183 GHz Mixer on InGaAs Schottky Diodes

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***Abstract*— This work reports on experimental results of a 183 GHz sub-harmonically pumped mixer based on InGaAs anti-parallel diode pair. The diode structure provides extremely low parasitic capacitance of about 2.5 fF. Roughly estimated series resistance junction capacitance and ideality factor 10Ω, 4fF/anode and 1.2, respectively. The optimal LO-Power is as low as 0.34 mW, whereas usable performance can be achieved even with less than 0.2 mW.**

I. Introduction

The Schottky junction is a generic technology, needed not only in space instruments but in practically all millimeter and sub-millimetre equipment, with the imaging evolving fast to become the primary area of application. During the last years the rapid progress in the development of Schottky technology has allowed efficient heterodyne receiver systems at frequencies up to 1.5 THz [1]–[3]. As the applications require a constant rise of the operation frequency, the expense of LO power used to drive the diode to the needed conductance is still a concern. A reduction of the LO frequency and thus the LO power requirements is possible by using subharmonically pumped mixers (SHM), where normally the LO is one half the RF frequency. GaAs antiparallel Schottky Diodes used in subharmonic mixer unfortunately require a significant DC bias or high LO power to drive the diode to an optimum conversion performance. Since it is difficult to bias diodes in this way the low Schottky barrier height of InGaAs material reduces the required LO power relative to diodes based on GaAs [4], [5]. Schottky barriers formed from $In_xGa_{1-x}As$ have a height that decreases with increasing indium mole fraction. A lower barrier height means that a smaller LO Power is required to effectively pump the diode. The higher electron mobility in InGaAs in comparison to GaAs should play a role in minimising the series resistance which will reduce the conversion losses especially at higher frequencies. InGaAs mixers are also very interesting for potential use in integrated InP based millimetre and submillimetre wave receivers with state-of-the-art noise performance.

II. Anti-parallel Diode Parameter Details

The anti-parallel diode (APD) was fabricated by so-called Film-Diode process, which has been particularly developed at ACST for THz devices and circuits. The diode structure is based on the Quasi-vertical diode design, developed at Technical University of Darmstadt [6] and represents a discrete Schottky structure suitable for hybrid integration. In contrast to traditional planar structures, Film-Diode fabrication implies two-side processing of the semiconductor wafer, which implies a more complex fabrication, but is more flexible concerning the reduction of structure parasitics. In turn this provides a better potential for improving performance and allows operation at higher frequencies. The APD mixer diodes use an $In_{0.53}Ga_{0.47}As$ active layer with a doping level of $8x10^{16}$ cm^{-3} which is lattice matched grown on an InP substrate. Recently Schlecht [7] discussed the principle of an $In_{0.25}Ga_{0.75}As$ based Schottky mixer, but no experimental results have been shown. Moreover the epitaxial growth of material with this indium mole fraction will not be lattice matched to InP and have much stress.

The structures have 1.2 µm anodes in diameter and estimated zero bias junction capacitance per anode is about 4fF. The employed Film-Diode approach uses a transferred membrane substrate process which provides for strongly reduced structure parasitics. The shunt capacitance of APD diodes is as low as 2.5fF. The series resistance R_s is extracted from simple I-V measurements and is slightly higher than expected. The high value of R_s, approximately 10Ω, can be caused by the wafer layout which was not optimised for mixing applications. On the other side the ideality factor η is 1.2 and is comparable to GaAs diodes. The calculated Schottky barrier height is around 0.21 eV and is about one quarter of the value for similar GaAs diodes. Figure 1 shows the typical I-V curves of an InGaAs and GaAs diode measured on-wafer. The typical turn-on voltage (1µA) for fabricated InGaAs diodes is below 50µV, which is drastically reduced in comparison to GaAs diodes.

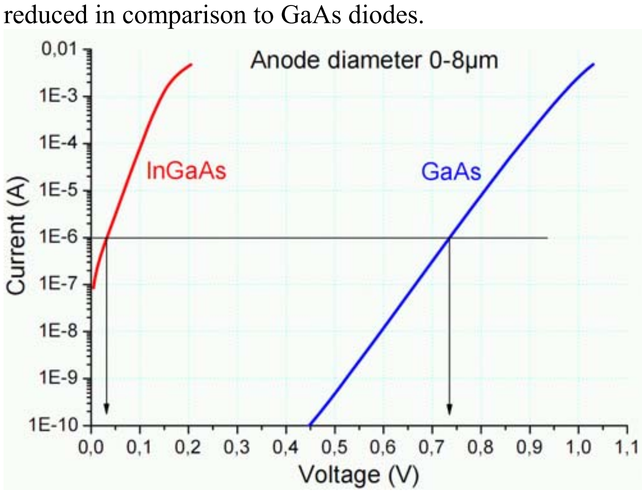

Fig. 1. Measured I-V Curves of InGaAs and GaAs Schottky Diodes

III. Subharmonic Mixer Performance

Since the InGaAs material was available for comparison with GaAs, no new mixer block was designed. A similar mixer block was used as for 183 GHz ALMA subharmonic mixers developed by RPG. The employed mixer block was originally designed for ACST GaAs diodes, which typically exhibits state-of-the-art performance of $T_{mix} \leq 450K$. The mixer design is very similar to [8] but employs discrete diode mounting. A small picture of the SHM is inserted on the left. The waveguides for RF and LO signals are fabricated from quartz and the diode is soldered using indium solder. The double sideband (DSB) noise temperature T_{sys} and conversion loss L_c of the mixer were measured using the standard Y-Factor measurement technique. One target at room temperature and another one immersed in liquid nitrogen are used at RPG as hot and cold load, respectively. The results are summarised in Fig. 2.

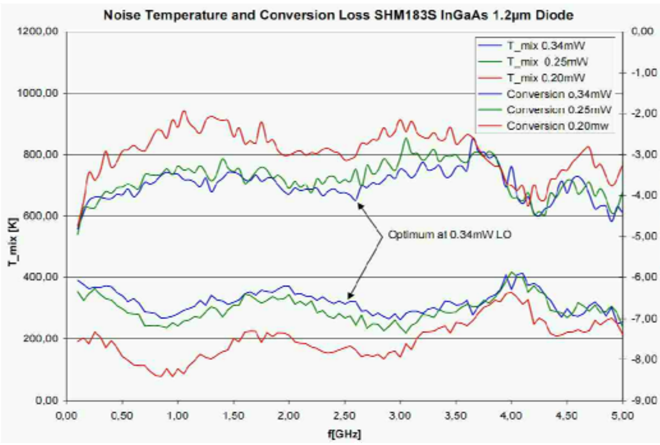

Fig.2. IF Plot showing conversion loss (right) and noise temperature of mixer for different LO powers.

The shown data is raw data from the power measurements and is not corrected for losses or mismatches in any way. It includes waveguide losses as well as the IF amplifier noise contribution. Although the measured mixer temperature is higher in comparison to state-of-the-art performance, it is still rather good and acceptable for many applications. Moreover, this can probably be improved by the optimization of wafer layout and mixer design. It has to be pointed out, however, that the optimal LO-power is as low as 0.34mW, whereas usable performance can be achieved even with less than 0.2mW. This value is at least one order of magnitude lower than typically required for GaAs-diodes.

Table 1 summarizes the sub-harmonic mixer parameter. In contrast to InGaAs mixer results, also the results for GaAs mixer are included (the values in green are the best achieved).

TABLE I

	Tmix	**Lc (DSB)**	**LO**
InGaAs	700 K	-6.6 dB	0.34 mW
GaAs	500 K (450 K)	-6.0 dB (-5.7 dB)	3.0 mW(2.2 mW)

As can be seen the mixer noise temperature, as well as the conversion efficiency is inferior to the results achieved with GaAs. However, this can be explained by the high value of R_s, which may result from the 70 nm thick active layer of the used wafer. The zero bias capacitance is slightly too high for 183 GHz which also may limit the performance of the mixer.

IV. Conclusions

The first test performed by using InGaAs antiparallel diode structures in a sub-harmonically pumped mixer, where no DC bias was required, is extremely encouraging. The receiver performance is only slightly worse than with a GaAs diode, but the Local Oscillator requirements are drastically reduced. Due to recent advances of millimetre wave power generation technology, the obtained results may be considered insignificant. However, this approach may open new perspectives for higher frequencies, where LO power is still a concern.

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