Film-Diode Process – a breakthrough technology for THz-Electronics

By Dr.-Ing. Oleg Cojocari
cojocari@acst.de
ACST GmbH: Company profile

- Founded in 2006 as a Spin-Off from TU Darmstadt
- First European commercial supplier of Schottky components for THz-Applications
  - Originally-developed fabrication technology, particularly developed for mm-wave and THz-applications
  - Discrete and monolithically-integrated Schottky-structures with state-of-the-art performance
  - So far the only European supplier of Zero-Bias Diodes for THz-applications
- Close collaboration with leading institutions concerning development of THz-technology
  - Space agencies (ESA, DLR, CNES)
  - Universities (TU Darmstadt, TU Berlin, TU Duisburg, TU Erlangen-Nuremberg, …)
  - International industry partners
- Leading Schottky technology with state-of-the-art performance
  - First ultra-wideband Schottky detector (75GHz-1.5THz, in year 2008)
  - First all-European 660GHz Heterodyne receiver with unprecedented performance
  - Integrated RTD-oscillator with highest ever reported oscillation frequency (1,111 THz)
- Anticipated participation in ESA MetOp Second Generation Program
Planar and vertical structures

Planar structure

- Schottky
- Ohmic
- Semiconductor

- No back-side process needed
- Nonuniform distribution of the current density

Vertical structure

- Schottky
- Ohmic
- Semiconductor

- Uniform distribution of the current density across contact area
- Back-side processing required
QVD Design Concept

Whisker-Contacted Diodes (WCD)

- Vertical structure
- Low parasitics
- Unreliable contact
- No integration possible

Quasi-Vertical Diode (QVD)

- Quasi-vertical structure
- Reduced series resistance
- Good heat-sink
- Suitable for integration.
Thermal simulations

Whisker-contacted diode (WCD)
- Whisker
- 70µm thick GaAs
- Contact pad
- 5µm anode
- Whisker
- 70µm thick GaAs

Planar Surface Channel Etched Diode (SCE)
- Contact pad
- 5µm (flip-chip) anode
- Anode-lead

Quasi-Vertical Diode (QVD)
- Back-side contact pad anode
- 5µm Air-bridge

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Comparative simulation results

The impact of mesa thickness on thermal performance of a QVD

Comparative results of considered structures

- QVD
- WCD
- SCE

Graphs showing the relationship between max. temperature (K) and dissipated power (mW) for different mesa thicknesses (h=1μm, h=2μm, h=3μm, h=4μm, h=5μm).
ACST APD by FD-process

- Quasi-vertical approach
- Transferred membrane substrate
- Suitable for both discrete structures and integrated circuits
- Accommodates beamleads, MIM-capacitors, two-level wiring...
- Aims at ultimate performance at MM/SubMM waves
332GHz Doubler IC

332GHz Doubler IC mounted in a WG-Block

Fabricated 332GHz doubler Integrated Circuit

In collaboration with RPG Radiometer Physics GmbH
332GHz Doubler performance

- Limited input power of about 40mW-50mW is insufficient to fully characterize the doubler.
- No sign of saturation: fully-pumped doubler should provide more output power.
- Higher input power would result in a higher output power.

In collaboration with RPG Radiometer Physics GmbH
332GHz Tripler IC

In collaboration with RPG Radiometer Physics GmbH
RPG 183GHz mixer with ACST APD

Typical conversion gain and noise temperature of a 183GHz subharmonic (LOx2) mixer.

- Noise temperature less than 500K over full IF-band.
- Integration times up to 200 sec. show no sign of instabilities or deviation from the radiometer law.

Allan Variance of a 183GHz mixer, operating in a switched-noise stabilised radiometer.
RPG 424GHz mixer with ACST APD

LO Power: 5 mW

Conversion = -7 dB

\[ T_{\text{mix}} = 800 \text{ to } 1200 \text{ K} \]

\[ T_{\text{sys}} = 1800 \text{ K} \]

Gain drop and NF rising of the Miteq Amplifier

casted be spurious LO harmonics
Fabricated 664GHz Mixer IC

Measured mixer performance

Side view of a free-standing IC

In collaboration with RPG Radiometer Physics GmbH
First all-European 664GHz receiver system

664GHz Mixer mounted with test horn, 332GHz Tripler, Isolator, powerful W-band source (x6 internal)

In collaboration with RPG Radiometer Physics GmbH
Zero-Bias Detector diodes

Discrete Diode mounted on CPW

Back-side contact pads

- Low video-resistance / high current responsivity;
- Optically-transparent membrane-substrate;
- Suitable for monolithic integration (THz-MIC);
- The technology is suitable for frequencies well beyond 1THz.

DC-Diode characteristics

- Diode current
- Differential resistance
- Current responsivity

Current (mA) vs. Voltage (mV) graph
InGaAs built-in voltage (barrier height) significantly lower than GaAs (0.2eV compared to 0.8eV)

(Reduced LO power required for SHM at 183 GHz: 0.34 mW (10 dB less!)

In collaboration with RPG Radiometer Physics GmbH
## Achieved Performance (RPG)

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Conversion L</th>
<th>LO power</th>
<th>Noise temperature</th>
<th>Noise temperature (old)</th>
</tr>
</thead>
<tbody>
<tr>
<td>183GHz InGaAs</td>
<td>-6.5dB (DSB)</td>
<td>0.34 mW</td>
<td>Tsys 800K (DSB no correction) Tmix 700K</td>
<td>-</td>
</tr>
<tr>
<td>183GHz GaAs</td>
<td>-4.2dB (DSB)</td>
<td>2 mW</td>
<td>Tsys 525K (DSB no correction) Tmix 430K</td>
<td>Tsys 750K (-6.0dB L) RPG</td>
</tr>
<tr>
<td>432GHz GaAs</td>
<td>-7.0dB (DSB)</td>
<td>5 mW</td>
<td>Tsys 1700K (DSB no correction) Tmix 1100K</td>
<td>Tsys 2700K (-9.7dB L) RPG</td>
</tr>
<tr>
<td>660GHz GaAs Integrated</td>
<td>-8.0dB (DSB)</td>
<td>4mW</td>
<td>Tsys 2300K (DSB no correction) Tmix 1600K</td>
<td>-</td>
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</tbody>
</table>

### Doubler

<table>
<thead>
<tr>
<th>Input power</th>
<th>Output Power</th>
<th>Efficiency</th>
<th>DC Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>44mW</td>
<td>11mW</td>
<td>&gt;20%</td>
<td>7V</td>
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</table>

### Tripler

<table>
<thead>
<tr>
<th>Input power</th>
<th>Output Power</th>
<th>Efficiency</th>
<th>DC Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>67mW</td>
<td>6mW</td>
<td>9%</td>
<td>8V</td>
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</tbody>
</table>
ACST THz Detector Module

Si-Lens  Antenna  Zero Bias Diode  Pre-Amp
Antenna integrated Zero-Bias diode
UWB measurements at TUD

Photoconductive generated CW THz signal modulated with 200kHz.
UWB measurement results

Measurement conditions:

Uncollimated Toptica photomixers.
Diameter of beam: approx 50 mm
Diameter of Golay cell window: 6 mm
Diameter of lens SBD: 12 mm
FTIR measurements at DLR

Courtesy of the department THz-Instrumentierung, Institut für Planetenforschung
Response time measurement at ANKA
• Real pulse length in the accelerator: about 14ps.
• Detector response: about 25ps. The delay is considered to be due to limitations of the SMA connector.
• HTS (YBCO) hi-temperature superconductor. -detector-20ps.
RTD-based THz-MIC

In collaboration with TUD
Mounting approach

Gold-bumps are used to increase local pressure while keeping low total pressure on the pad.

Mounted circuit by thermo-compression via insulator membrane

Gold-bump Array on contact-pads

Thin-film resistor
Assembled RTD-oscillator

In collaboration with TUD
Oscillation frequencies up to 1111 GHz. This is the highest RTD-oscillation frequency reported so far.

In collaboration with TUD
Thank You!