Traveling-wave parametric amplifiers for microwave and millimeter-wave radiometers

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Objectives

Wideband superconducting parametric amplifiers have been developed for frequencies up to 10 GHz and have demonstrated quantum-limited sensitivity and dynamic range consistant with the requirements of astronomical instruments. The objective of this task was to adapt that technology to higher frequency bands in the range of 20-100 GHz and higher and to demonstrate its utility for astronomical receivers by working toward integrating the amplifiers into a receiver module.

Background

In astronomy, amplifiers are used as front ends in many receivers including mm/submm radiometers and interferometers and as IF amplifiers in spectrometers with SIS or HEB mixers. Cryogenically cooled transistor amplifiers can have very wide bandwidth and high dynamic range, but while their sensitivity is quite good, they still add noise that is several times the limit set by quantum mechanics. Astronomical instruments, especially for space missions, typically deman the highest possible sensitivity. Examples of mission targets are a space CMB polarization mission or a satellite VLBI mission.

Approach and Results

The wideband parametric amplifiers, which were invented at JPL [Eom et al., Nature Physics (2013)], make use of the nonlinear response of the kinetic inductance of a superconducting transmission line to produce gain in a traveling-wave geometry. This amplifier concept was originally demonstrated in the 5 to 10 GHz range. In order to raise the operating frequency range of the paramp into the millimeter-wave range we have

- Changed the transmission line geometry to from CPW to microstrip, which is more suitable for high frequencies
- Miniaturized and thinned the chips by fabricating them on SOI wafers and removing the handle as a last step
- Developed wide-band isolators, as well as other cryogenic components, that isolate the paramps from noise from following amplifier stages.

Significance/ Benefit to JPL and NASA

Our results have shown that operation of wideband parametric amplifiers is possible well into the millimeter-wave band using the new microstrip geometry that we have developed along with high-frequency packaging techniques. These new amplifiers have the potential to drastically improve the performance of microwave radiometers, for example for CMB measurements in the 10-40 GHz range, heterodyne systems for high-resolution spectroscopy throughout the millimeter range, or receivers for very long baseline interferometry (VLBI) which may be used for exploring physics around black holes. State-of-the-art instruments based on transistor amplifiers or SIS mixers that have been used for these applications are typically several times the quantum limit for sensitivity. By offering sensitivity at the quantum limit, the new amplifiers can reduce integration times for these types of measurements by an order of magnitude.

Publications

[1} Zobrist, Nicholas, et al. "Wide-band parametric amplifier readout and resolution of optical microwave kinetic inductance detectors." *Applied Physics Letters* 115.4 (2019): 042601.

[2] Shu, S., Klimovich, N., Eom, B. H., Beyer, A. D., Thakur, R. B., Leduc, H. G., & Day, P. K. (2021). Nonlinearity and wide-band parametric amplification in a (Nb, Ti) N microstrip transmission line. *Physical Review Research*, *3*(2), 023184.

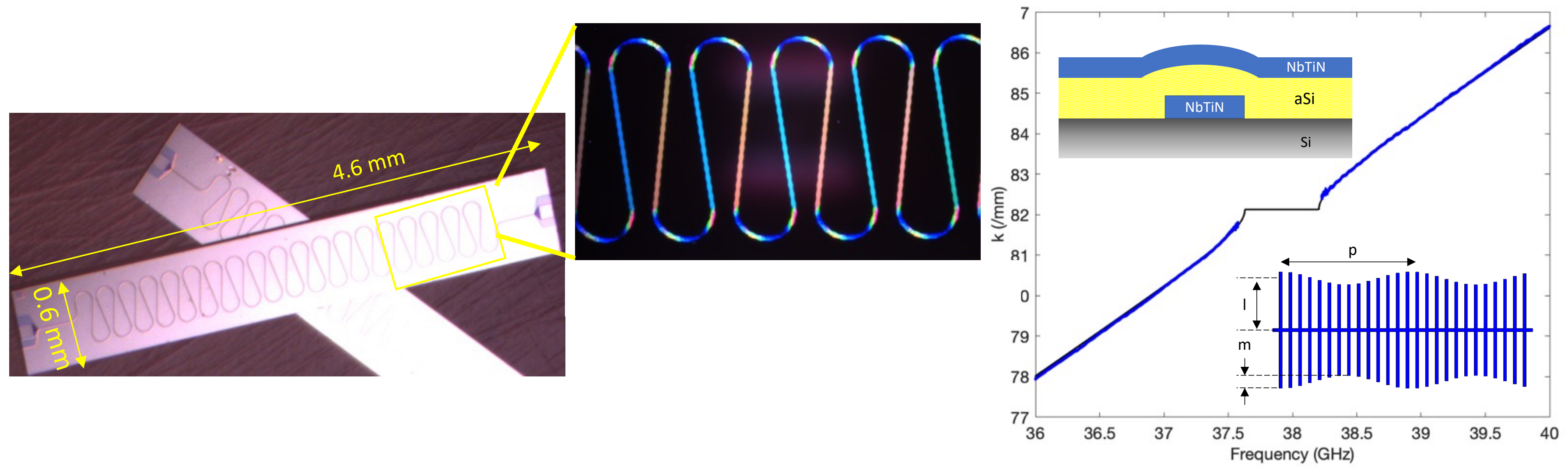

Fig. 1: Left: Paramps fabricated on 100 micron thick substrates designed for millimeter band operation. Center: A section of the meandering NbTiN microstrip transmission line that constitutes the gain medium of the amplifier. Right: An example of a band gap produced by modulating the microstrip line geometry. Upper inset: Layer stack-up of the device. Lower inset: Geometry of a section of the stub-shunted, modulated microstrip line.

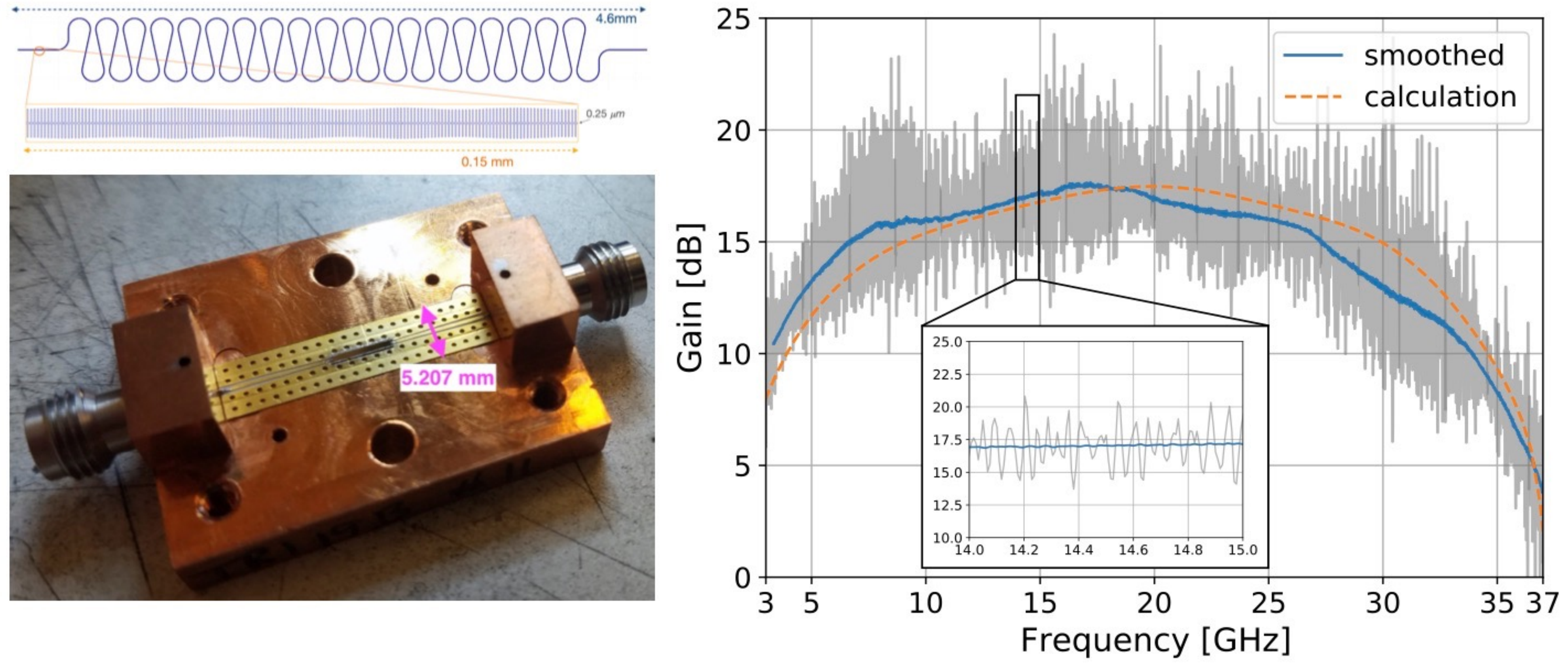

Fig. 2: Left: A paramp chip mounted in a millimeter-wave housing for testing. Right: Measured wide-band gain of the device. The paramp in this case operates in three-wave mixing mode with a pump at 39 GHz. The rapid gain variations are due to reflections at the ends of the amplifier and are not intrinsic to the operation of the device.

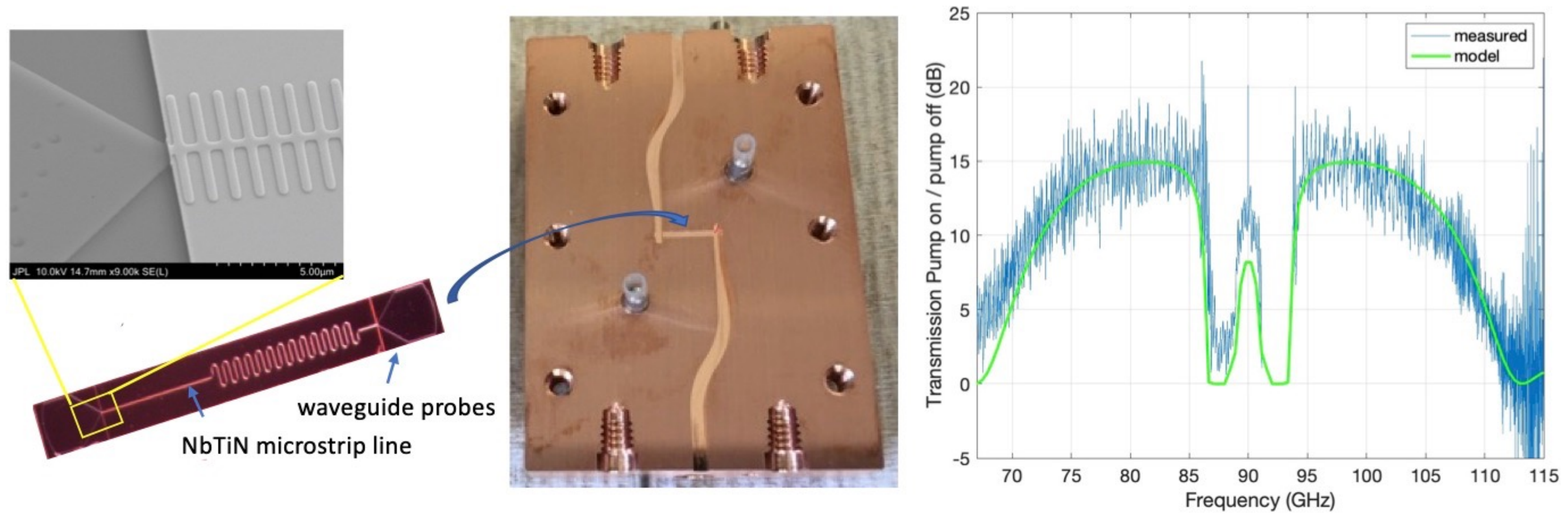

Fig. 3: Left: Images of the waveguide-coupled paramp chips. The upper SEM image shows the connection of the waveguide probe to the microstrip line. Center: the waveguide split block housing. WR-10 waveguide sections connect to the input and output of the paramp. Right: Measured W-band gain. The green line is the prediction of the coupled-mode model calculation, which transmission line parameters adjusted to match the data.

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