Si metal-oxide-semiconductor field-effect transistor for THz detection

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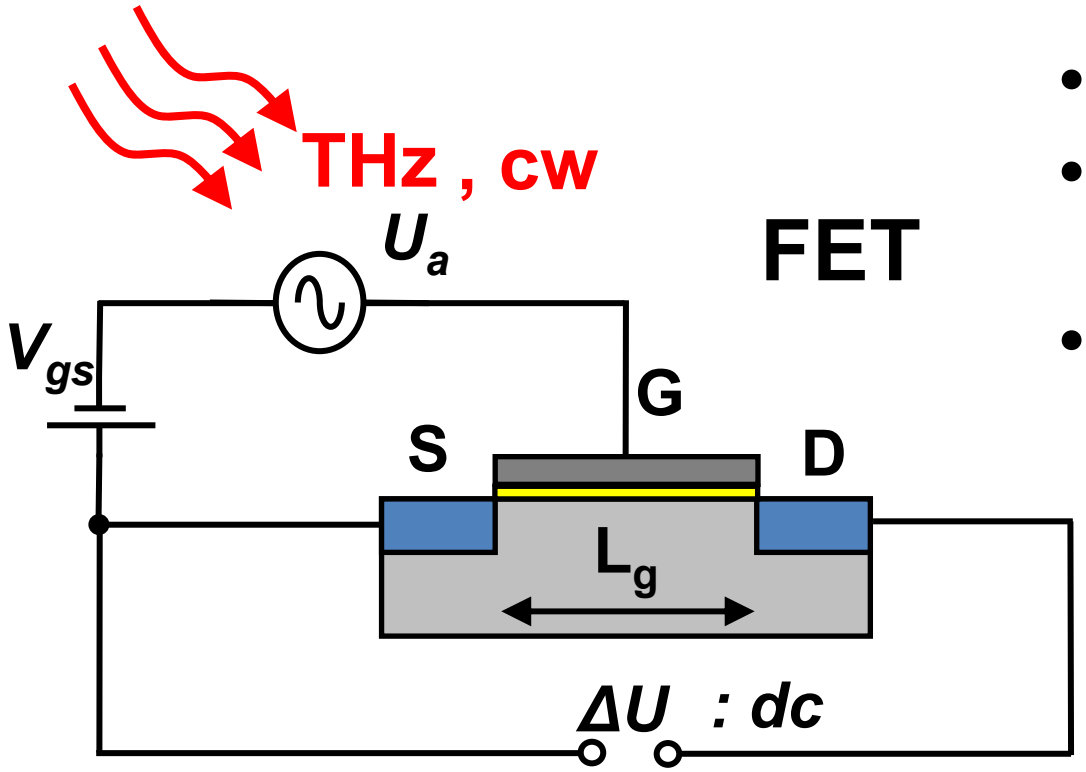
"Functional Nanomaterials and Devices….", Kyiv, April 8-11, 2013

Outline

1. Introduction - Si MOSFETs as THz detectors
2. Design and fabrication of detectors
3. Results: resonant detection @ 340 GHz
4. Conclusions

Experiments on THz excitations in FETs



- *Vgs*: Source-Gate bias
- *Ua*: irradiation induced *ac* voltage
- *ΔU*: *dc* photoresponse

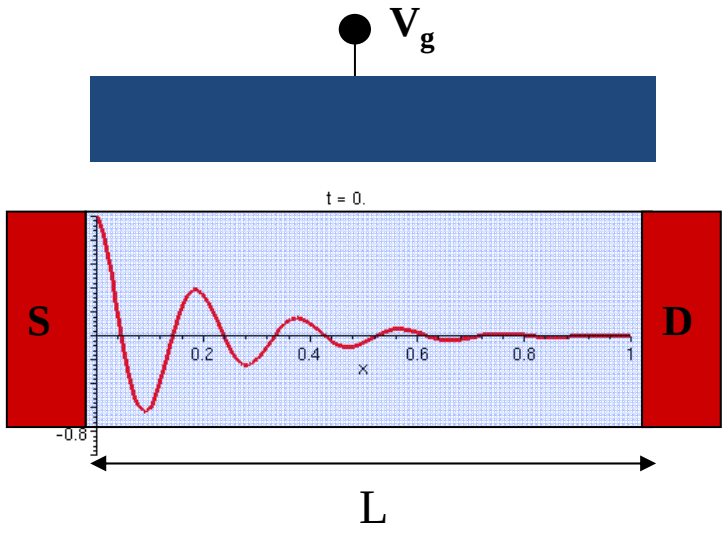
!!Nonlinearity – THz modulates simultaneously !!carrier density and drift velocity!!

"Functional Nanomaterials and Devices….", Kyiv, April 8-11, 2013

Regimes of plasma waves (high mobility/ frequency)

$\omega\tau >> 1$ Plasma waves are weakly damped

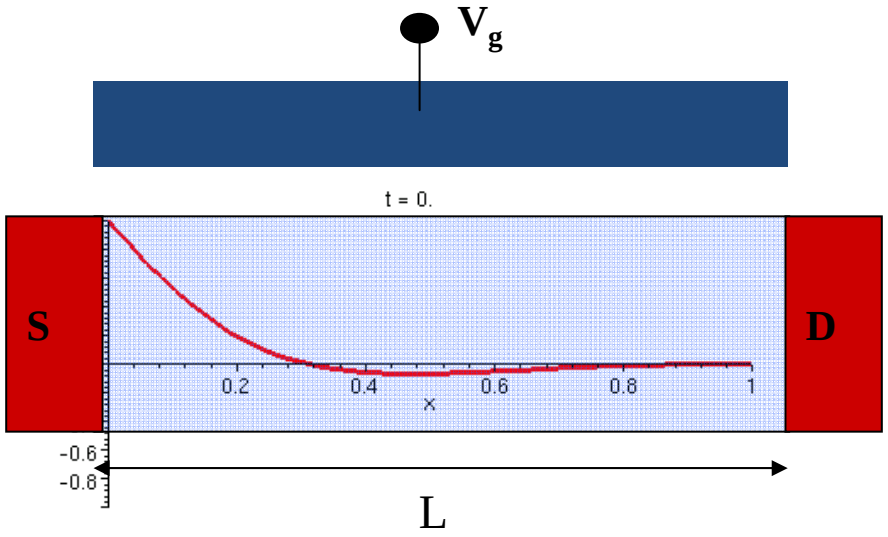
Characteristic damping length: $l = s\,\tau$



Long gate: $L >> s\tau$

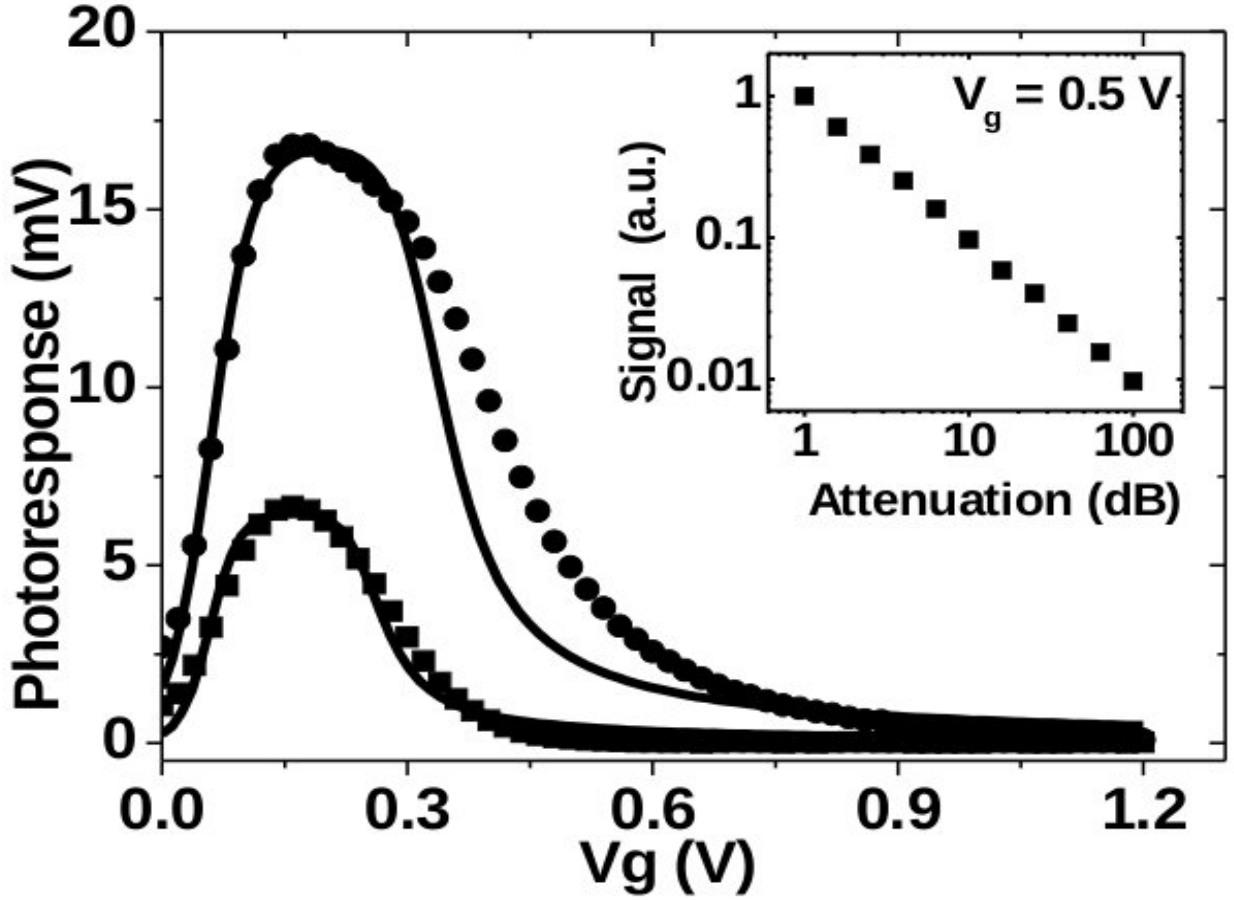
300K , Silicon – low mobility - overdamped plasma oscillations

$$\omega\tau << 1$$



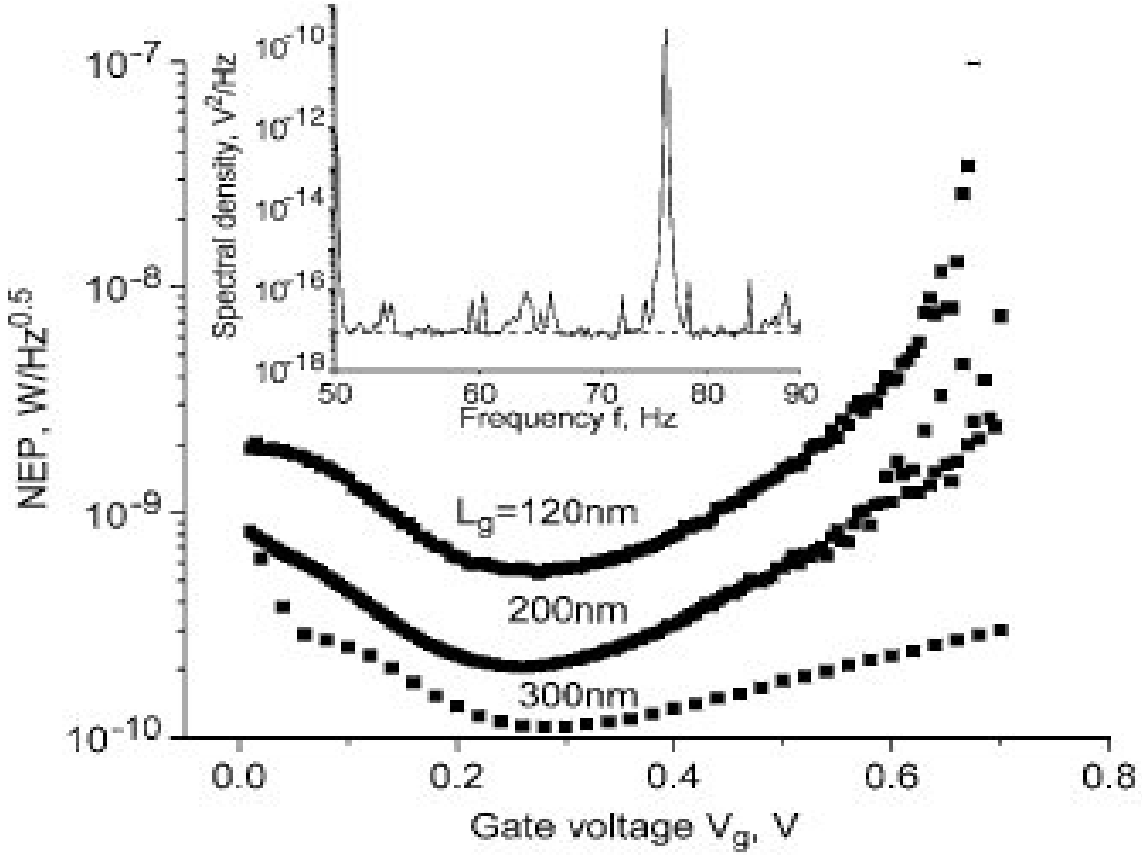
Characteristic length: $l = s\sqrt{\tau / \omega}$

Si MOSFETs as THz detectors (2)



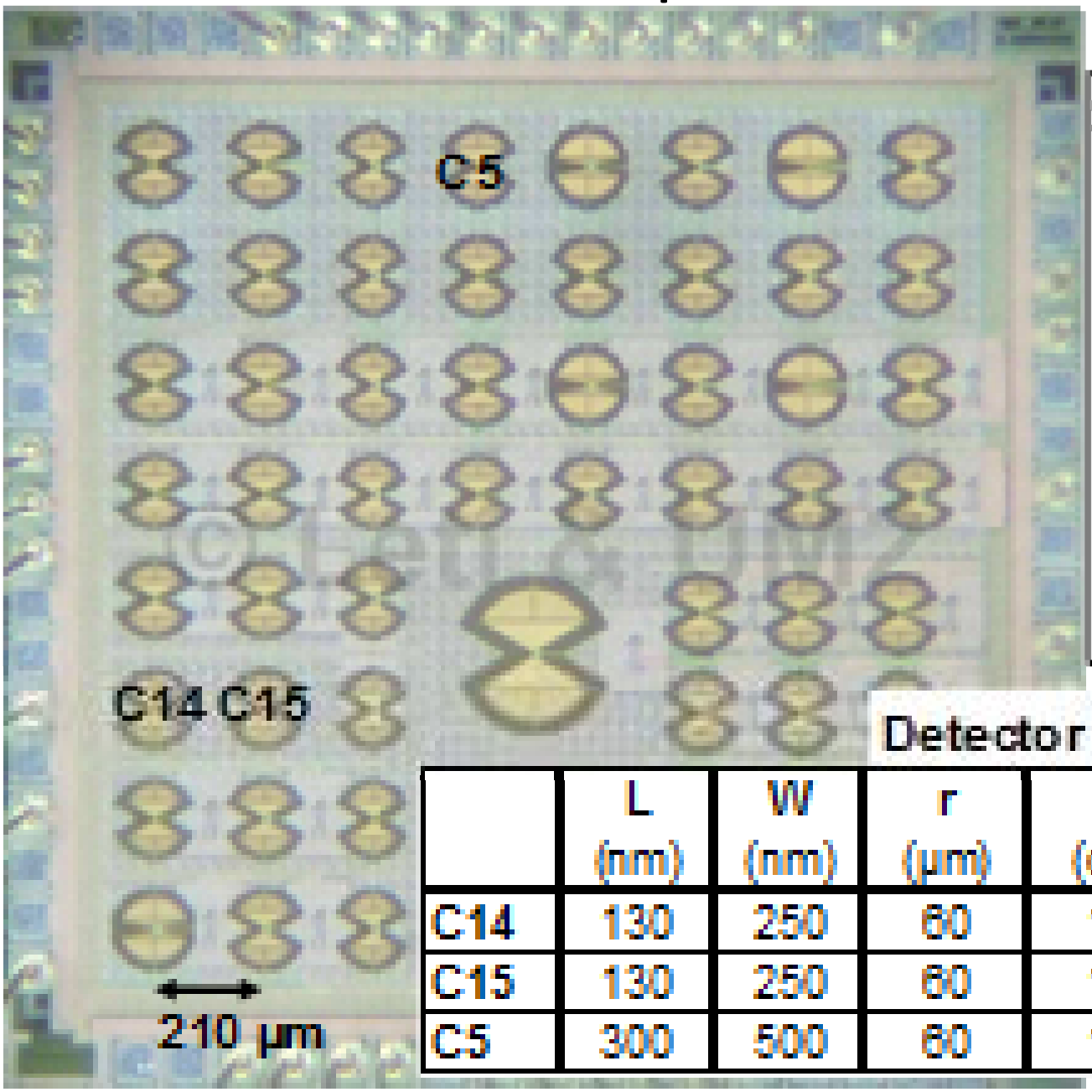
Plasma wave detection of sub-terahertz and terahertz radiation by silicon field-effect transistors
W. Knap et al., Appl. Phys. Lett. 85, 675 (2004)

Si MOSFETs as THz detectors (3)

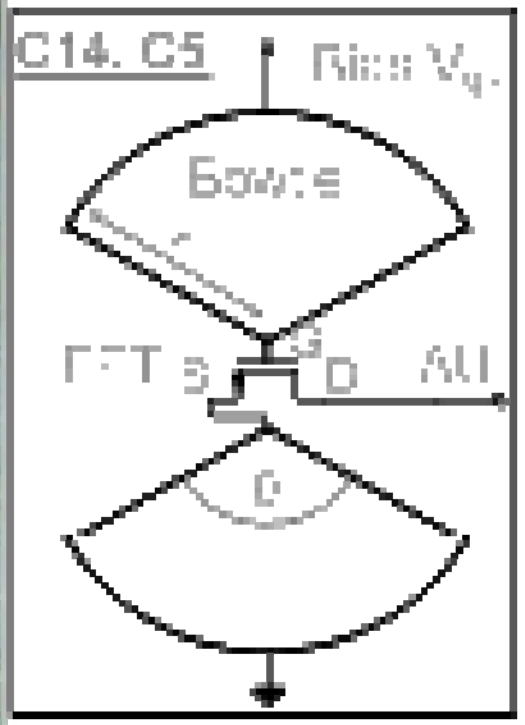


Plasma wave detection of terahertz radiation by silicon field-effect transistors: Responsivity and noise equivalent power
R. Tauk et al., Appl. Phys. Lett. 89, 253511 (2006)

0.13µm CMOS

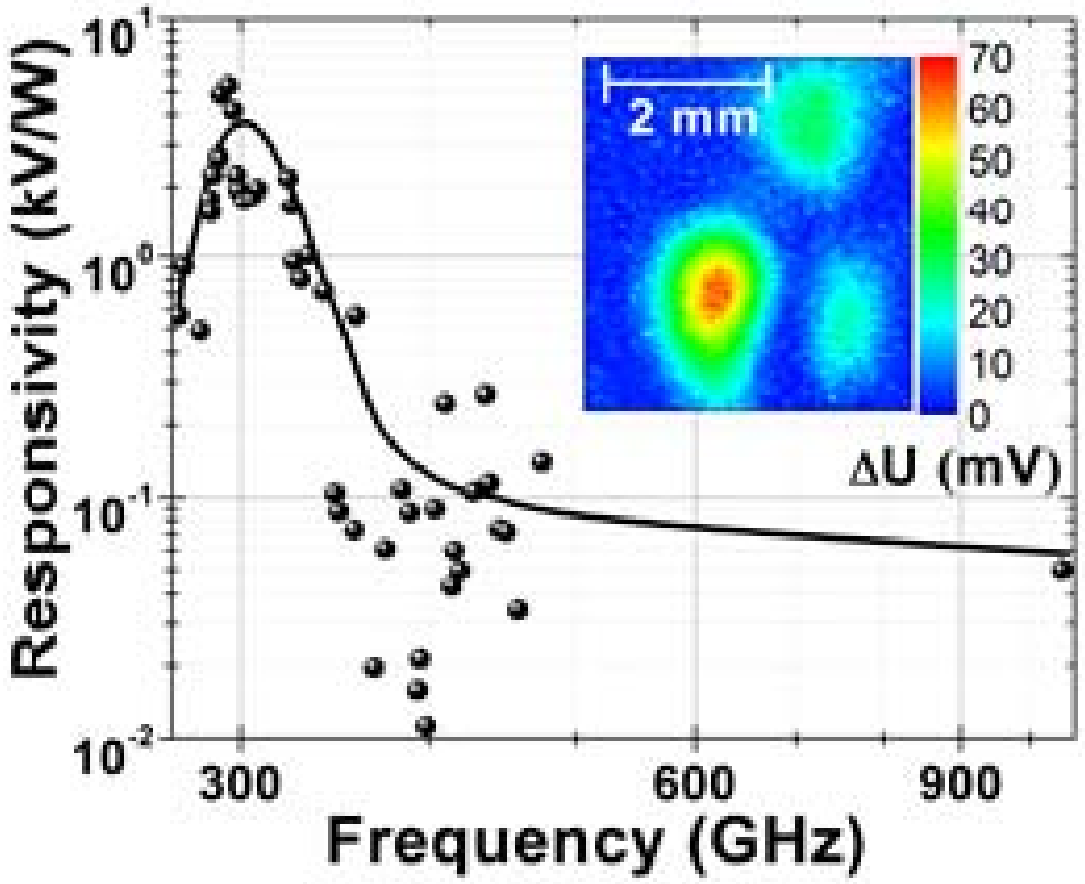


Schematic



Detector Characteristics

	L (nm)	W (nm)	r (µm)	θ (deg)	Antenna Connection
C14	130	250	60	120	gate-source
C15	130	250	60	120	source-drain
C5	300	500	60	120	gate-source



"Broadband terahertz imaging with highly sensitive silicon CMOS detectors,"

F.Schuster et al

Optics Express, vol. 19, pp. 7827-7832, (2011)

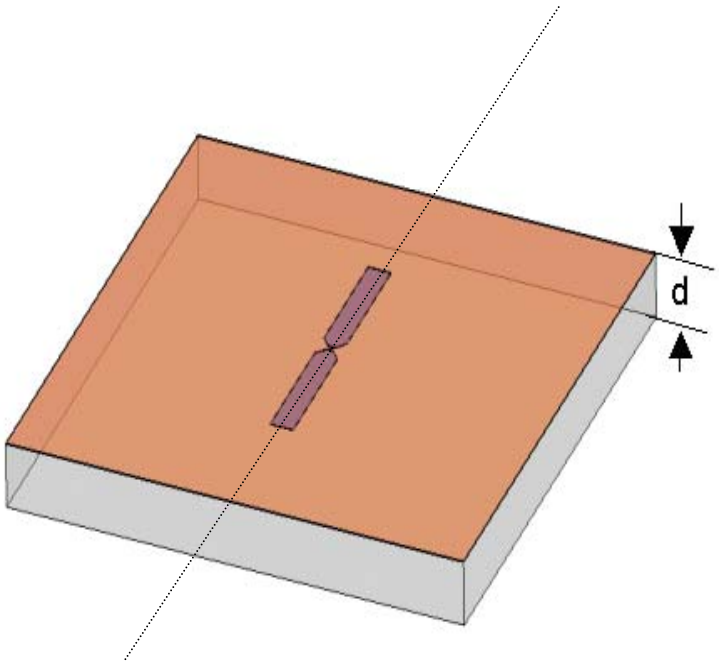
Laser Focus World, vol. 47(7), pp. 37–41, (2011)

Si MOSFETs as THz detectors (5)

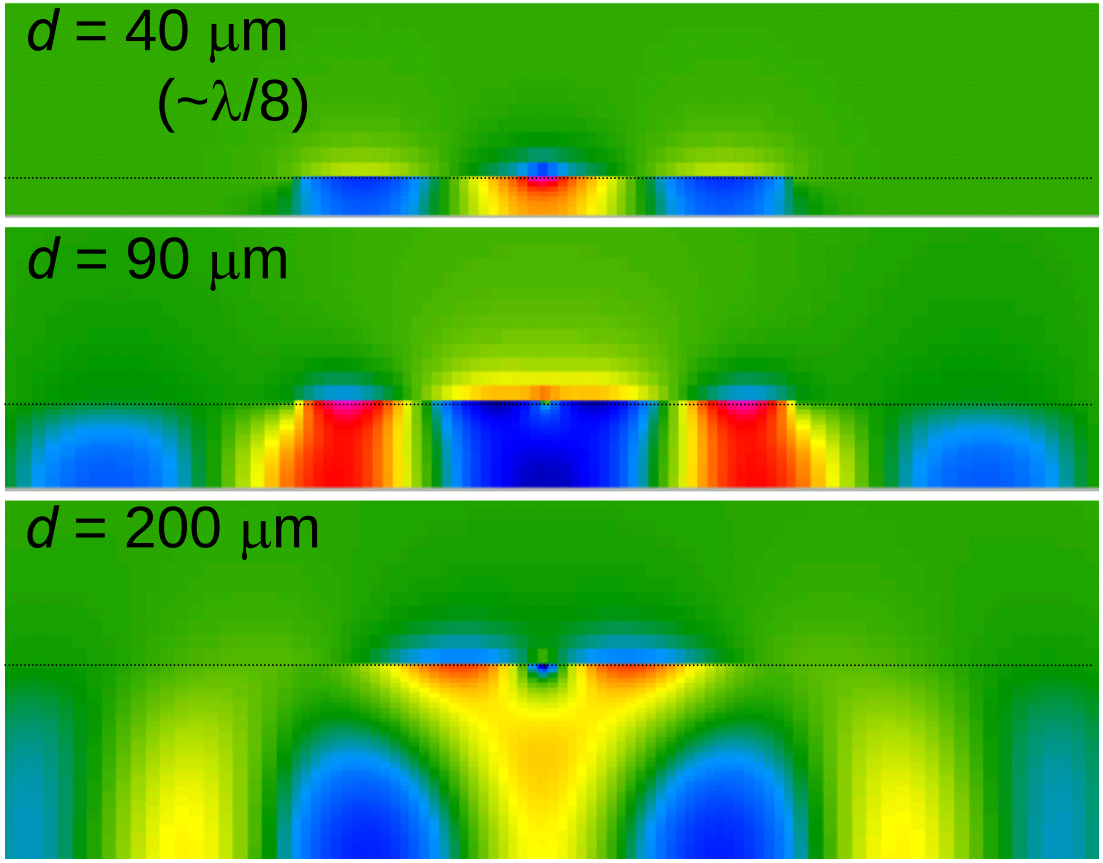
Main directions of development:
(Germany,USA,Japan & Poland ITE initiative)
- multipixel arrays ,- heterodyne detection
- on-chip integration with amplifiers
-special antennas design
-(ITE, PW, WAT,UV initiative)

The goal:
to achieve a resonant (spectrally narrow) response with a non-resonant (spectrally broad) MOSFET

Antennas design and technology (2)

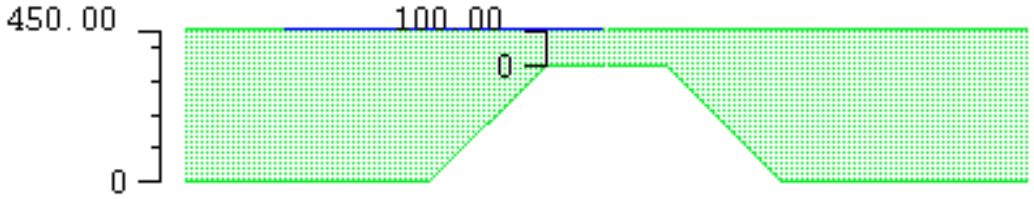


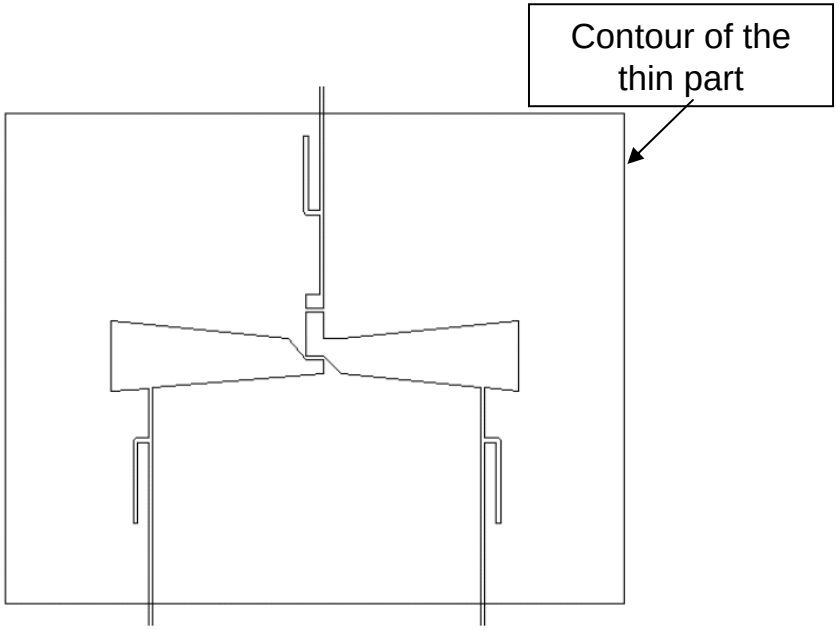
Printed dipole on thick silicon (ε_r = 11.65) substrate



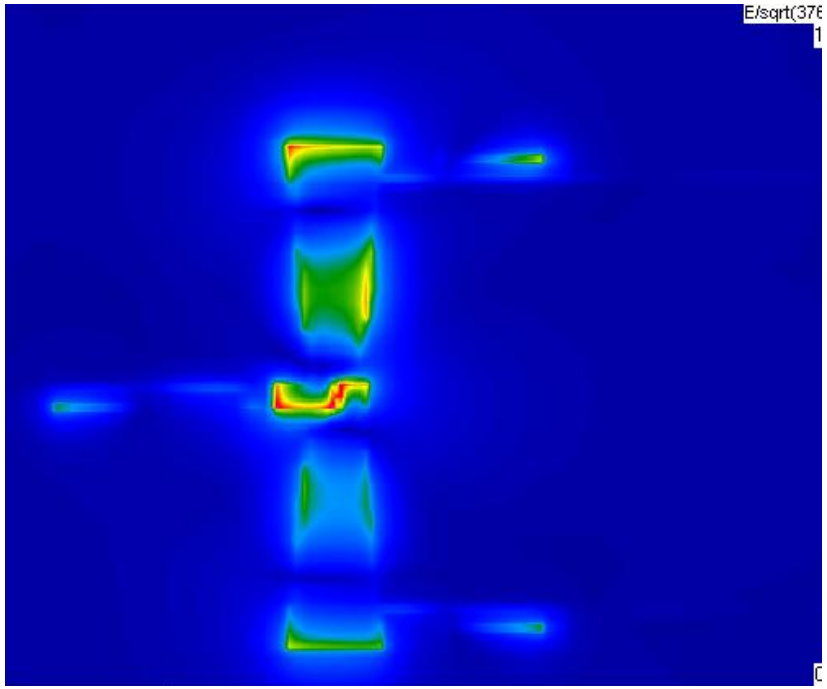
Instanteneous H-field distribution in the axial-plane of antenna (f = 300 GHz)

Antennas design and technology (3)

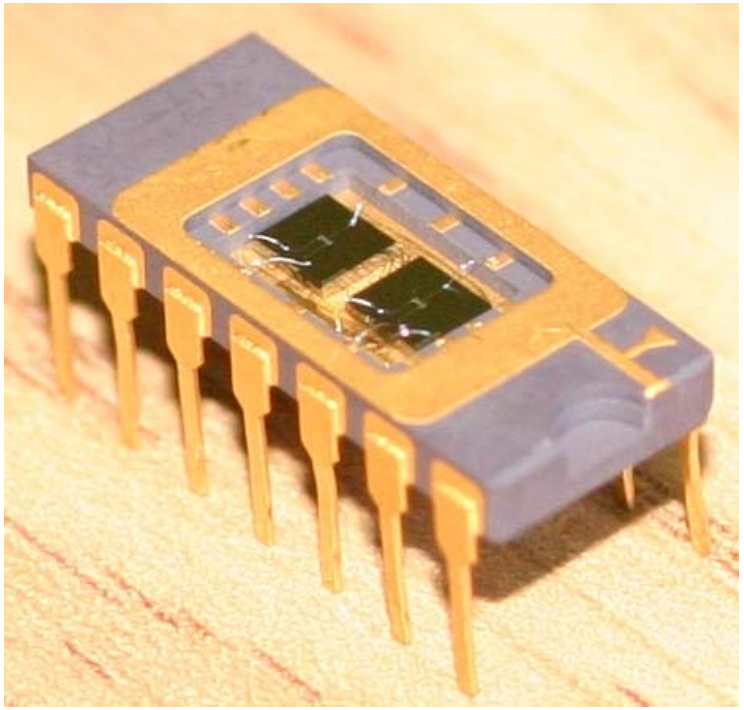


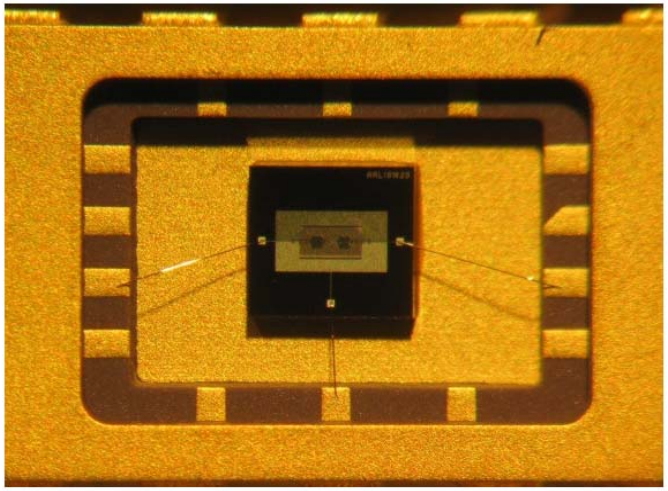


Example geometry of bow-tie antenna on thinned-down substrate

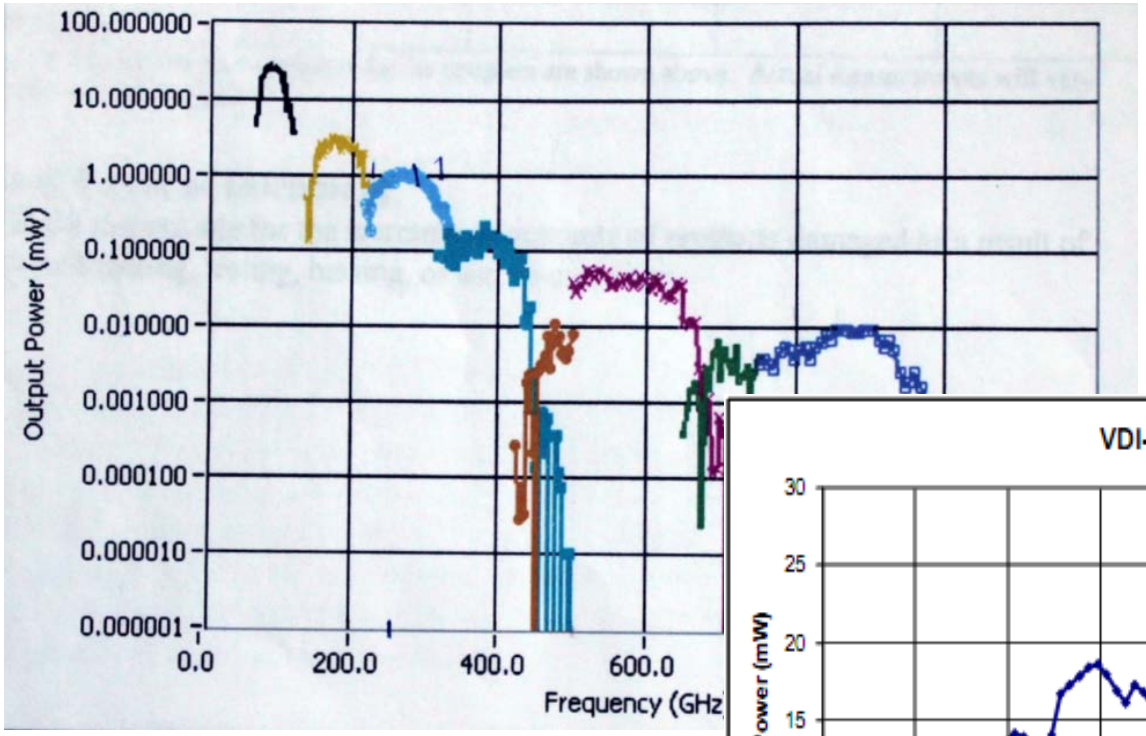


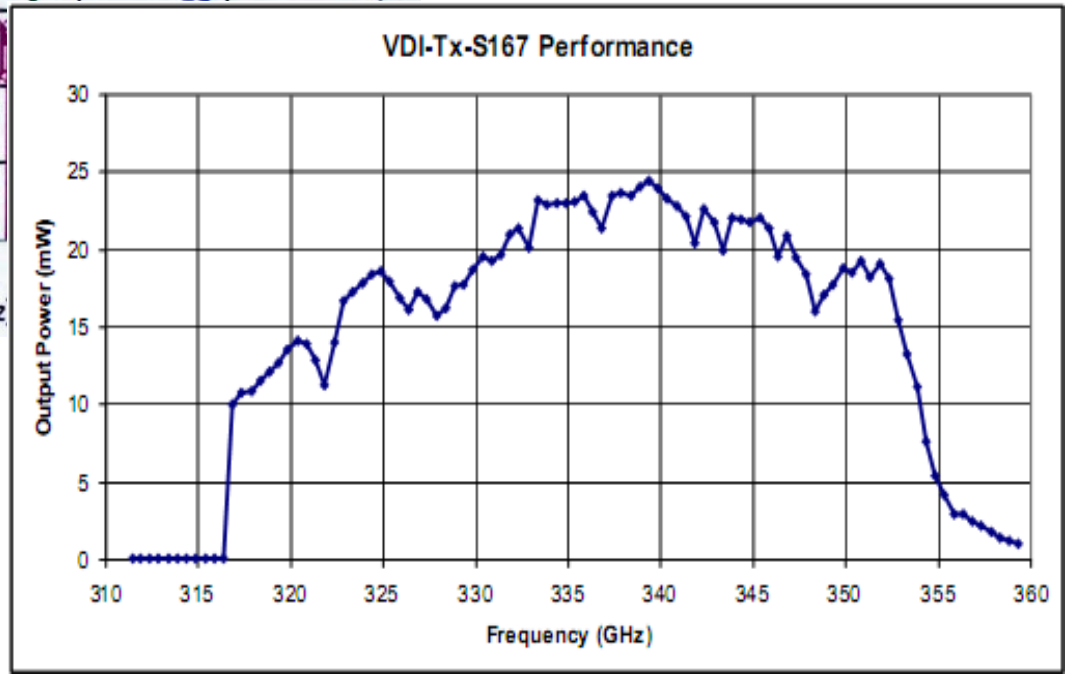
The dominating E-field component magnitude (TM_{00})

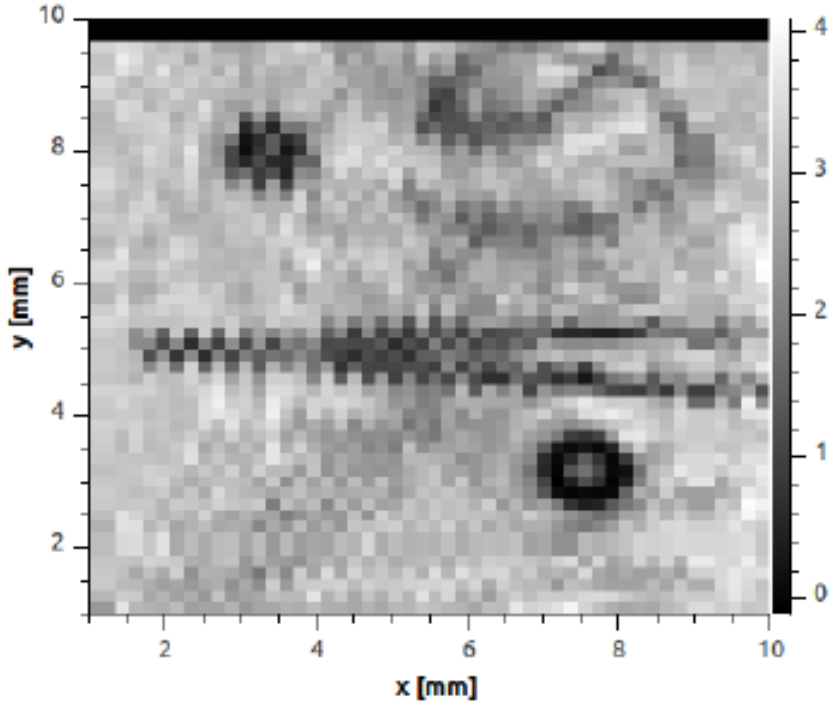


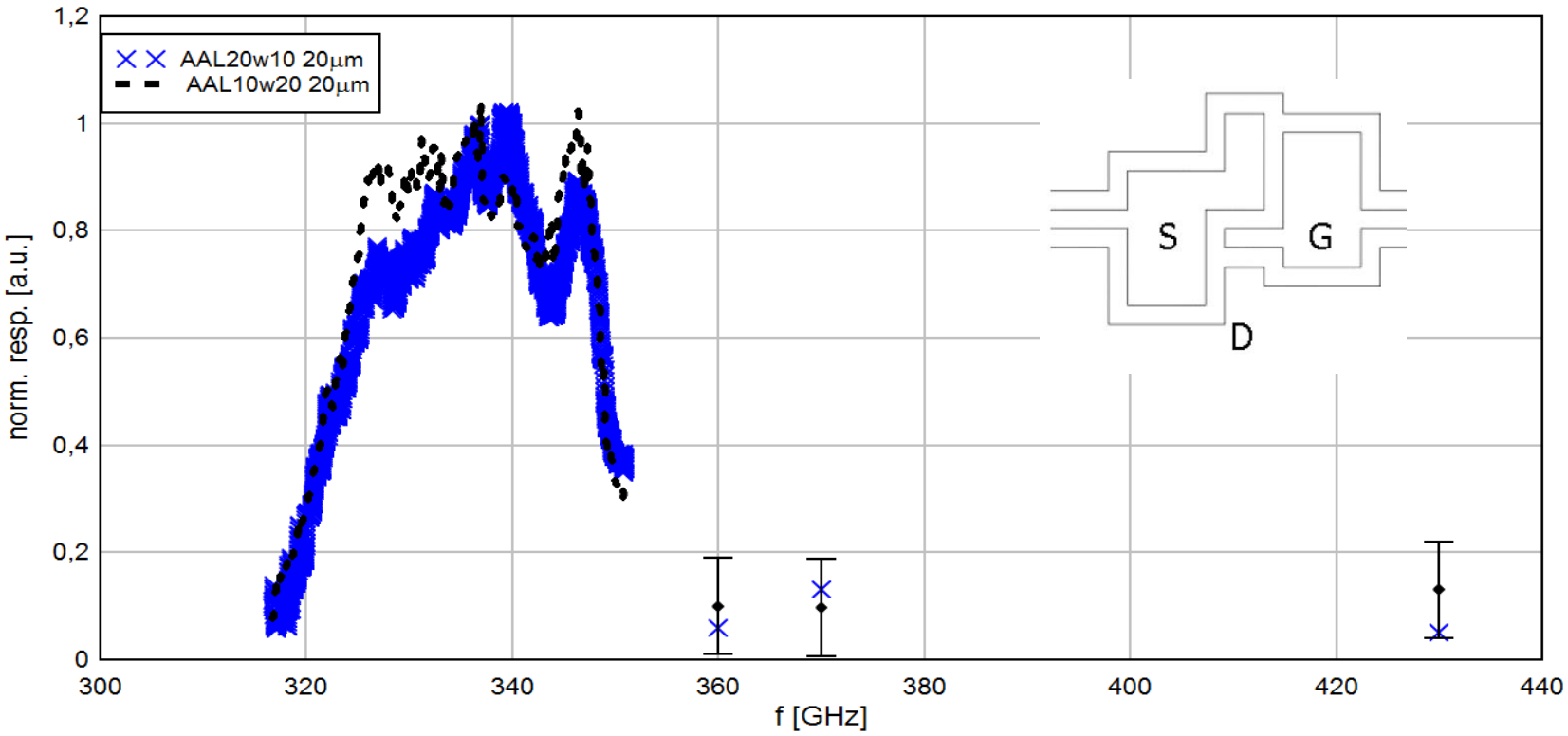


VDI multipliers



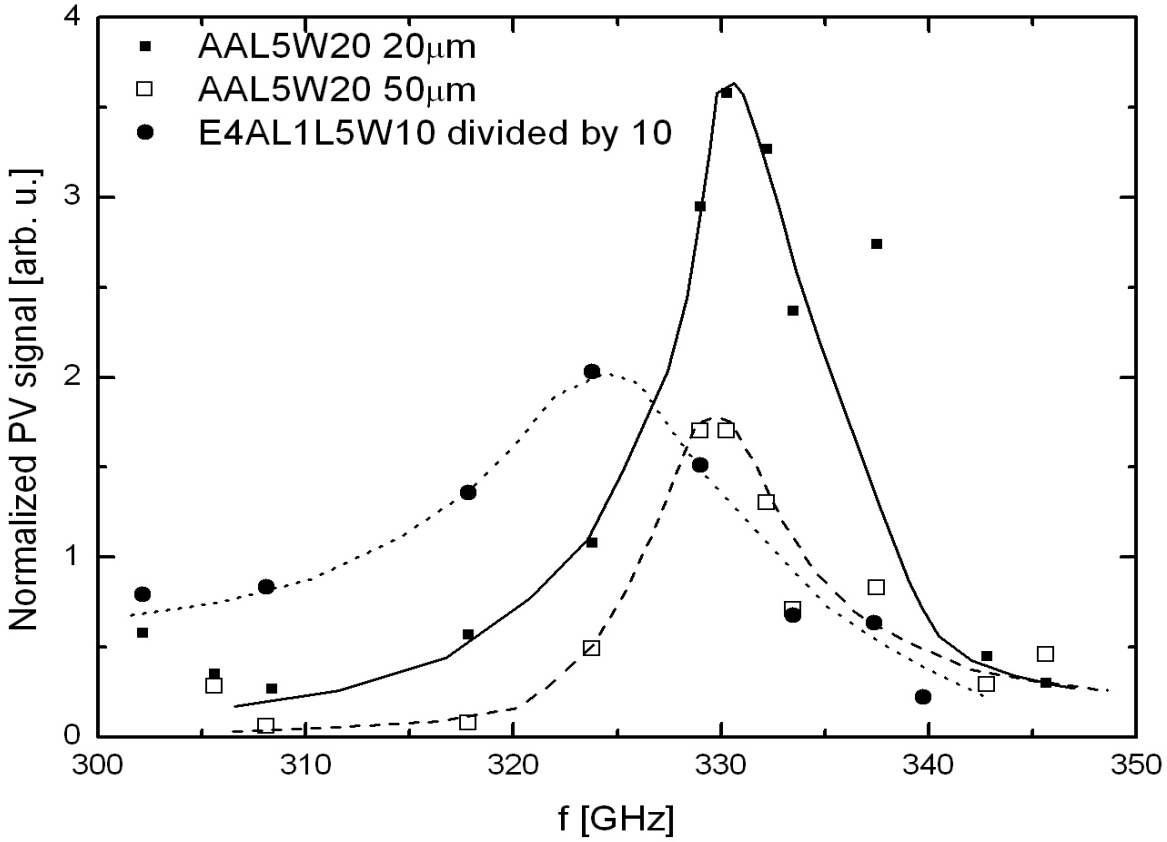



y [mm]
x [mm]
10
8
6
4
2
2
4
6
8
10
4
3
2
1
0



Antennas were calculated for f=340GHz,
Δ f=20GHz

Experiment and results (2)



Conclusions

1. **Original Si FET technology for THz detectors**

2. **Good results for detectors fabricated on a thinned substrate**

3. **A sharp resonanses aound 300GHz suitable for spectroscopy applications**

Acknowledgments

The work was supported
by The National Centre for Research and Development, Poland
under grant
"Multipixel detector of THz radiation based on selective MOS transistors and its application in biology, medicine and safety installations", PBS1/A9/11/2012

Thank You – recent references to review papers

W. Knap and M. I. Dyakonov, *'Field effect transistors for terahertz applications'* in D. Saeedkia, **Handbook of terahertz technology for imaging, sensing and communications, Cambridge, Woodhead Publishing, 121-155(2013)**

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W Knap, S Rumyantsev, M S Vitiello, D Coquillat, S Blin, M Shur, A Tredicucci and T Nagatsuma *Nanometer size field effect transistors for terahertz detectors* **Nanotechnology 24 (2013)**