Investigation of Millimeter Wave Membrane Supported Structures up to 110 GHz

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Outline

- Introduction
- Model description
- Simulations
- Equivalent circuit
- Experimental results
- Conclusions

Introduction

- Investigation of membrane supported millimeter-wave TLs up to 110 GHz
  - Modeling
    - EM simulations (CST MWS)
    - Equivalent circuit
      - Effective permittivity
      - Characteristic impedance
  - Experimental results
    - Scattering parameters

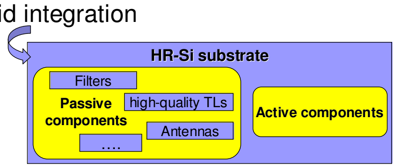
Comparison

Applications

- Millimeter wave imaging
  - automotive collision avoidance radars
  - enhanced vision systems
  - concealed weapon detection
  - medical field
- Working bands -> local minimum in atmospheric attenuation
  - 35 GHz, 94 GHz, 140 GHz and 220 GHz
- Requirement
  - integration of high performance passive circuits fabricated on thin dielectric membranes with active/semiconductor devices (Schottky diodes, transistors, MMICs) mounted on silicon bulk

Why use membranes?

- Reduced losses
- Reduced dispersion
- Suppression of higher order substrate modes
- TL with high characteristic impedance and ε~1
- Hybrid integration



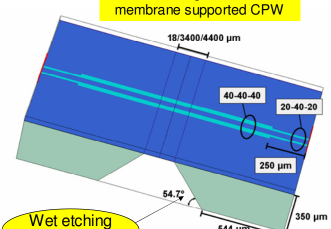
Layer structure

- High-resistivity silicon substrate
  - ρ≥5kΩ·cm
  - ε_{Si}=11.9
  - 350 µm
- Dielectric membrane (ε_r=5)
  - 0.8 µm SiO_2
    - Thermal oxidation
  - 0.6 µm Si_3N_4
    - Chemical vapor deposition
- Metallization
  - 2 µm Au (σ=3*10^7S/m)
    - Electrochemical deposition

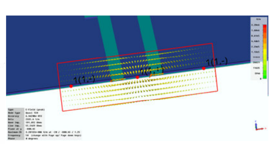
Geometry

- Parametric CST model

Three lengths for the membrane supported CPW



Wet etching KOH 30%

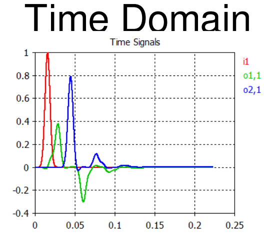


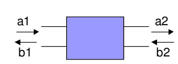
Waveguide multi-pin port => Q-TEM propagation

EM modeling problem

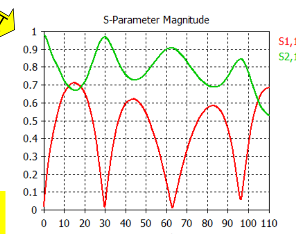
- The accurate modeling of the transition from silicon bulk to dielectric membrane

Time Domain Simulation





DFT

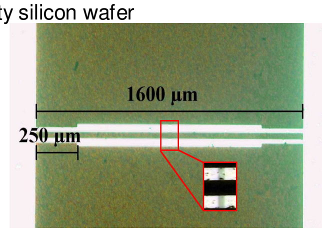


Broadband simulations in a single sweep!

"The time domain solver calculates the development of fields through time at discrete locations and at discrete time samples"

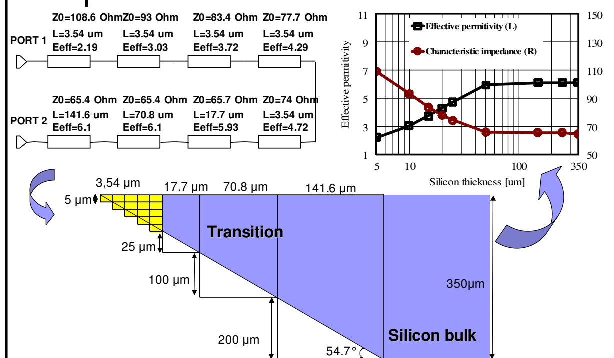
Test structures

- Several test structures were micromachined on a high resistivity silicon wafer



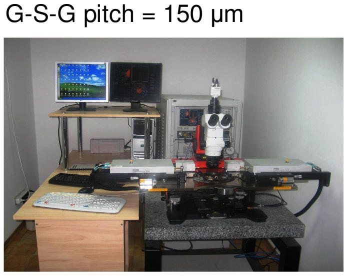
Zero-length transmission line and detail of the transparent membrane

Equivalent circuit



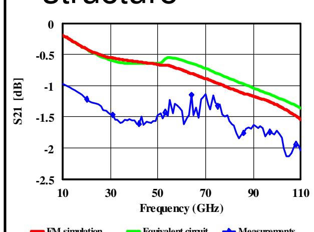
Experimental setup

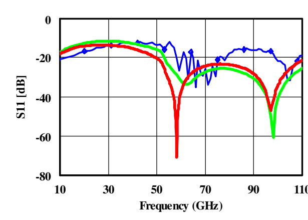
- SOLT calibration
- G-S-G pitch = 150 µm



VNA ANRITSU 37397D (up to 110 GHz) with Karl Süss on wafer characterization system

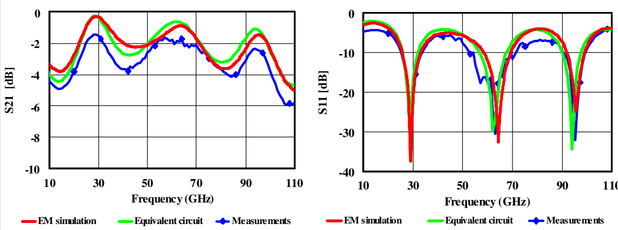
The S-parameter for the ZLTL structure





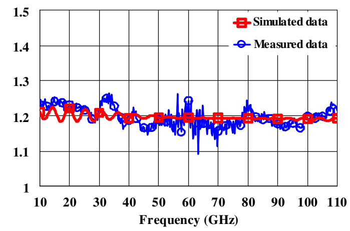
- Length of the membrane supported CPW-TL = 18 µm
- Insertion losses of 1-2 dB up to 110 GHz
- Good agreement between EM simulations, equivalent circuit approach and measurements

The S-parameter for the LLTL structure



- Length of the membrane supported CPW-TL = 4400 µm
- Insertion losses of 2-6 dB up to 110 GHz
- Good agreement between EM simulations, equivalent circuit approach and measurements

The extracted effective permittivity



$$\gamma = \frac{1}{\Delta L}\,\mathrm{arg\,ch}\left(\frac{S_{11}^{B}S_{22}^{A} + S_{11}^{A}S_{22}^{B} - \Delta_A - \Delta_B}{2 - S_{21}^{B}S_{12}^{A}}\right)$$

$$\Delta L = L_B - L_A$$

$$\Delta_A = S_{11}^{A}S_{22}^{A} - S_{12}^{A}S_{21}^{A}$$

$$\Delta_B = S_{11}^{B}S_{22}^{B} - S_{12}^{B}S_{21}^{B}$$

$$\varepsilon_{eff} = \frac{\mathrm{Im}(\gamma)}{\omega^2 \mu_0 \varepsilon_0}$$

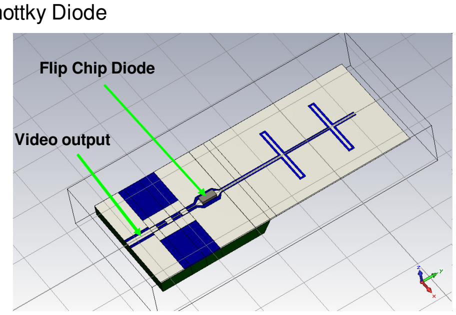
- The effective permittivity of the membrane supported CPW line was extracted from both measurement and EM simulated results
- The extraction method was based on wide band S parameters measurements for two transmission lines of different lengths
  - test structures SLTL and LLTL
- Good agreement between simulation and measurements

Conclusions

- Investigation up to 110 GHz of membrane supported circuits
  - fabricated using HR silicon micromachining
- EM simulations and equivalent circuit model approaches
  - validated by experimental results
- Good agreement between measurements and simulations for the extracted effective permittivity of a membrane supported CPW line
- The success of this investigation opens a window of opportunity for the accurate modeling and design of complex W-band front-ends that integrate high performance millimeter wave passive circuits fabricated on thin dielectric membranes with active/semiconductor devices (Schottky diodes, transistors, MMICs) mounted on silicon bulk.

Project perspectives

- Receivers with membrane-supported antenna and Schottky Diode



Thank you
for your attention!