SiGeSIMMWICs

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Abstract

Millimeterwave transit time devices are monolithically integrated on high resistivity silicon substrate. The resonant structure acts as an active antenna at 76.5 GHz with a synchronization network. As a subharmonic synchronization oscillator a coplanar SiGeMMIC for 25.5 GHz power generation is described. The realized module shows a frequency tuning range of > 250 MHz which can be adjusted by the frequency of the synchronization oscillator.

Introduction

The suitability of high resistivity silicon as a substrate material for the monolithic integration of millimeter wave devices and circuits opens new possibilities for applications of high frequency techniques in commercial sensor and communication systems [1]. Two-terminal based Silicon Millimeter Wave Integrated Circuits with Schottky and IMPATT diodes for frequencies up to above 100 GHz already have been fabricated, and the suitability of silicon as the base material for monolithic integrated millimeterwave circuits has been successfully demonstrated.

In the frequency region above 60 GHz SIMMWICs with only a few millimeters dimensions may also include planar antenna structures. The integration of the antenna structures allows the direct coupling of SIMMWICs to the radiation field. Complete receivers and transmitters may be integrated monolithically using IMPATT diodes, SiGe-HBTs, PIN diodes and Schottky diodes. The SiGe HBT provides a three-terminal device which, of course, offers many advantages compared to the diode circuits. The advantages of millimeter waves are high bandwidth for communication applications, high resolution for sensor applications, and high antenna gain also with small antennas. Various applications with SIMMWICs have already been investigated [2,3,4]. For near range sensor applications SIMMWICs with IMPATT diodes operated in a self-oscillating mixer mode allow the realization of cost effective solutions.

Motivation

The distance to be covered by a radar sensor is limited by the coherence length of the free-running IMPATT oscillators [2]. An integrated transmitter for automotive applications delivered a radiated power of 1 mW at 79 GHz [5]. An excellent carrier-to-noise ratio of 81.7 dBc/Hz at an offset of 100 kHz has been achieved. However, the frequency stability of these free-running oscillators is critical and modulation is difficult. Fundamental or subharmonic injection locking using an HBT oscillator improves the coherence length of the transmitter and would enable frequency modulation. The future availability of low-cost millimeterwave components and millimeterwave monolithic integrated circuits (MMICs) will stimulate the penetration of millimeterwave technology into commercial and consumer electronics [6].
In this contribution we give an overview on the most recent developments of an active antenna for 76 GHz which can be subharmonically injection locked and on the development of the corresponding SiGeMMIC oscillators. Finally measurement results of the injection locked module are given.

SIMMWIC

SIMMWICs may find useful applications in simple near range Doppler sensors where load pulling doesn't affect the sensor operation. If a distance resolution is required or communication applications are considered a frequency stabilization scheme and a modulation input port is required. From an economical point of view we consider a synthesizer approach, i.e. the subharmonic injection locking of the mm-wave oscillator.

The mm-wave oscillator (76.5 or 61.5 GHz) consists of a double low high low IMPATT diode monolithically integrated in a planar dipole resonant structure acting as an active antenna [7]. The design of the devices is optimized with respect to the following criteria: (i) a 'robust' design which can be reproducibly realized by silicon molecular beam epitaxy (ii) a design with maximum real part of the diode impedance and (iii) a design for a high conversion efficiency [8].

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The impedance of fabricated diodes is measured with an on-wafer S-parameter measurement set-up. The impedance of the dipole structure is calculated using spectral domain methods. In contrast to former experiments with planar slot resonators no parasitic modes are observed with the dipole structure [9].

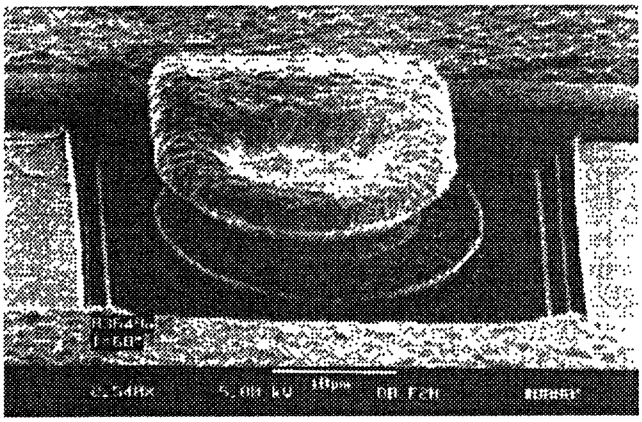

Fig.1: SEM of an integrated DLHL diode with airbridge contact. Diode diameter is 22 μm.

The dipole is located within a rat race coupler in microstrip technique providing the input ports for the synchronizing 25.5 GHz or 20.5 GHz signal. DC supply is fed to the diode through MIM capacitors.

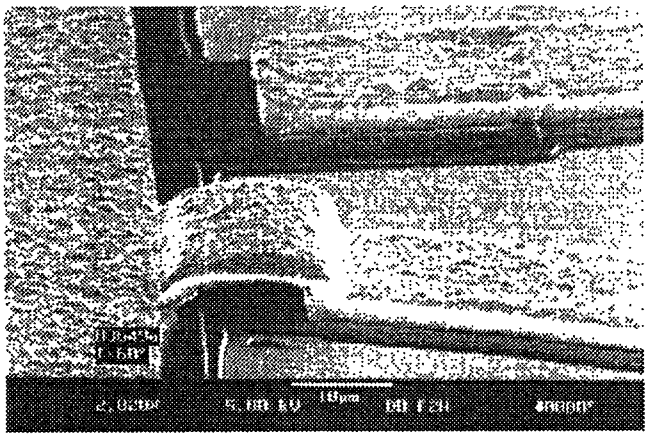

Fig.2: SEM of a MIM capacitor for the DC supply.

To obtain a high radiation efficiency a 125 μm thick high resistivity silicon substrate is used for the active dipole antenna. The total radiated power is up to 5 dBm at 76 GHz [10].

SiGeMMIC

As a local oscillator a SiGe Heterojunction Bipolar Transistor MMIC is used [11]. The n(Si) - p(SiGe) - n(Si) HBT layer sequence is grown on a n^+ buried layer on a high resistivity silicon substrate by molecular beam epitaxy. The standard design of the HBTs for MMICs is given in Tab. 1.

Collector	
Thickness (nm)	300
Doping (cm^{-3})	$5*10^{16}$
Base	
x(%)	30
icb (nm)	7
wb(nm)	25
Nab(cm^{-3})	$8*10^{19}$
ieb(nm)	2
Emitter	
Thickness (nm)	50
Doping (cm^{-3})	$1.5*10^{18}$
Ic(mA)	3
Vce(V)	5
fT(GHz)	44
fmax(GHz)	80

*Tab.1 : Design parameter and measured fT and fmax values of 1*16 μm^2 HBT devices*

The HBT oscillator circuit is realized on a 525 μm thick substrate in a coplanar line technique [12]. To suppress unwanted slotline modes airbridge connections of the ground metallization lines are required (Fig.3)

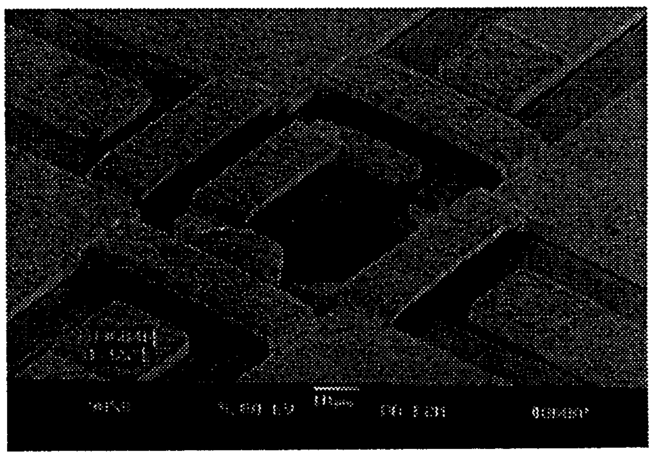

Fig. 3: SEM of a CPW-crossing with integrated HBT and air-bridged ground metallizations

The SiGeSIMMWIC module

To connect both chips a coplanar to microstrip transition is designed and separately investigated [13]. The insertion loss is below 1 dB. The transition is then realized on the chips by a coplanar contact pad on the SiGeMMIC and a microstrip contact pad on the SIMMWIC. The 125 μm thick SIMMWIC is mounted on a metallized carrier (Fig. 5) in a way next to the coplanar HBT chip that the bottom metallization of the SIMMWIC chip contacts the ground line of the coplanar chip. The microstrip and coplanar contact pads are then connected via a bond ribbon.

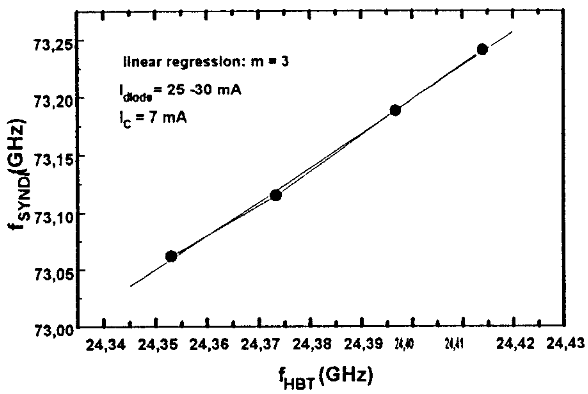

Fig.4: Frequency of the radiated mm-wave power as a function of the frequency of the SiGeMMIC. Synchronization on the third harmonic.

Synchronization by subharmonic injection locking of the mm-wave chip is obtained within a 3 dB bandwidth of > 250 MHz and an injection power of 0 dBm. Within the locking bandwidth the phase noise is solely determined by the phase noise of the injection oscillator.

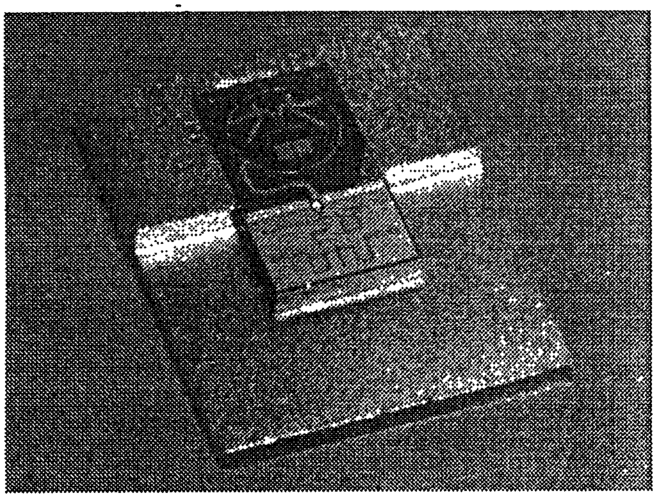

Fig.5: The SiGeSIMMWIC module

Conclusions

Based on the integration of millimeterwave transit time diodes and heterobipolar transistors on high resistivity silicon substrate a frequency stabilized active antenna module is described. This stabilized and frequency tunable unit (Fig.5) finds useful applications in near range radar sensors and short range communication links [3,14]. The expected performance improvement of the SiGeSIMMWIC technique in the near future and the basic possibility to combine millimeterwave functions with CMOS circuitry [15] will lead to new applications with cost effective solutions.

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