Bandwidth performance of a THz normal metal TiN bolometer-mixer

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***Abstract*—We report on the bandwidth performance of the normal metal TiN bolometer-mixer on top of an Al_2O_3 substrate, which is capable to operate in a wide range of bath temperatures from 77 K – 300 K. The choice of the combination TiN / Al_2O_3 is related to an advanced heat transport between the film and the substrate in this pair and the sufficient temperature coefficient of resistance.**

The data were taken at 132.5 – 145.5 GHz with two BWOs as a signal and an LO source. Measurements were taken on TiN films of different thickness starting from 20 nm down to 5 nm coupled into a spiral Au antenna, which improves matching of incoming radiation with the thin TiN fim. Our experiments demonstrate effective heat coupling from a TiN thin film to an Al_2O_3 substrate (111) boosting gain bandwidth (GB) of TiN bolometer up to 6 GHz for 5 nm thin film. Current results indicate weak temperature dependence of GB on the bath temperature of the TiN bolometer. Theoretical estimations of GB performance meet with experimental data for 5 nm thin TiN films.

***Index Terms*— Bolometer, gain bandwidth, mixer, normal metal, TiN.**

Introduction

Modern approaches to low signal THz observations usually based on two main technologies, namely superconducting and semiconducting one.

The superconducting technology, at the cost of cryogenic operation, is presented with such devices as SIS and HEB mixers. On the one hand, SIS usually provides ultimate noise performance of few quantum noise limits with gain bandwidth of several tens of GHz at signal frequencies up to 1 THz [1]. On the other hand, HEBs provide noise performance of several quantum limits with gain bandwidth of several GHz [2] without upper limit in terms of LO frequencies.

The semiconductor technology is associated with Schottky diodes based mixers, which are able to operate up to THz frequencies, providing good noise performance about one thousand of kelvins with gain bandwidth of several tens of GHz [3]. But their performance rapidly deteriorates, while the LO power consumption increases with rising of signal frequency above several THz [4]. Another semiconductor type of devices is mercury cadmium telluride (CMT) mixer, which is the only one available detector above 30 THz [5].

Here we report on the IF bandwidth performance of a normal metal TiN bolometer on top of an Al_2O_3 substrate, which has advanced heat transport between a metal film and a substrate material [6], can provide up to 6 GHz of gain bandwidth in a wide range of temperature from 77 K up to 300 K and is capable to operate in the wide LO frequency range 3-30 THz.

Experiment

A. *Normal metal TiN bolometer*

The studied bolometers were made out of a TiN film on top of an Al_2O_3 substrate (111). The film was deposited by means of a DC magnetron sputtering. TiN film thickness varies from 20 down to 3 nm.

B. *Experimental Setup*

The experimental setup utilized two BWOs, one as a signal source with frequency tuning range from 132.5 – 145.5 GHz, while the second BWO was set to 132.5 GHz. The total output power of two sources was controlled by an RF thermistor power meter and hold at the level of 100 μWatts. Signals from two sources were further combined with the quasi-optical part and coupled through a free space and an HDTP window to the hemispherical silicon lens. The lens with a device under study was mounted of the cold plate of a cryostat. The necessity of a cryostat in our setup comes from two reasons. The first reason

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is the temperature range from 300 K down to 77 K. The other reason in the bias voltage of our bolometer, which varies in the range of 1 - 10 mV, and can cause degradation of TiN film, due to its' oxidization at room temperature. The gain bandwidth data were recorded by a spectrum analyzer (Rohde&Schawarz FSV 9 kHz – 13.5 GHz) as the difference spike between to signal and LO frequencies at the RF input of the bolometer.

Results and Discussion

The measurements were taken on several different devices, in term of the TiN film thickness, which was presented by three different sizes: 20 nm, 10 nm and 5 nm. If the phonon cooling mechanism is considered for the type of films, then the cut-off frequency of such films can be derived as follows: $f_{3dB,ph} = 1/(2\pi\tau) = G_{int}/(2\pi Cd)$. Where τ - the response time of the bolometer, G_{int} – the interface heat conductance, C – the film heat capacitance, d – the thickness of the film, κ - the heat conductivity. The above equation is considered under the condition of $G_{film} = \kappa d >> G_{int}$, which is automatically met if d < 100 nm. Considering numerical values of above specified film parameter ($\kappa \sim 20$ Wm^{-1}K^{-1}; C ~ 3×10^6 Jm^{-3}K^{-1}; $G_{int} \sim 5\times10^8$ Wm^{-2}K^{-1}) 3 GHz of gain bandwidth for d = 10 nm is expected.

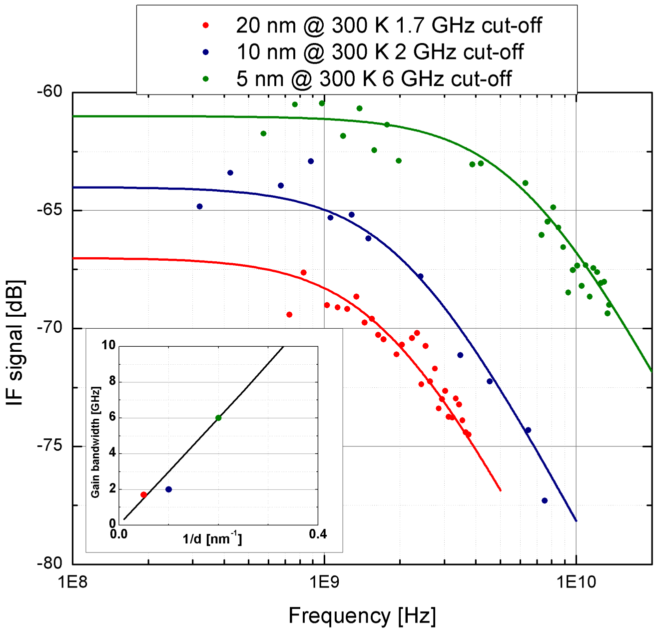

Fig. 1. Gain bandwidth as the function of the film thickness. The data were fitted with the second order Lorenz. The black line on the insert stands for the theoretical expectations of the gain bandwidth performance. Colored dots indicate measured results.

As can be seen on the insert in Fig.1, there is some mismatching between the theoretical expectations and the measured result for 10 nm thin film. We believe, that the origin of this difference is related to the film thickness, which probably is ~ 15 nm instead of 10 nm. Further studies of the impact of an operation temperature on the gain bandwidth indicate very weak correlation between the two parameters, as shown in Fig.2.

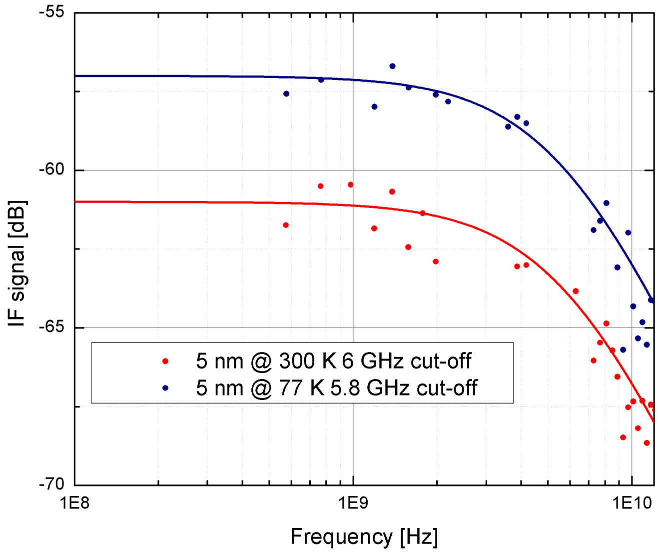

Fig. 2. The gain bandwidth as the function of operation temperature.

Lack of visible dependence of the gain bandwidth (the response time) of the TiN bolometer on its' temperature in the range 77-300 K, is related to the fact, that C - the heat capacitance and G_{int} - the interface heat conductance (as well as κ - the heat conductivity of the film) have nearly the same (nearly linear) dependence on the temperature.

Conclusion

The normal metal TiN THz bolometer-mixer on a sapphire (111) substrate can provide an advanced gain bandwidth performance of 6 GHz at 5 nm thin TiN film. Such gain bandwidth performance can place TiN bolometers in one row with the mature Schottky technology, but for higher operation frequencies.

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