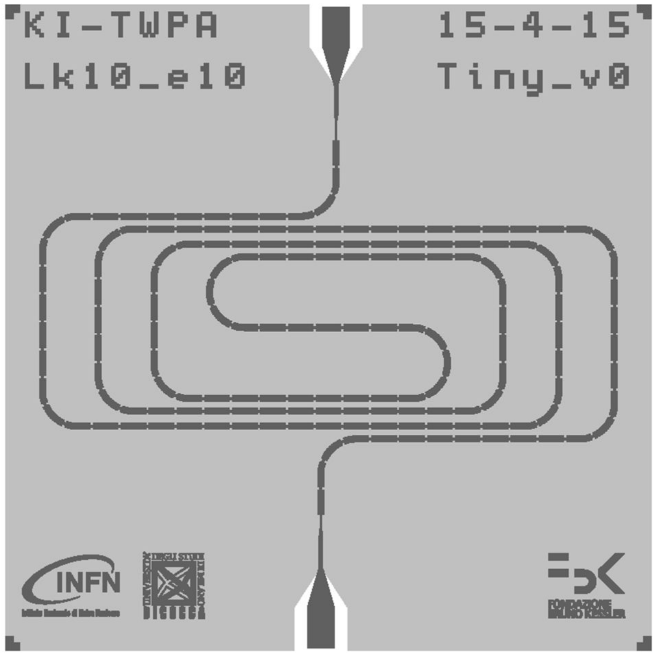
✔ **Gain**: up to ~ 10 dB (with I_{dc} = 1 mA)

✔ **Noise**: down to 2.5-3 noise quanta

Kinetic Inductance Travelling Wave Parametric Amplifier (KI-TWPA)

Microstrip KI-TWPA





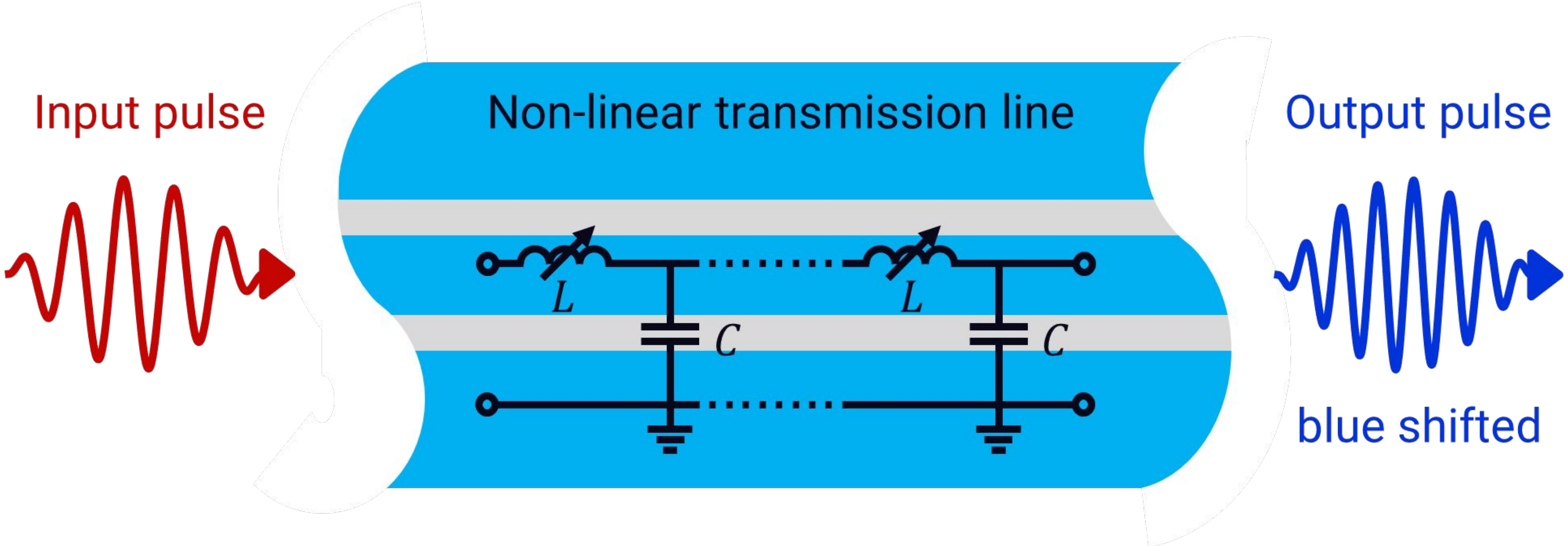
Advantages:

- More **compact** design
- Improved **grounding**
- High fabrication **yield**

Challenges:

- Development of **low-loss dielectric**
  - PECVD **a-Si**
  - ALD **AlOx**
- **Increase** sheet kinetic **inductance**

Travelling wave photon energy lifter (TWPEL)



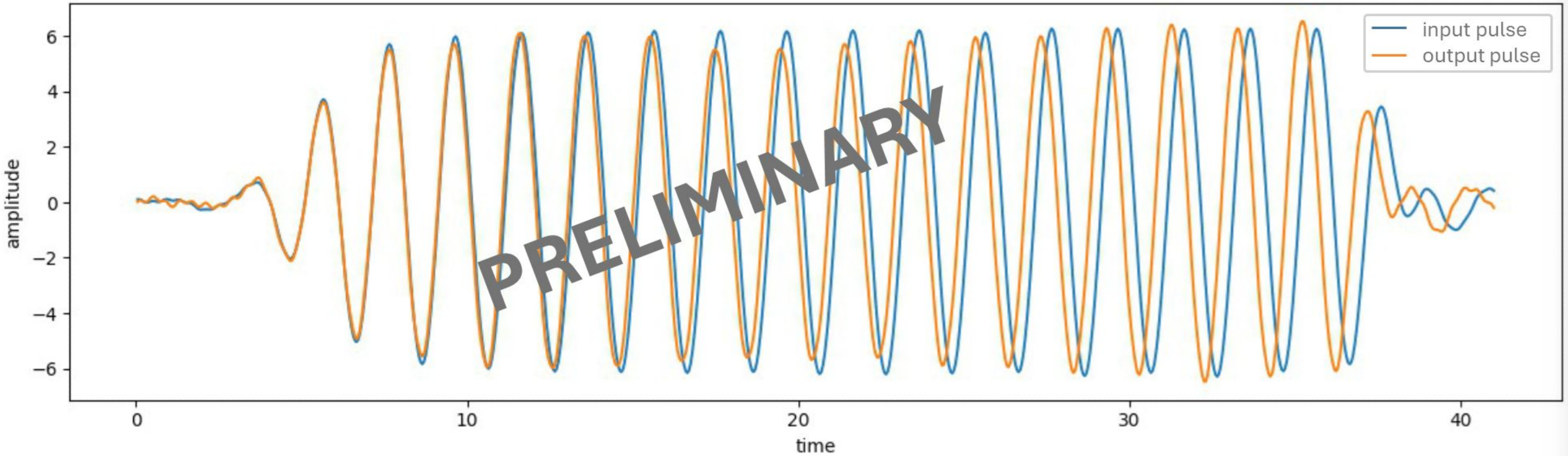
PATENT IN PREPARATION

Advantages:

- Broadband
- Pulse shape preserving

Travelling wave photon energy lifter (TWPEL)

Measurements ongoing!



Advantages:

- Broadband
- Pulse shape preserving

Challenges:

- Dedicated dispersion engineering
- Sufficient tunability and non-linearity

Conclusions

- **Kinetic inductance** materials: versatile tool for **many applications**
- Our kinetic inductance devices:
  - Current **sensors** (KICS)
  - Low-noise microwave **amplifiers** (KI-TWPA)
  - **Novel** microwave photon **energy lifter**