HIGH EFFICIENCY PLANAR OSCILLATOR WITH RF POWER OF 100 mW NEAR 140 GHZ

M. Wollitzer, J. Buechler, J.-F. Luy

Daimler Benz Research, Wilhelm-Runge-Str.11, 89081 Ulm

ABSTRACT

An integrated planar oscillator on a high resistivity silicon substrate generates an RF-power of 100 mW in D-band with a peak efficiency of 4.5 %. The single sideband S/N ratio of the oscillator is -75 dBc/Hz @ 100 kHz off carrier. The investigated disc resonator with capacitive coupling to a microstrip line is manufactured by application of micromachining techniques.

THE PLANAR OSCILLATOR

In this paper, we present recent results on the realization of planar high power oscillators in the D-band. The planar resonant structure consists of a disc resonator which is realized on a high resistivity silicon substrate with a thickness of 70 µm. The outer disc diameter is varied from 400 to 500 µm. The inner diameter of the disc is 200 µm. The 50 Ω microstrip line by which the RF-power is extracted is coupled to the disc resonator by a narrow gap with a width of 20 µm. The DC-bias is fed into the oscillator through a planar bandstop filter. The size of the chip is 2.5 x 3.0 mm. Fig. 1 gives a view of the topology of the planar resonator.
Silicon IMPATT diodes are used as the active devices. The doping profile of the active DLHL (double-Read) IMPATT transit time devices is optimized for operation in the planar circuits by use of a drift-diffusion model. Thickness and doping level of the optimized layer sequence are summarized in table 1. The weakly doped 80 nm wide central layer i contains the avalanche zone which is confined by the highly doped spikes $\delta_{p,n}$. The two driftzones are denoted $n_{n,p}$.

The active layers that are deposited on highly doped silicon by molecular beam epitaxy and are processed as beamlead diodes as has been described earlier [1]. The devices are of the same lot with those in a waveguide resonator mount where 300 mW rf-power have been obtained in D-band [2].

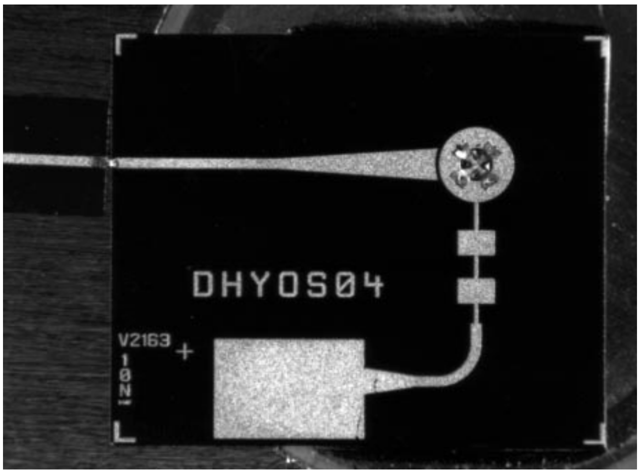

Fig.1: Layout of the planar D-band oscillator

n_n	δ_n	i	δ_p	n_p
180 nm, $1.5\cdot10^{17}cm^{-3}$	20 nm, $3.5\cdot10^{12}cm^{-2}$	80 nm	20 nm, $3.5\cdot10^{12}cm^{-2}$	120 nm, $2\cdot10^{17}cm^{-3}$

Table 1: Parameters of the IMPATT layers

The diodes are mounted in a via hole in the center of the disc resonator by thermal compression bonding

0-7803-4603-6/97/$5.00 (c) IEEE

on a metallic heatsink which also acts as a backside metallization for the planar resonant structure. Typical diameter of the diodes is 20 µm. The via hole is realized by utilizing micromachining techniques like electrochemical etching of the substrate in an aqueous KOH solution. Thermally grown SiO_2 with a thickness of 600 nm is used as an etch mask. This provides excellent reproducibility of the structural dimensions with deviations of only a few micrometers. Figure 2 shows a detailed view of a beamlead diode in an assembled planar oscillator circuit.

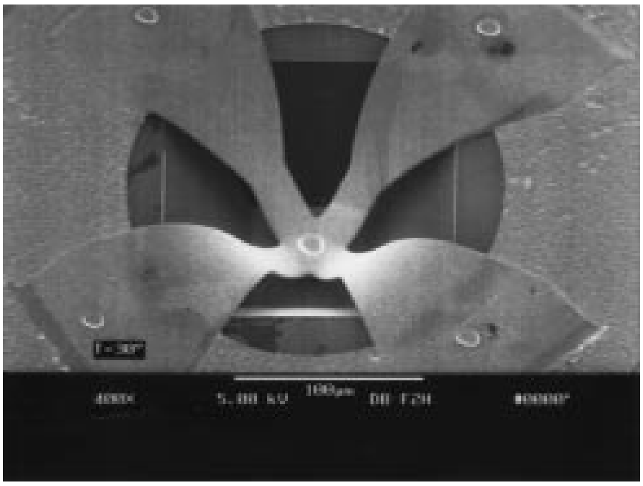

Fig.2: SEM-picture of a beamlead diode mounted in the center of a disk resonator.

MODELLING OF THE RESONATOR

The impedance which is seen at the inner radius of the disk resonator can be determined analytically [3]. Therefore the termination of the disk resonator at its outer radius is composed of its quasistatic fringing field capacitance and the radiation resistance in parallel to the wave impedance of the microstrip line, which is capacitively coupled to the disk. The coupling capacitance is determined by application of the reaction concept.

A considerable inductive load is presented to the active device by the mounting topology of the two terminal beamlead devices in the via hole. Thus, the RF impedance transformation from the device to the inner radius of the disk resonator is investigated by FDTD calculations, using a commercially available software package. The backside of the chip is not metallized. A narrow gap of 2 µm between heatsink and chip is observed when attaching the chip to the carrier with an epoxy adhesive. The effective permittivity of the layered dielectric can be estimated in the case of the considered layer sequence by

$$\varepsilon_{eff} = \frac{h_{tot}}{\frac{h_{Si}}{\varepsilon_{Si}} + \frac{h_{SiO_2}}{\varepsilon_{SiO_2}} + \frac{h_{gap}}{\varepsilon_{air}}},$$

resulting in ε_{eff} = 8.80, where the permittivity of silicon is 11.68. Assuming ε_{eff} as the permittivity of the layered dielectric between the two plates of the radial line results in an imaginary part of the impedance of the disc resonator, which is $j5\Omega$ lower at 140 GHz, compared to silicon as dielectric.

The results of the FDTD simulations which have been carried out under the assumption of the layered dielectric are plotted in figure 3 together with the impedance of an analytical model of the disc resonator. The diameter of the radial line is 450 µm. The topology of the model and extracted lumped and distributed equivalent circuits for the ribbon are depicted in figure 4.

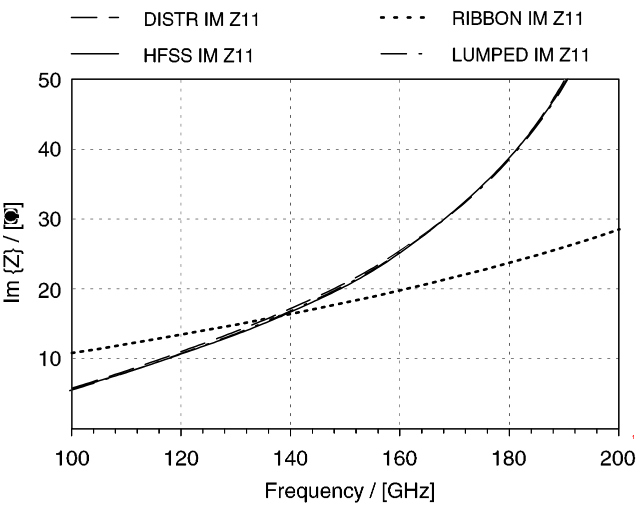

Fig. 3: Calculated imaginary part of the impedance of a disk resonator

Comparison of the theoretically estimated oscillation frequency of the planar oscillator with experimentally obtained results shows excellent agreement as can be seen in fig. 5. The load presented to the disk resonator at the outer radius by the capacitively coupled microstrip line has been modeled by the coupling capacitance of the gap in series with the wave resistance of a microstrip line with a width of 170 µm, which is the length of the coupling gap.

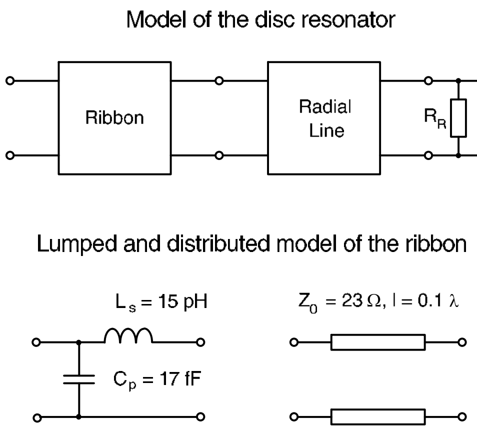

Fig. 4: Model of the disc resonator and equivalent circuits of the cross ribbon

The microstrip line is tapered to the width of the 50 Ω line. Squares indicate the calculated absolute value of the real and imaginary parts of the IMPATTs impedance. The diameter of the diode is 19 µm. An oscillation frequency of 139 GHz is predicted for the experimentally observed threshold current density of 24.5 kA/cm^2. The measured oscillation frequency is 147 GHz which is in reasonable agreement with the calculated value. A cross marks the real part of the diode's impedance at the oscillation frequency, driven at the threshold current. The calculation shows that the additional series resistances of oscillator and the diode amount to below 1.5 Ω.

MEASUREMENT

Fig. 6 shows RF-power, DC to RF efficiency and oscillating frequency over the DC-current. Maximum RF power is 100 mW, highest efficiency is 4.5 % at 147 GHz. The oscillating frequency can easily be tuned to 140 GHz by a slightly larger diameter of the active device. Fig. 7 is a plot of the RF spectrum at maximum output power. The single sideband noise is -75 dBc/Hz at 100 kHz off carrier. The results are a significant improvement over the hybridly integrated planar oscillator which emitted an rf-power of 17 mW at 112 GHz [4].

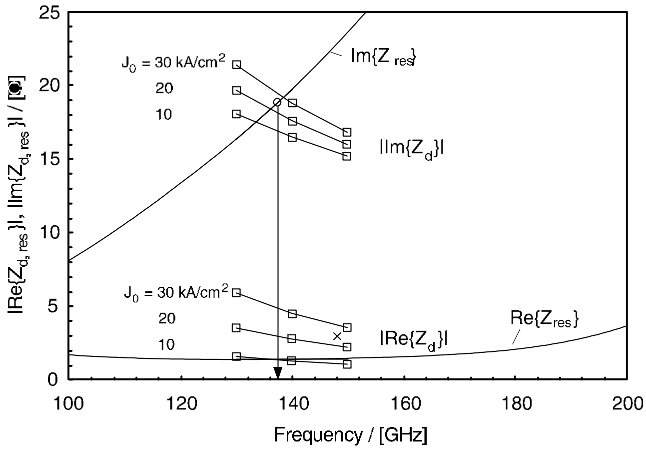

Fig. 5: Investigation of the oscillating frequency of the planar oscillator

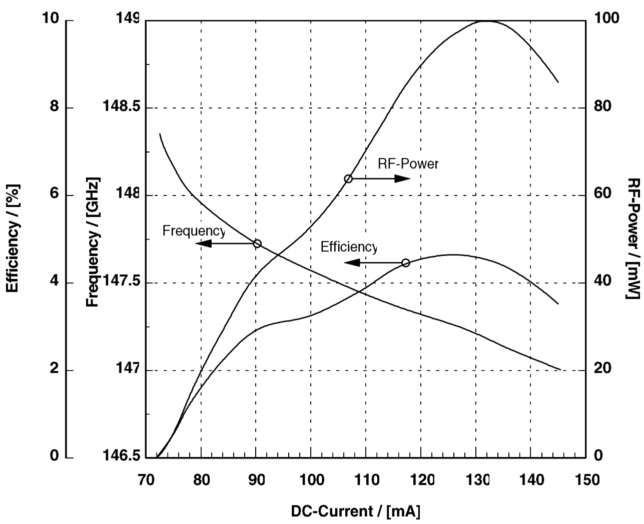

Fig. 6: RF-power, efficiency and frequency of a planar oscillator over the DC-current

A wideband microstrip to waveguide transition that was used for the characterization of PIN-swiches in E-band [5] has been redesigned and modified for the experimental characterization of the oscillators in the D-band. As is depicted in Fig. 8, FDTD calculations predict an insertion loss below 0.5 dB over several GHz bandwidth. Transmission measurements utilizing two transitions showed an experimental value for the insertion loss of below 0.8 dB near 140 GHz. The big advantage of this transition is its mechanical ruggedness and the highly reproducible assembly compared to finline transitions due to its planar layout.

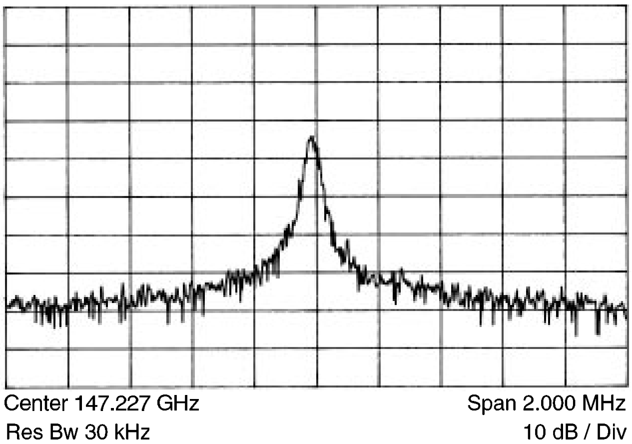

Fig. 7: Spectrum of the planar oscillator at an RF-Power of 100 mW.

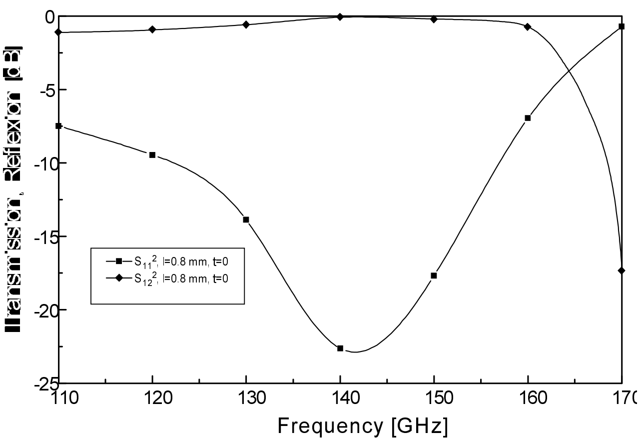

Fig. 8: Transmission loss and return loss of the microstrip to waveguide transition

CONCLUSIONS

These remarkable results indicate the high potential for the use of high ohmic silicon as substrate material for planar circuits in the upper millimeterwave range. It also demonstrates the feasibility of planar high power two terminal oscillators at frequencies beyond 100 GHz. The low weight and volume of the oscillator due to its planar topology, the high output power and its mechanical ruggedness make it attractive for high resolution automotive radar systems. Future developments could lead to a monolithically integrated planar disc oscillator that has been shown at lower frequencies in V - and W-band in [6]. The implementation of a varactor will also improve the functionality of the oscillator as part of a millimeterwave frontend.

LITERATURE

[1] M. Wollitzer, J.-F. Luy, J. Buechler, 'D-band high power IMPATTs made by MBE', *Proc. of the Intern. Workshop of the German IEEE Joint MTT/AP Chapter*: 'Silicon Based High Frequency Devices and Circuits', Günzburg-Schloß Reisensburg, Nov. 10-11, 1994.

[2] M. Wollitzer, J. Buechler,F. Schäffler, J.-F. Luy.: 'D-band Si-IMPATT diodes with 300 mW CW output power at 140 GHz', *Electron. Letters*, 1996, **32**, pp 122, 123.

[3] J. Buechler in: J.-F. Luy and P. Russer (Eds):'Silicon-based millimeter-wave devices', (Springer series in electronics and photonics: 32, 1994), Chap. 5.

[4] U. Güttich, J. Wenger, 'Planar D-Band Oscillator on Semiinsulating GaAs', *AEÜ*, 1988, vol 42, pp. 388-389.

[5] A. Klaassen, H.-E. Sasse, 'E-Band Monilithic Silicon PIN Diode Switches', *Proc. of the Intern. Workshop of the German IEEE Joint MTT/AP Chapter*: 'Silicon Based High Frequency Devices and Circuits', Günzburg-Schloß Reisensburg, Nov. 10-11, 1994.

[6] K. M. Strohm, J. Buechler, E. Sasse, F. Schäffler, J,-F. Luy, 'Monolithic Integrated Radiating 55-72 GHz Disc Oscillators', *Proc. of the Intern. Workshop of the German IEEE Joint MTT/AP Chapter*: 'Silicon Based High Frequency Devices and Circuits', Günzburg-Schloß Reisensburg, Nov. 10-11, 1994.