Experimental Study of Superconducting Microstrip Travelling-wave Parametric Amplifiers

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The emerging superconducting travelling wave parametric amplifiers[1] (STWPA) bring an opportunity of realizing heat-free cryogenic microwave amplifiers that are essential for future large format mm/sub-mm superconducting heterodyne array receiver, in which there are large amount of in-plant IF amplifiers in the frontend operating at cryogenic temperature[2]. Besides the merit of no heat generation, STPAs are also believed to have lower noise than HEMT amplifiers and reasonable bandwidth (>1 GHz) that partly meets the requirement of molecular line observation. A travelling wave parametric amplifier in form of CPW has been demonstrated at 0.3 K[1].

We have designed, fabricated and tested STWPAs based on microstrip line structure. The reasons for using microstrip line instead of CPW are threefold: (1) the microstrip STPAs are more compact than CPW ones because the travelling wave is slower in microstrip by a factor of 5 using a typical set of design parameters; (2) it is practical to achieve 50 characteristic impedance by using microstrip, so that the standing waves trapped in the transmission line can be prevented and flat gain in the working frequency band can be expected; and (3) crosstalk in a microstrip meander line is weak, while it is often a problem in a CPW meander line. The meandering STPA that we designed for this study is about 18 cm long, equivalent to 60 wavelengths at 3 GHz, as shown in Fig.1. The conductive strip is in general 1.5 m wide but is perturbed by 3 m- wide sections located at every one-sixth wavelength to prevent the 3rd harmonic generation. The conducting strip and the ground plane are both 30 nm NbTiN thin films and the dielectric layer is 50 nm SiO_2. The Tc of NbTiN is about 13 K and the resistivity at room temperature is about 130 cm. In order to measure loss and evaluate nonlinearity of the microstrip line, testing chips containing capacitively coupled microstrip resonators are also fabricated and tested.

Testing chips and STWPA devices have been measured at liquid helium temperature. The transmission loss of the 60 wavelength long microstrip line results to be about 1 dB at 3 GHz and it shows apparent dependence on temperature at 4 K, roughly one-third of T_c. The loss of pump power along the amplifier weakens the nonlinearity of the overall transmission line and thus should be minimized by reducing the temperature. When a strong pump power of about -15dBm and a weak signal are applied, four-photon mixing phenomenon can be observed. By switching on and off the pump, we estimated the parametric amplification of signal is about 4 dB. Increase in the pump power can enhance the nonlinearity of the device and therefore increase the parametric gain. However there is a maximum pump power of about -15 dBm for these samples, above which the transmission line abruptly turns to a lossy state. The original state cannot be recovered by reducing the pump power back to that value prior to the trigger point, and an irreversible dependence of the transmission line loss on the pump power was observed.

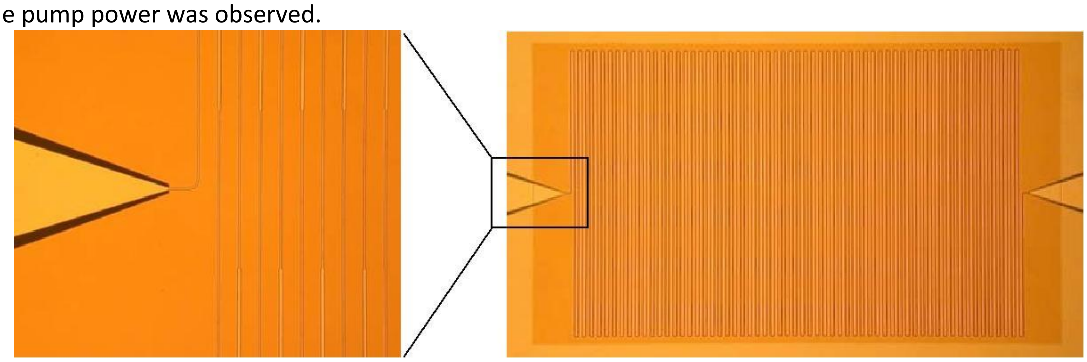

Fig.1 A microstrip line traveling wave parametric amplifier of size 1.5mm x 2.4mm. left panel shows an enlarged part.

References
1. Byeong Ho Eom, Peter K. Day, Henry G. LeDuc and Jonas Zmuidzinas, "A wideband, low-noise superconducting amplifier with high dynamic range," Nature Physics, 8, 623-627, 2012.
2. Wenlei Shan, Shengcai Shi, and Ji Yang, "An integrated SIS multibeam receiver for terahertz astronomical observation," the 23th ISSTT, Tokyo, Japan, 2012.