ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Université de Neuchâtel unine

# Study and improvement of THz Quantum Cascade laser beam-pattern for different waveguides configurations


*M. I. Amanti, C. Walther, M. Fischer, G.Scalari, J.Faist*

***Institute of Physics, University of Neuchâtel, Switzerland***
***From July 2007 ETHZ Zurich***



***Collaboration with:***
J.N Hoverier and J.R. Gao
Kavli Insitute of Nanoscience Delft

Financially supported by:

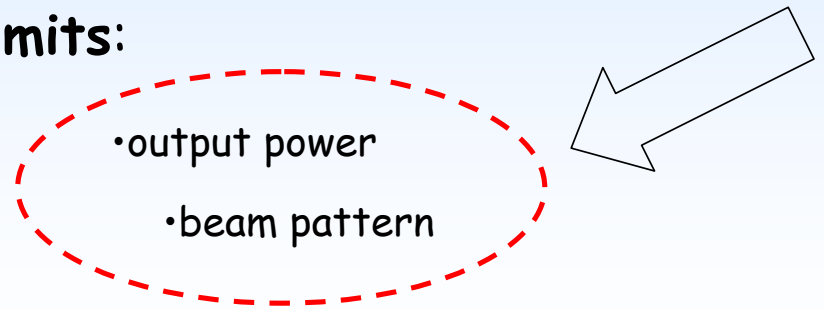
quantum qp photonics
National Centre of Competence in Research

THz Quantum cascade lasers (QCL) are emerging as new useful laser sources in the THz spectral range, working from 60 to 250μm

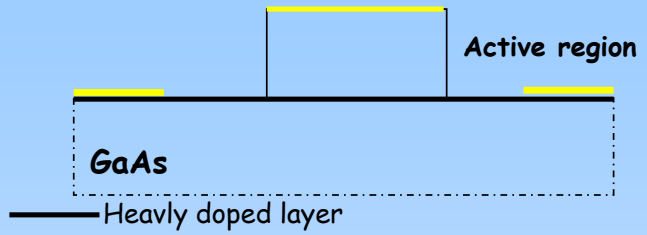
## Terahertz quantum cascade applications:

- Imaging (medical, security application)
- Local oscillator for heterodyne receiver in astronomy
- Spectroscopy

## Limits:

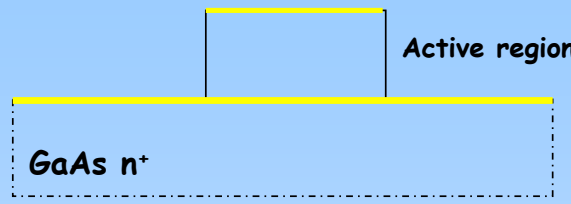


## Single plasmon waveguide




**One interface plasmon+one bounding doped layer**

## Double metal waveguide




**Active region sandwiched between two metal layers**

## Advantages

- high output power
- narrow beam pattern
- higher operating temperature
- higher overlap of the optical mode with the active region

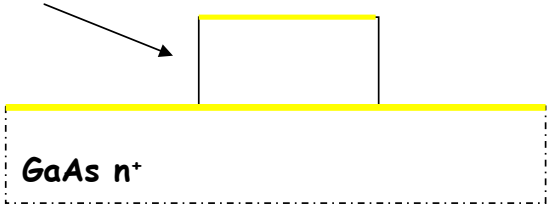
## Disadvantages

- low operating temperature
- appearance of interference rings in the beam pattern
- highly divergent beam pattern
- low output power

*A.J. L Adam et al APL 88, 151105 (2006)

# Double metal waveguide

**active region (~13μm)**

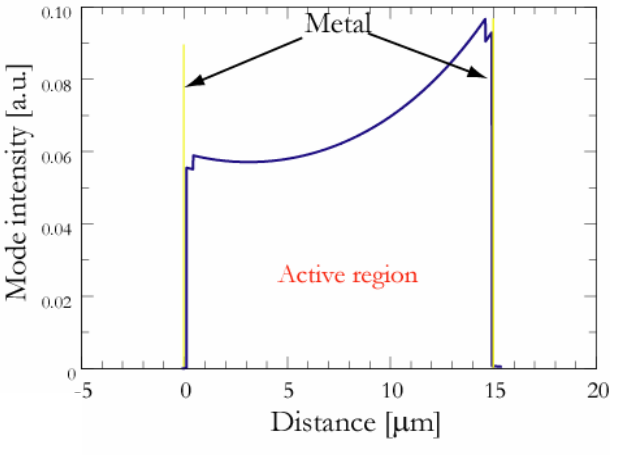



The active region is sandwiched between a top metal contact and a metal substrate, as in common ***microwave microstrip***

Laser mode is completely confined in the active region

**Due to subwavelength vertical dimension**

**laser beam highly divergent**

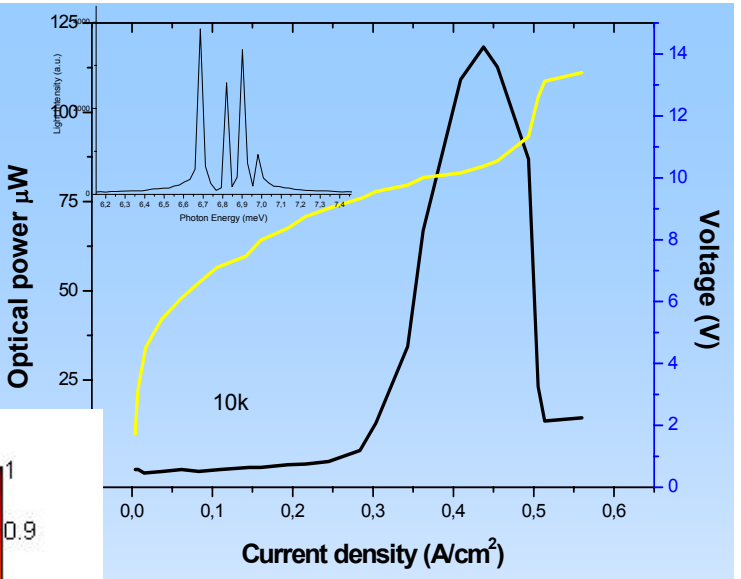


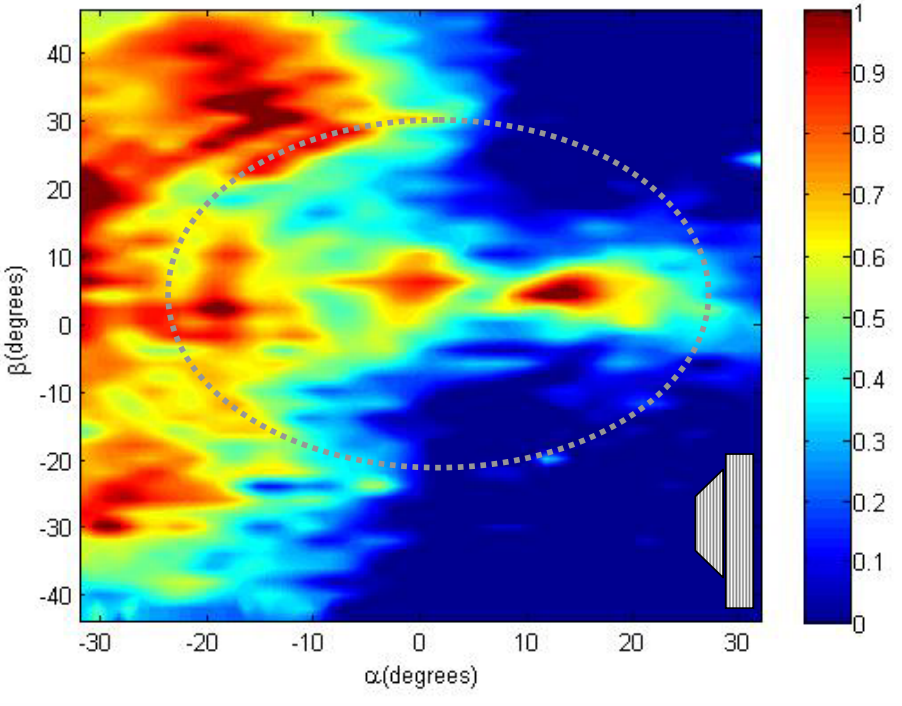

**high facet mirror reflectivity**

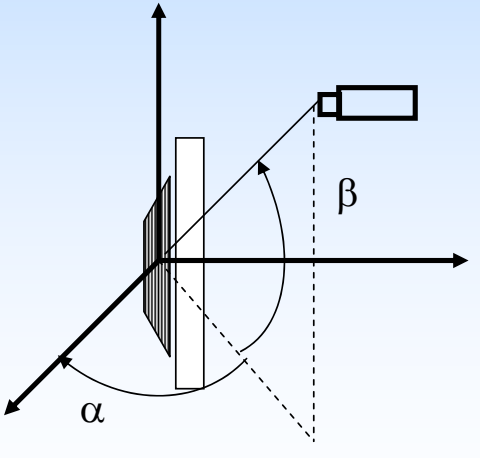
# Study of the beam pattern

λ~175μm operating in CW

Optical power hundreds of μW



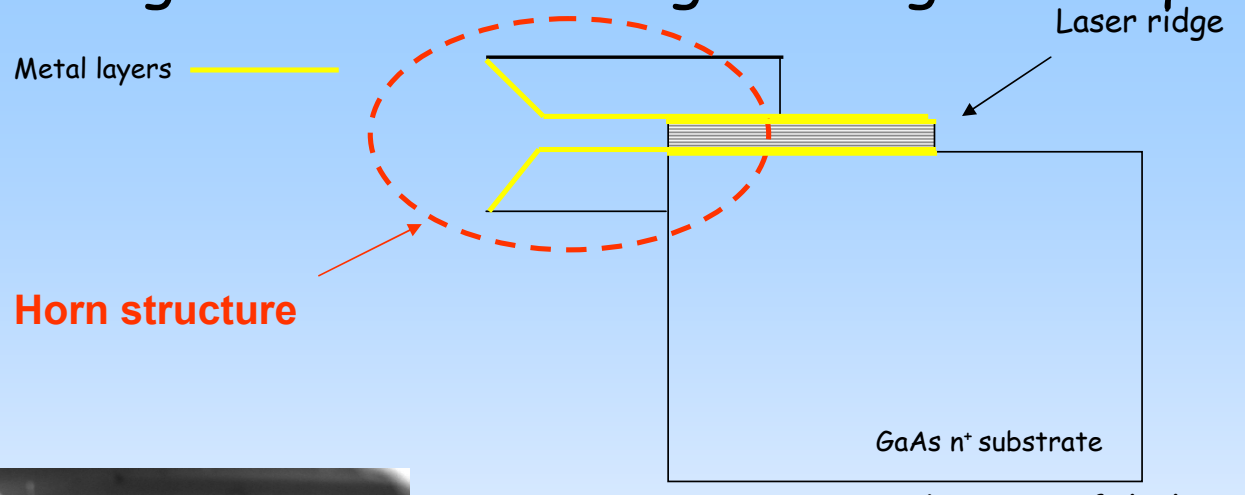



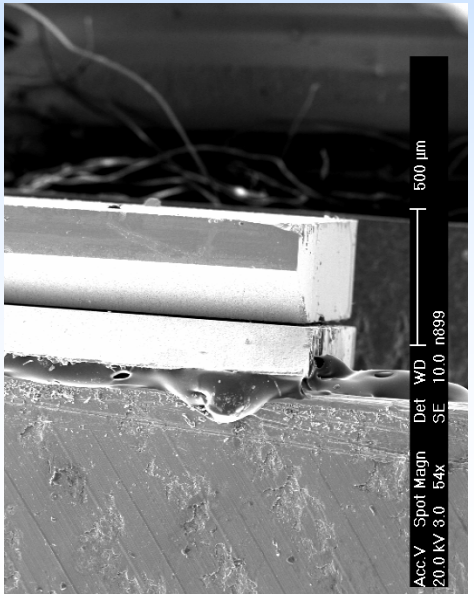

Angular resolution: 2° for both direction
Sample dimension: 200X500μm

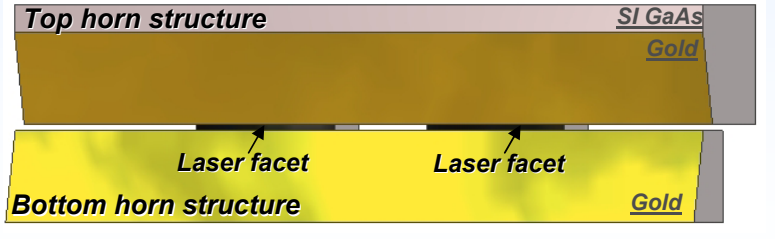
C. Walther et al. "Low frequency terahertz quantum cascade laser operating from 1.6 to 1.8 THz", Appl. Phys. Lett. 89, 231121 (2006).

# … looking to microwave engineering technique

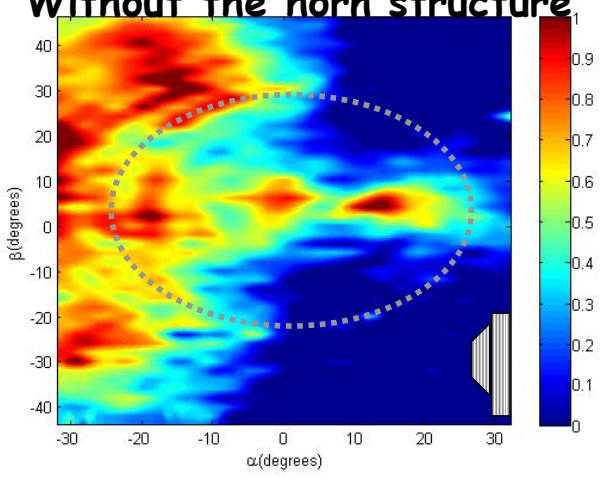



Later view of the laser chip (in scale)

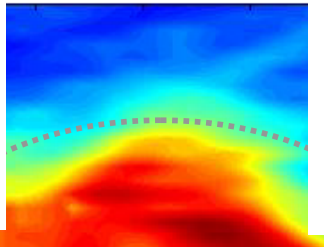


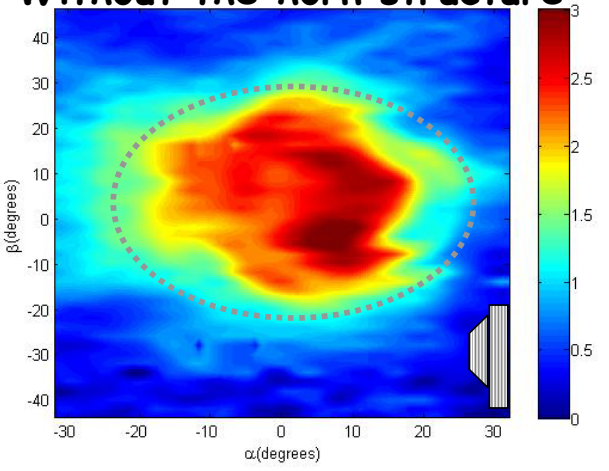
Without the horn structure



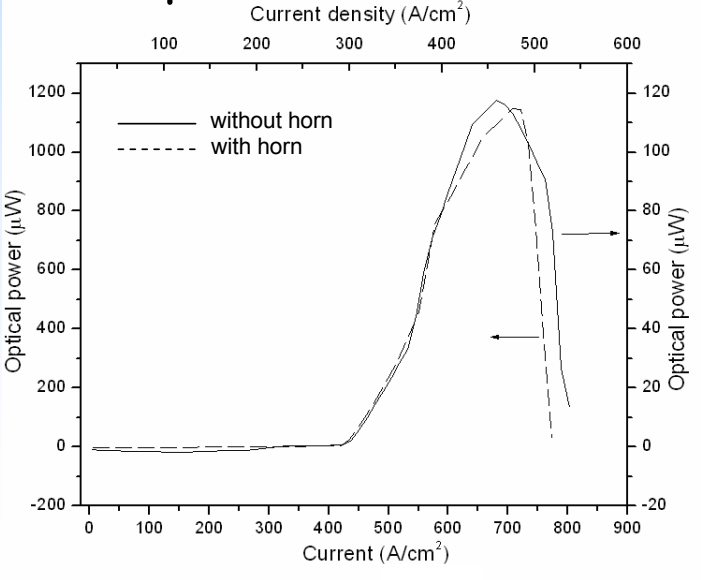

Effect?...

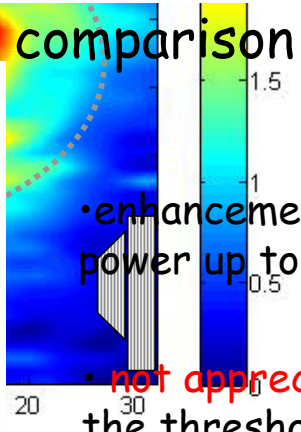


Without the horn structure




# CW power measurements comparison



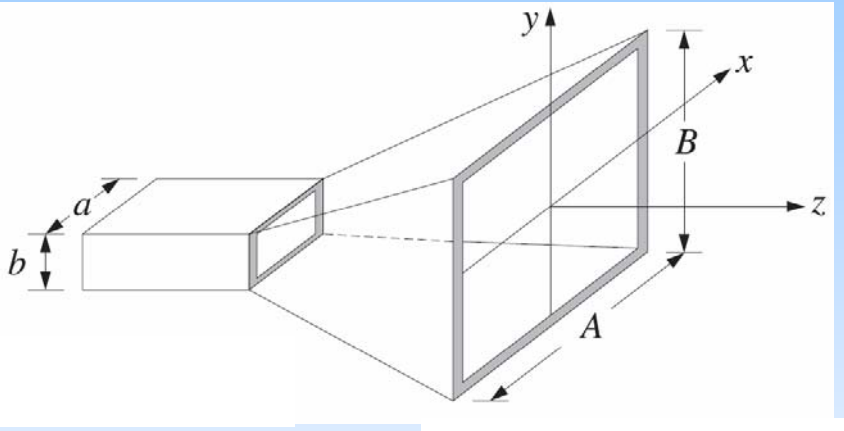



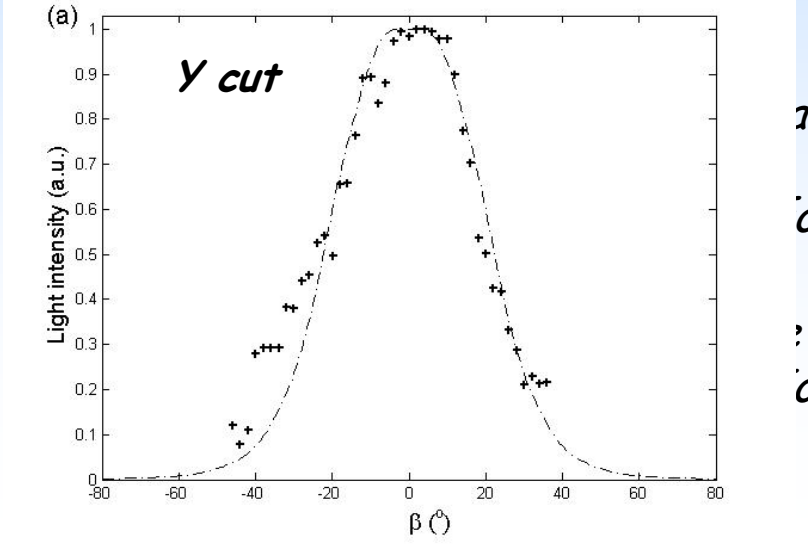
- enhancement of the optical power up to ten times
- not appreciable change in the threshold current density

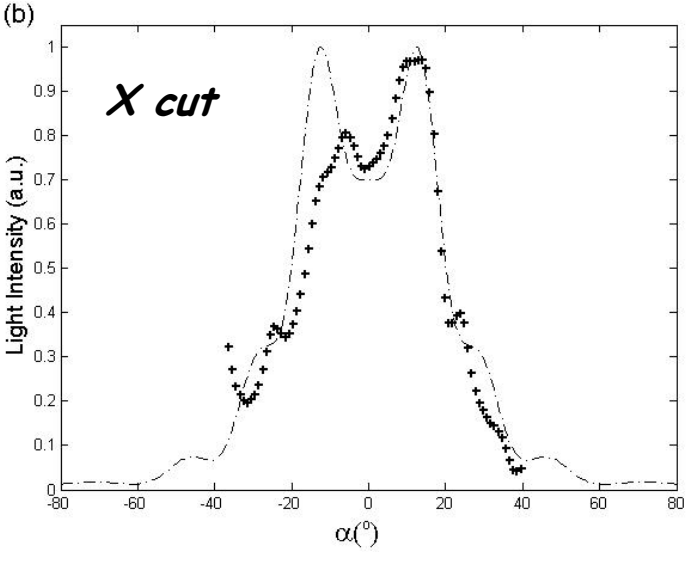
** M.I. Amanti et al. "Horn antennas for THz quantum cascade lasers" Electronics Letters Vol 43, p. 573-574*

# Simulation of the beam pattern

Far field pattern can be simulated using models avaible for microwave waveguides :

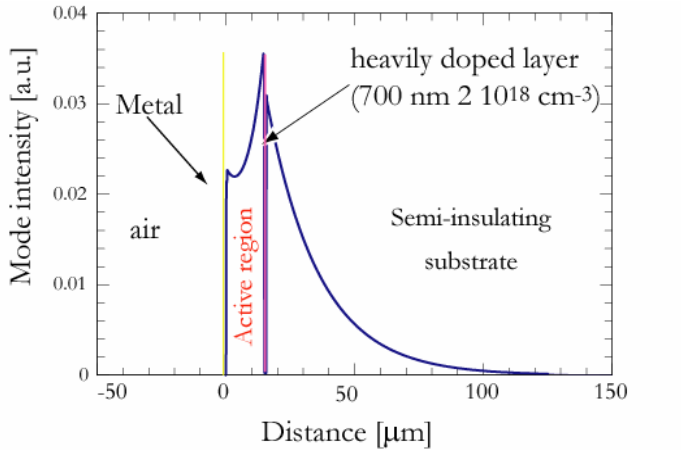


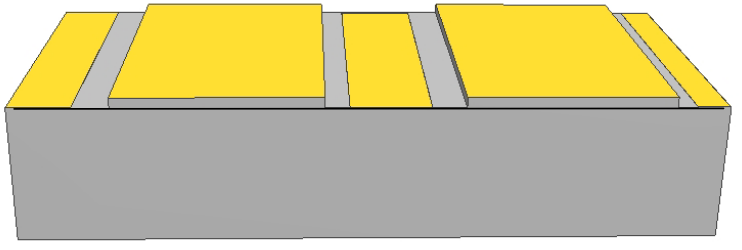



# Single plasmon waveguide

[2]



[2] R. Kohler et al., Nature **417**, 156 (2002)

Optical mode is confine in region comparable with the wavelength

- Less divergent beam pattern
- Higher optical power

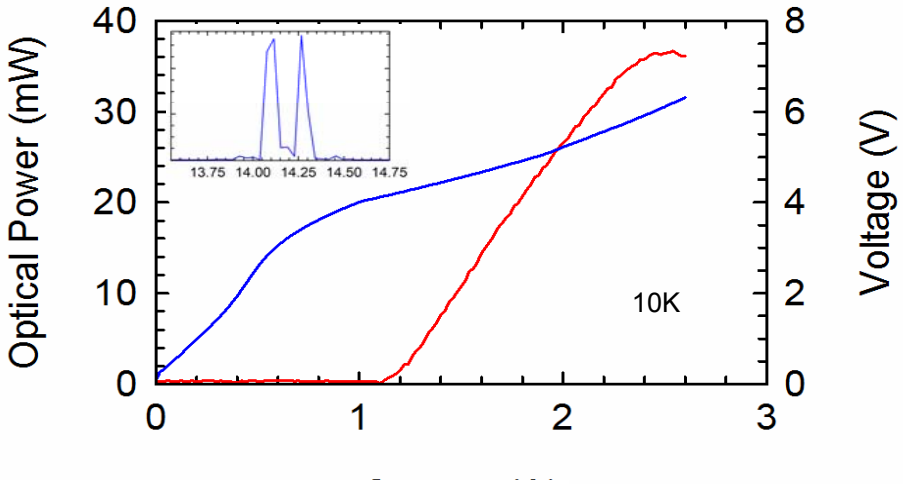
**In collaboration with the Kavli Insitute of Nanoscience Delft University of Delft (group J.R.Gao)**

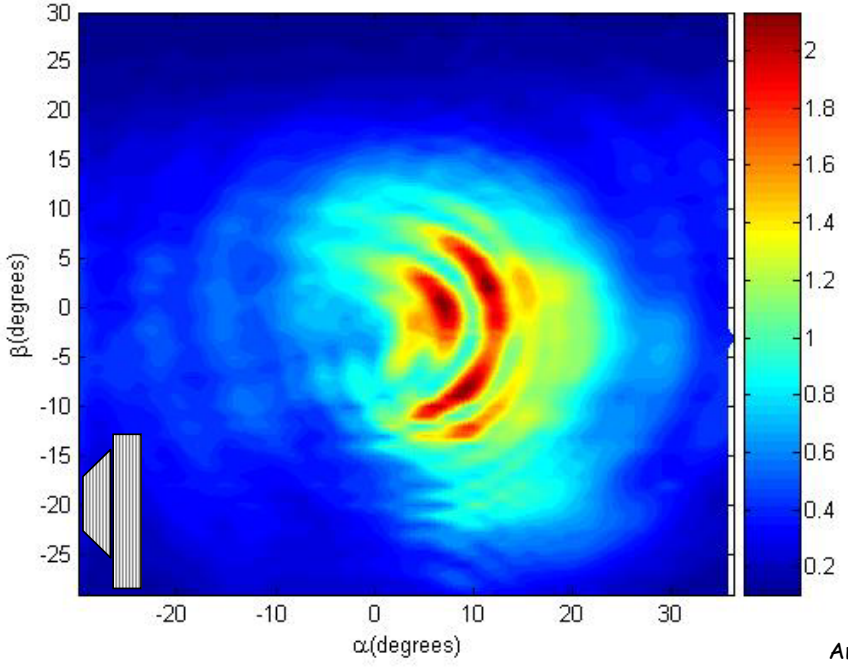
**A2986a5 200μmx2200μm**

λ~85μm

Lasing up to 100K

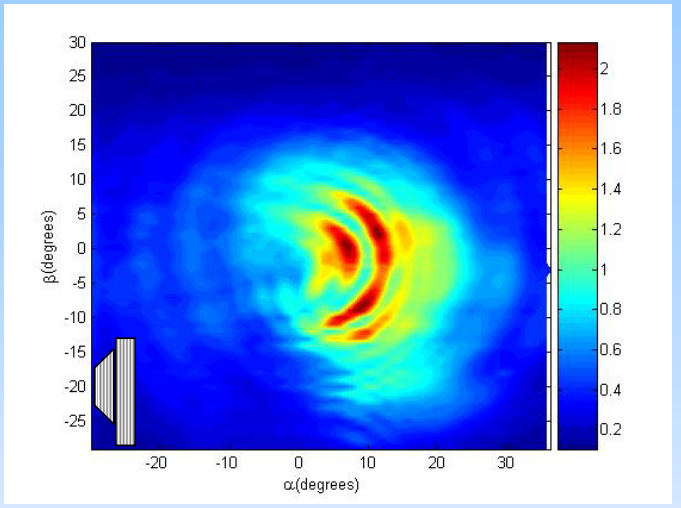
Optical power CW 38mW

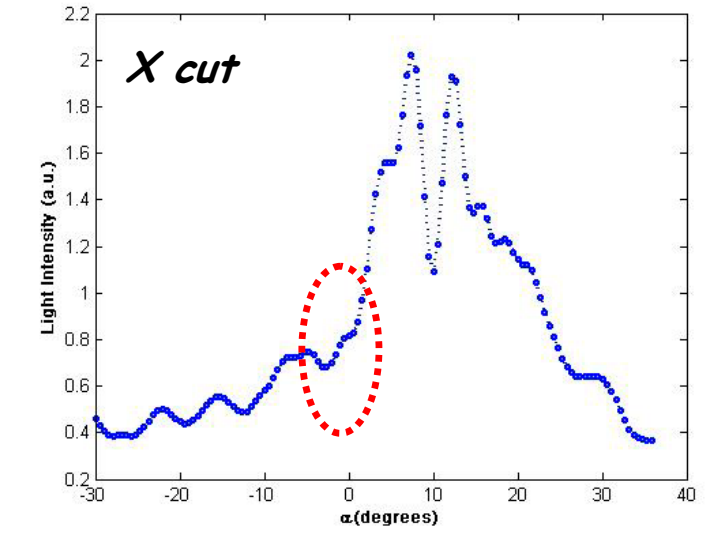


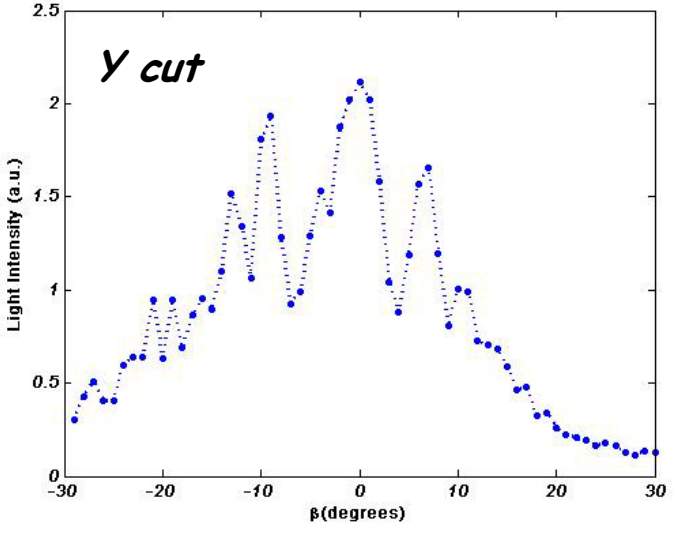




Angular resolution: 1° for both direction

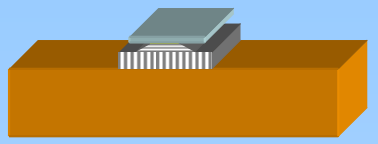
# Study of the beam pattern

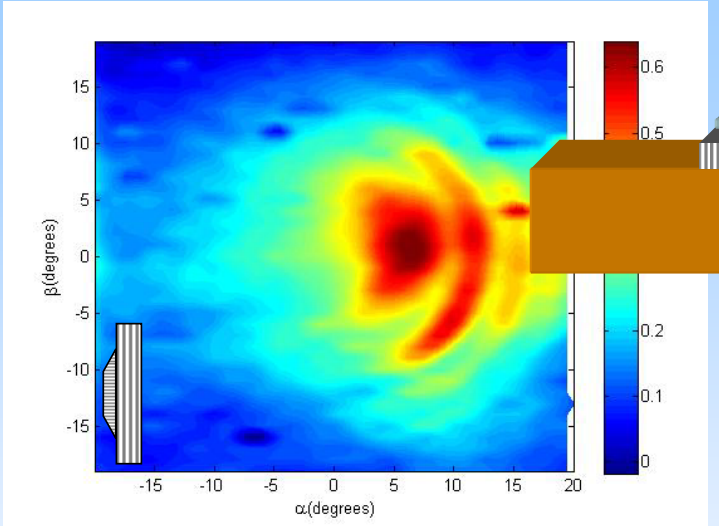


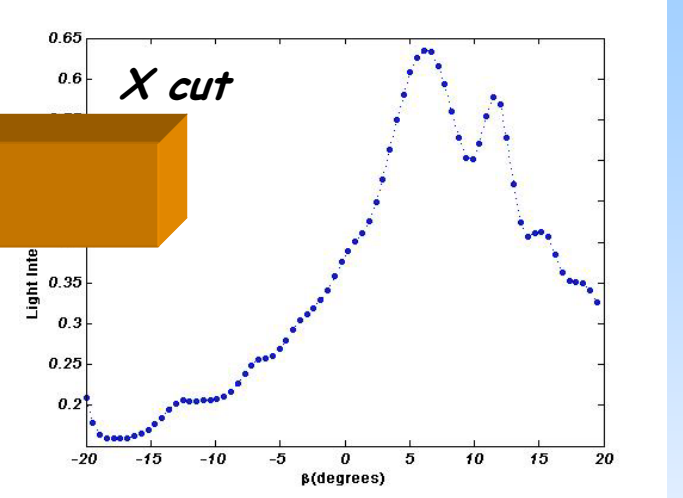



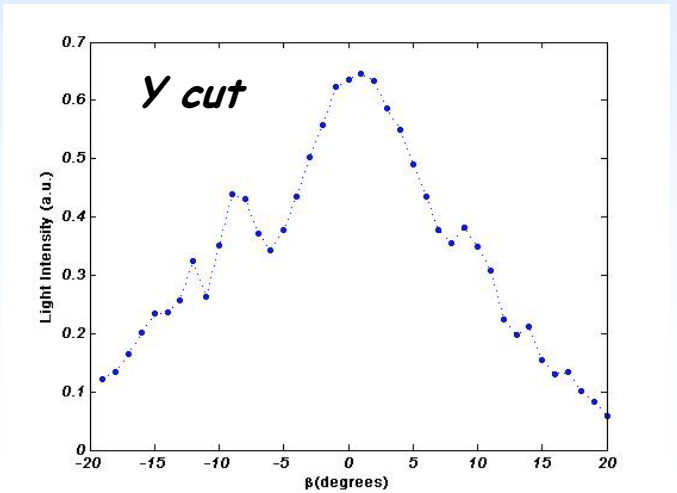



# Reshaping the beam: STEP 1



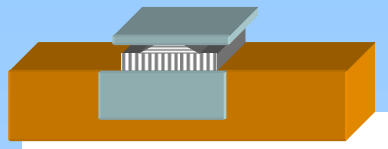


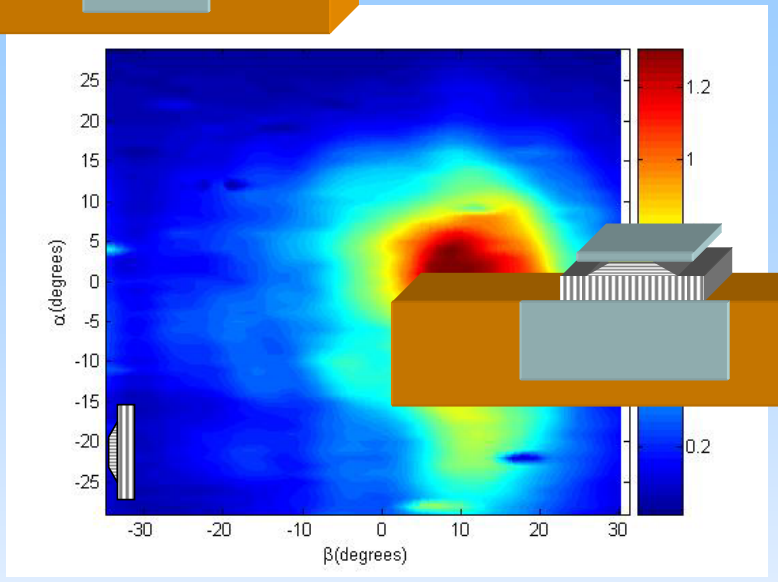



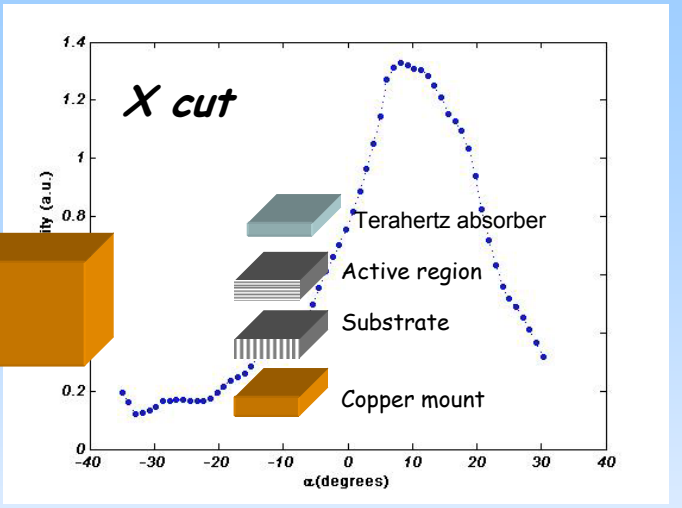



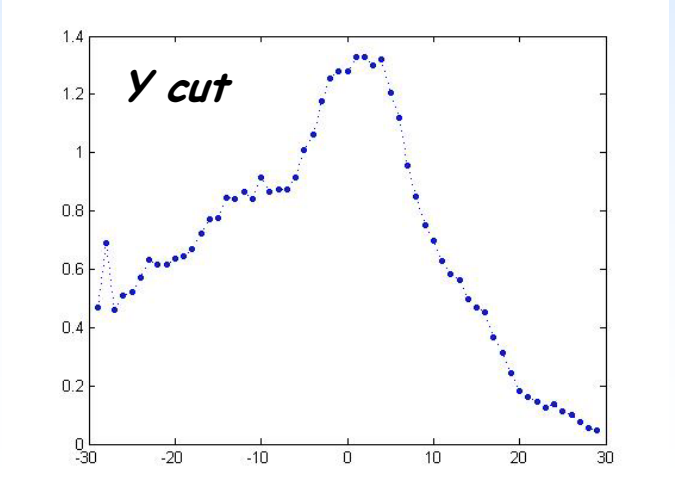

*Reduction of the interference rings*

# Reshaping the beam: STEP 2





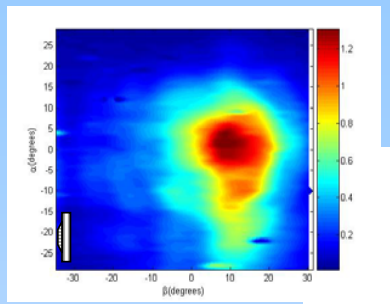



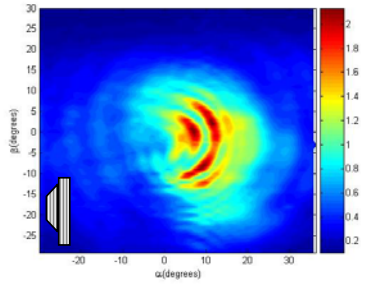



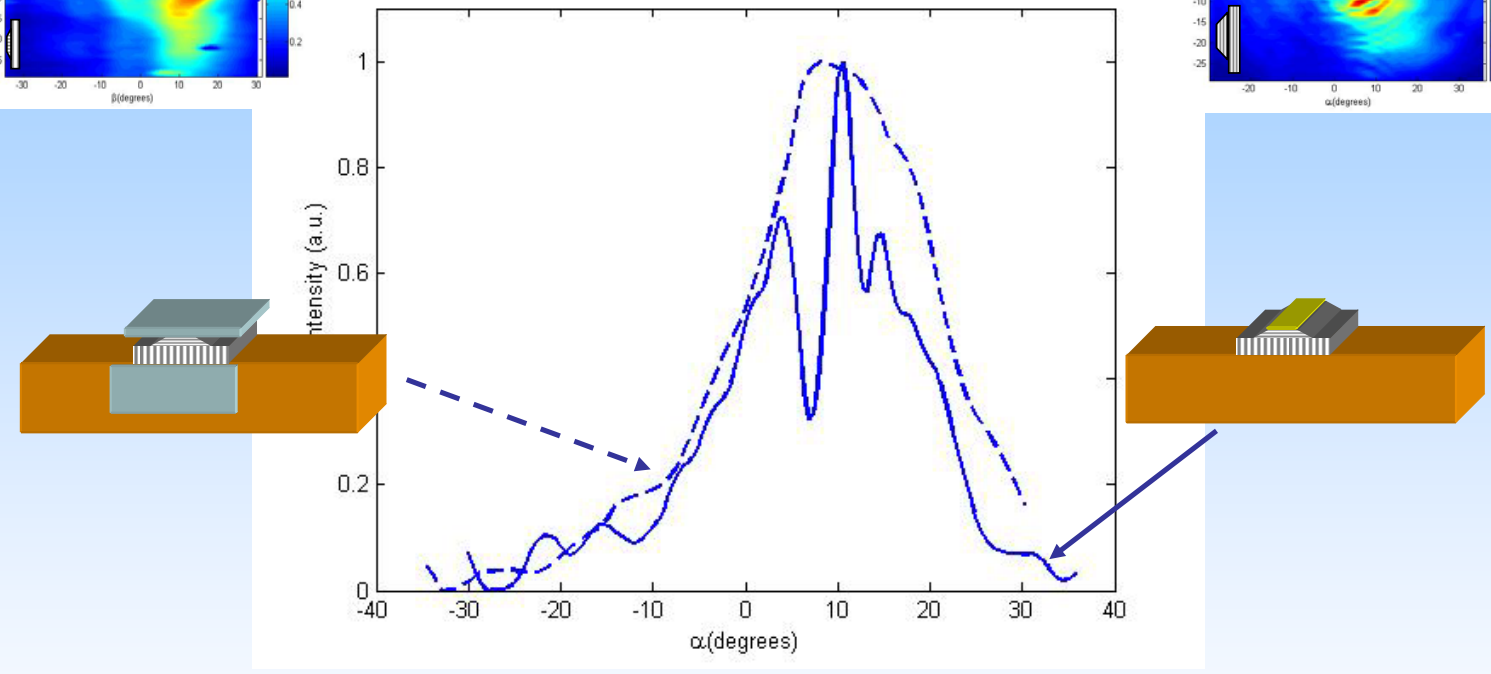

FWHM $25^0$

For both direction

# Final result



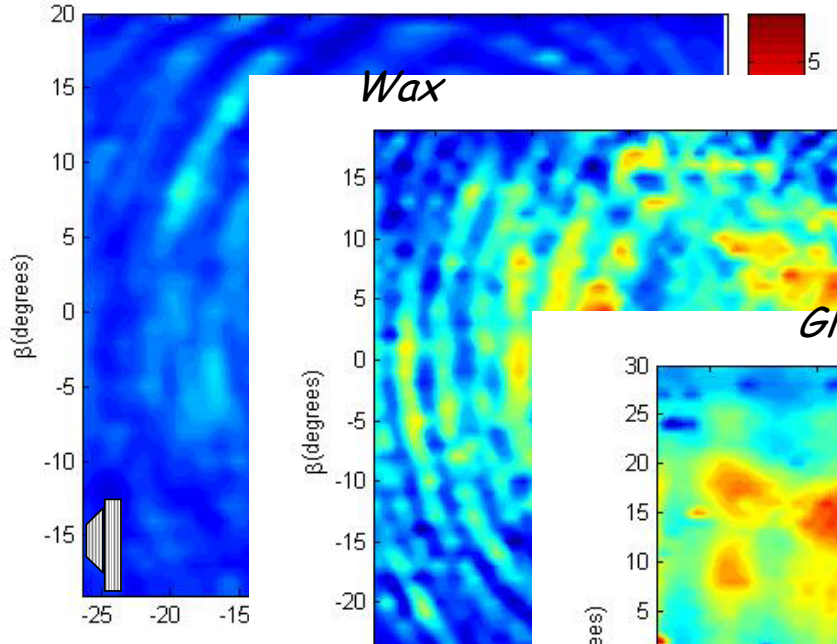





**Terahertz absorber eliminate completely interference rings!!!**

# Test for different absorbing materials

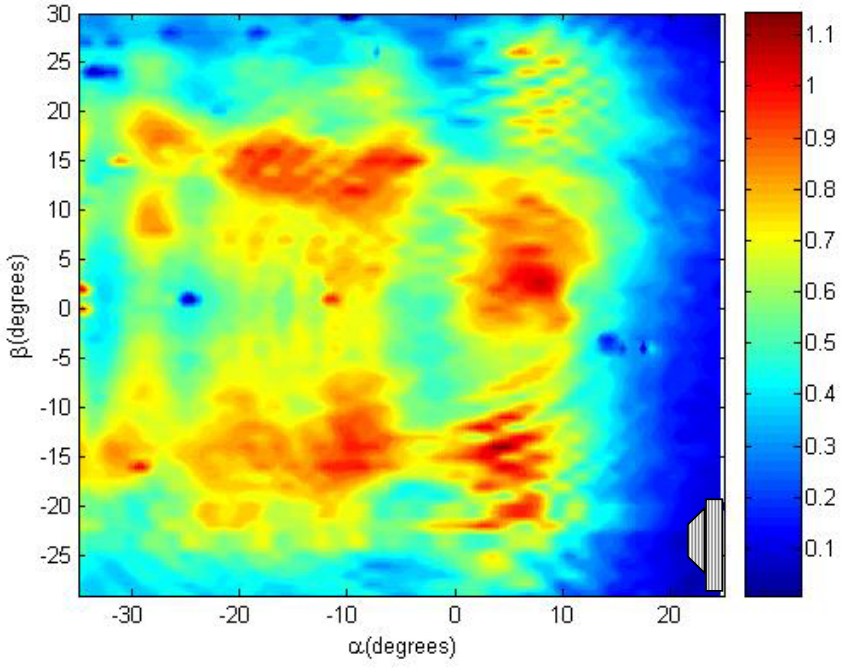
*GaAs $n^+$ on the top*



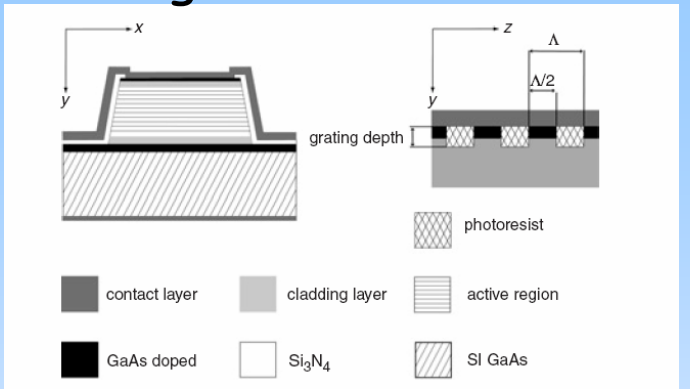

*Wax*

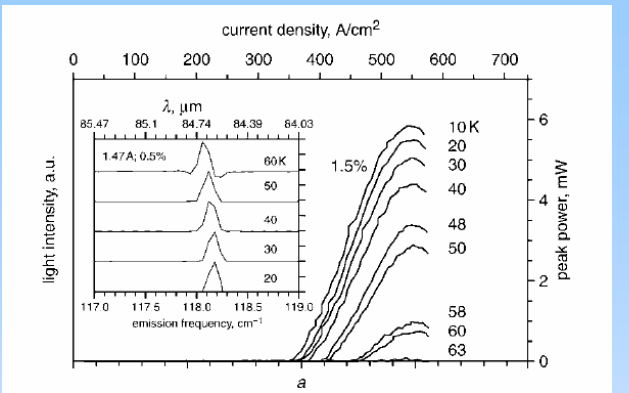



*Glass*

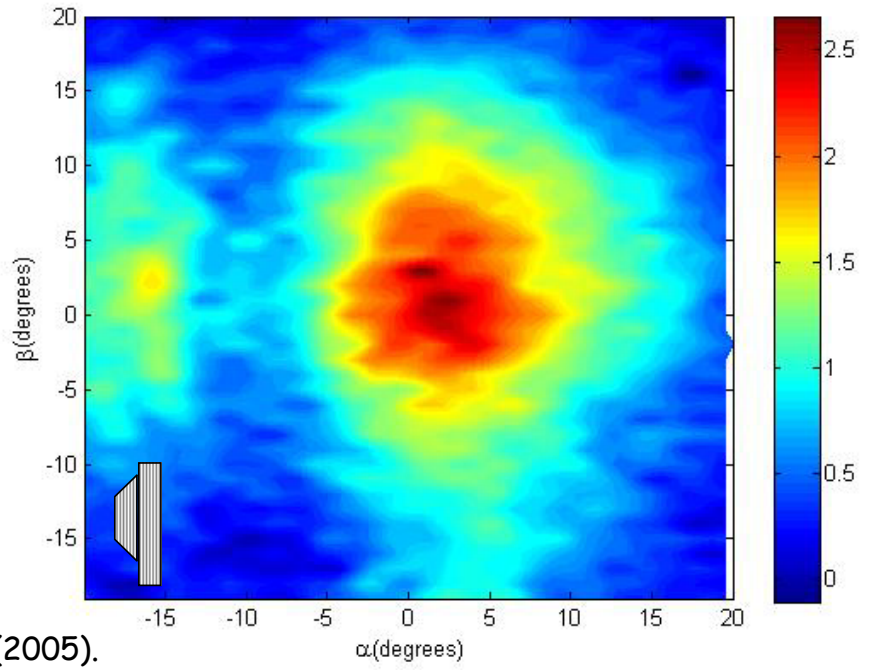


# DFB Single Plsmon Laser



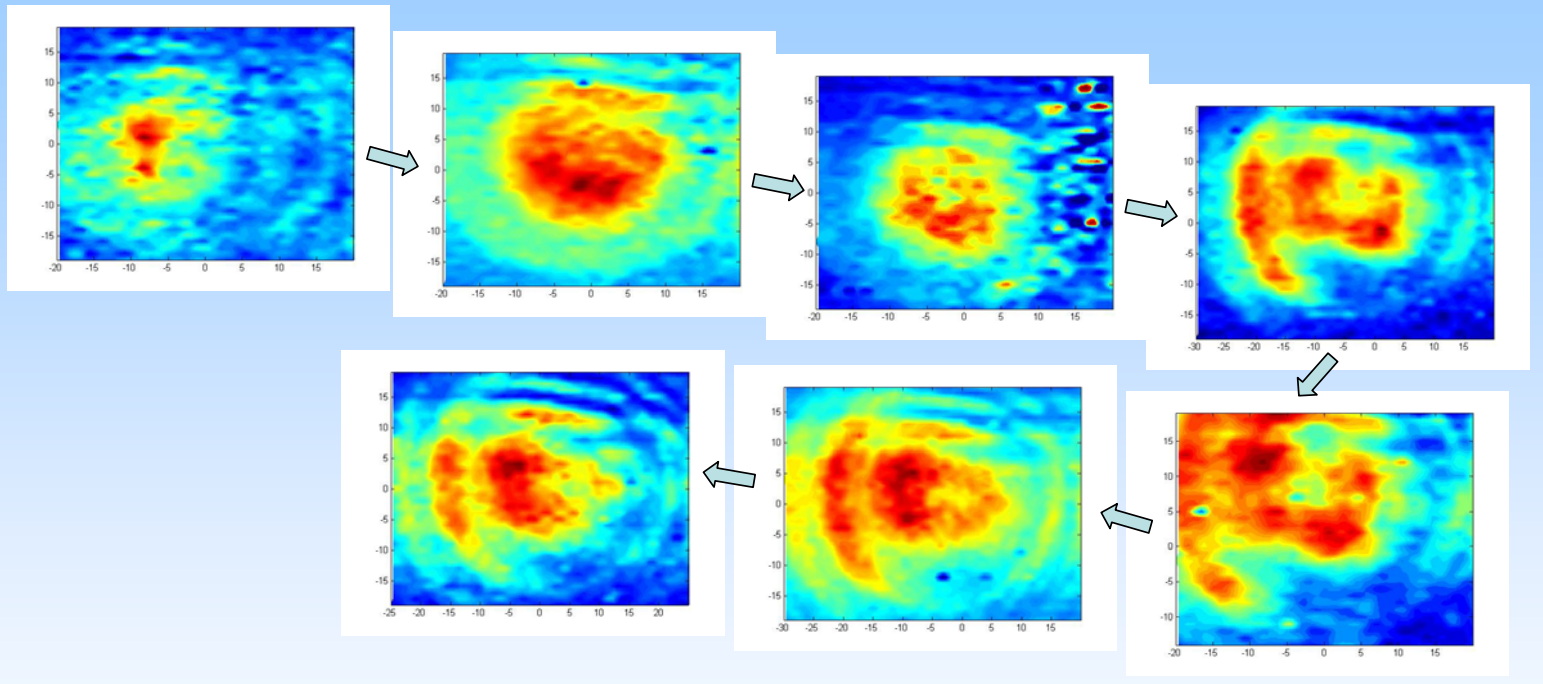




***With terahertz absorber***




*L. Ajili Elect. Lett. **41**, 419 (2005).

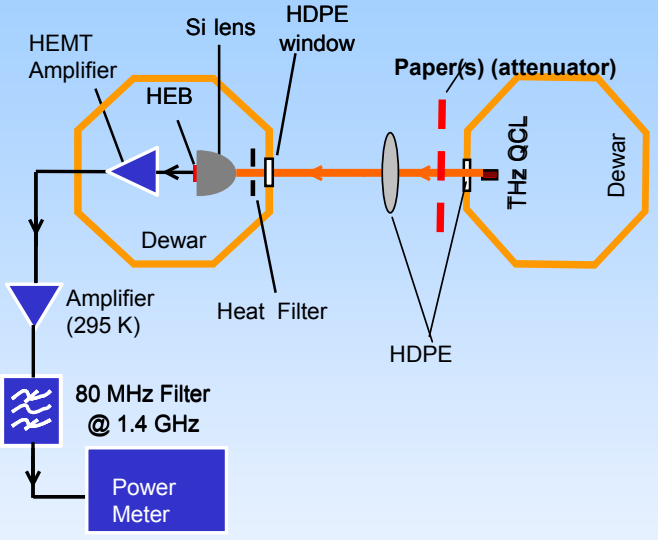
# *Moving the Thz absorber*

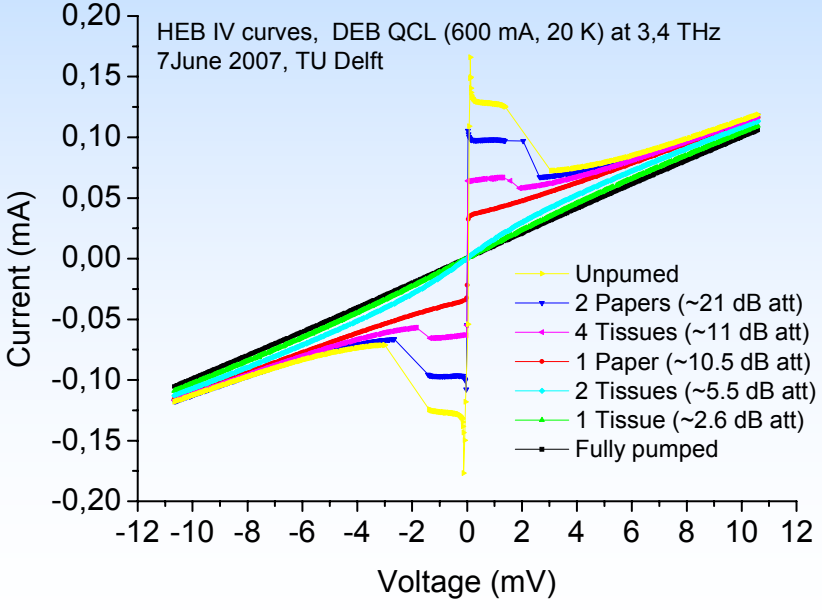


***Strong dependence on the position on the terahertz absorber***

# A bit of application…

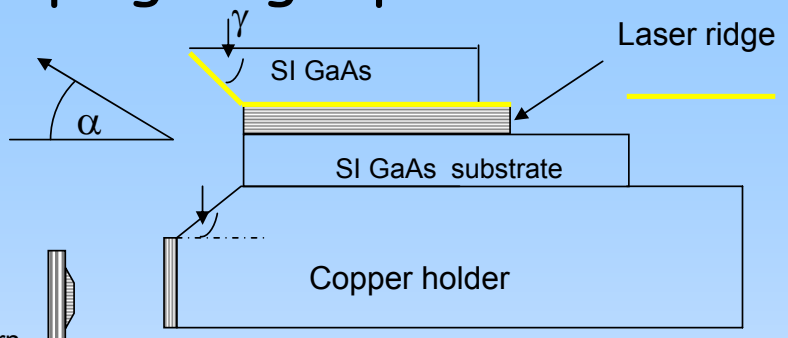
## *DFB THz QCL pumping of Hot Electron Bolometer**



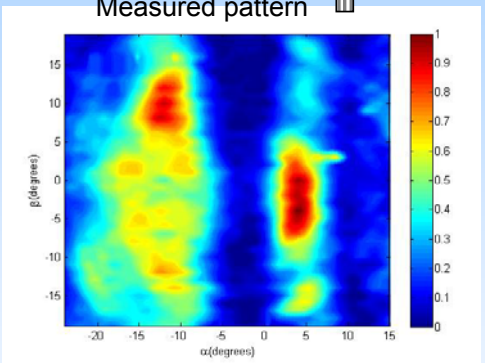

*Measured at Kavli Insitute of Nanoscience Delft (J.R. Gao)

# Reshaping single plasmon beam pattern

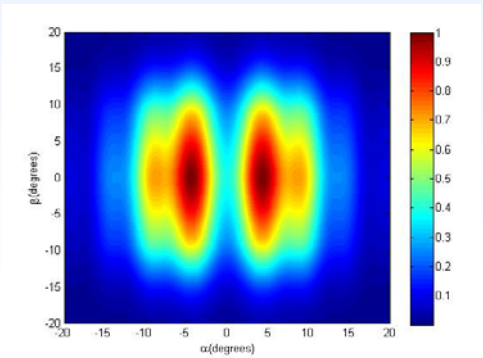



γ=15°

Measured pattern

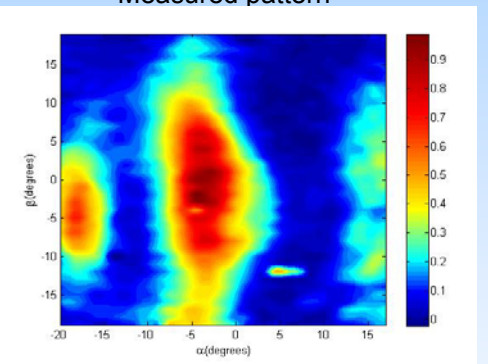



Simulated pattern

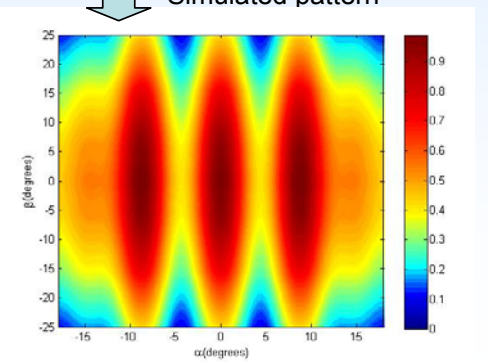



γ=45°

Measured pattern




Simulated pattern




**(angular resolution 1° for both directions )**

# Conclusion:

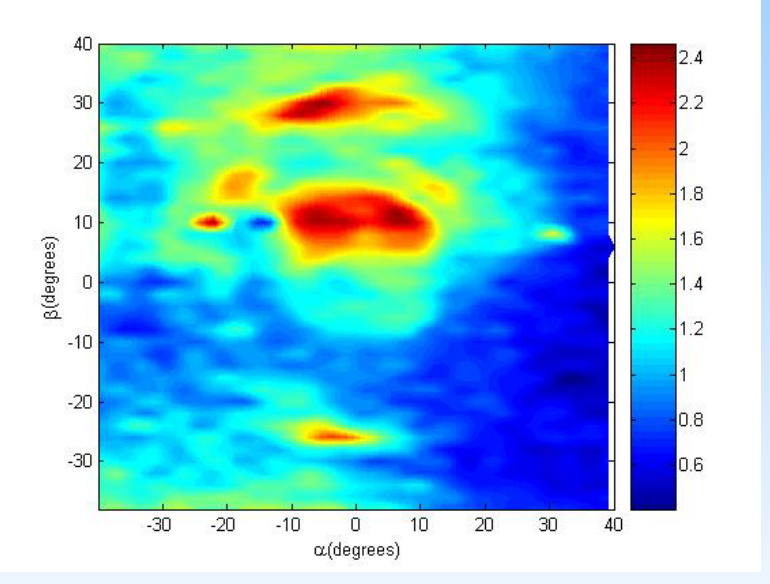
- Reshape of the beam pattern for double metal metal waveguide up to a quasi circular shape

- Elimination of the interference rings in the single plasmon waveguide

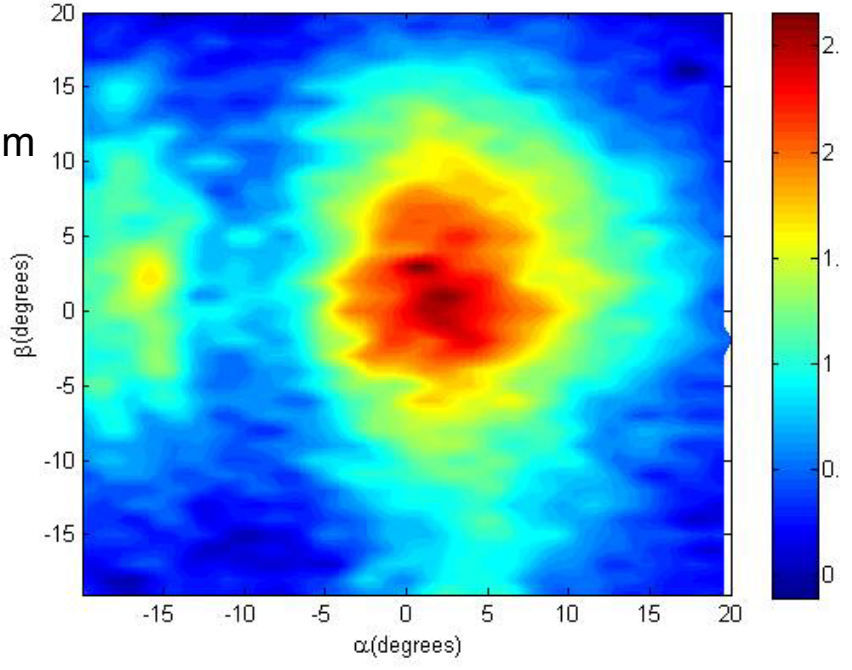
- Use of the horn structure in single plasmon waveguide

*Thank you for the attention!!!!*

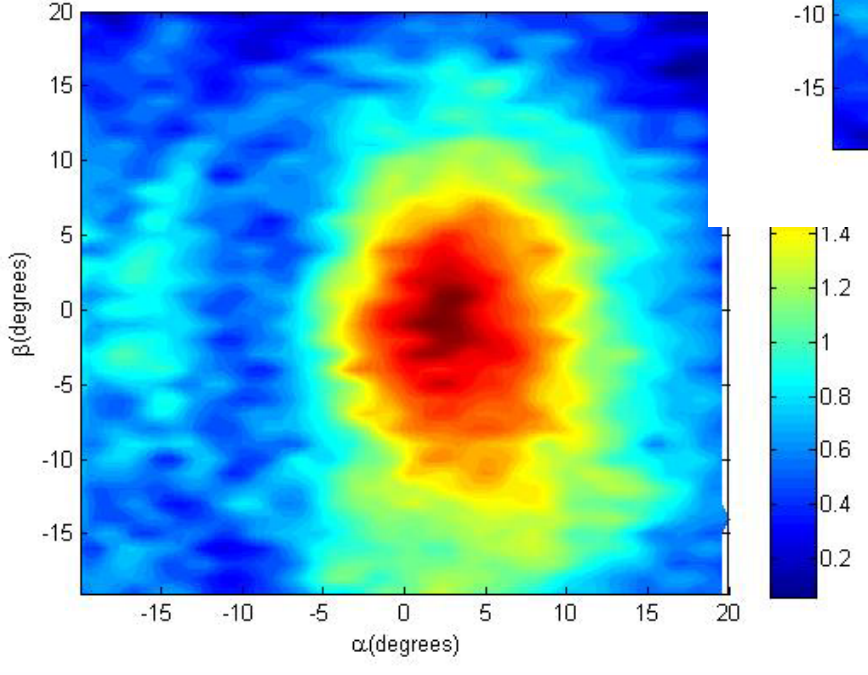
N892 1000X150um



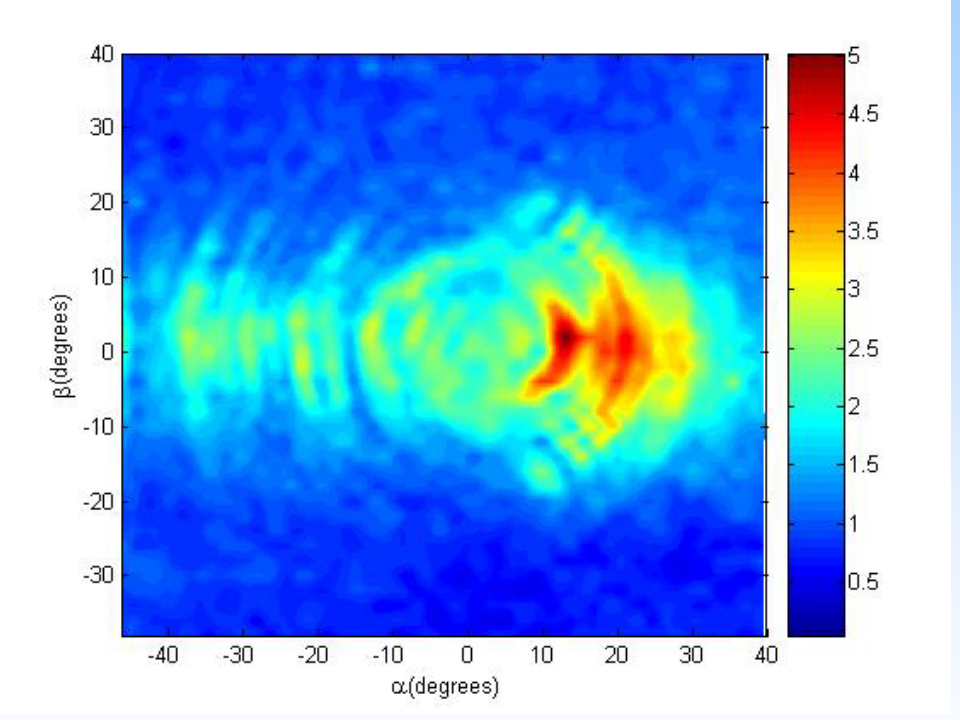
200um



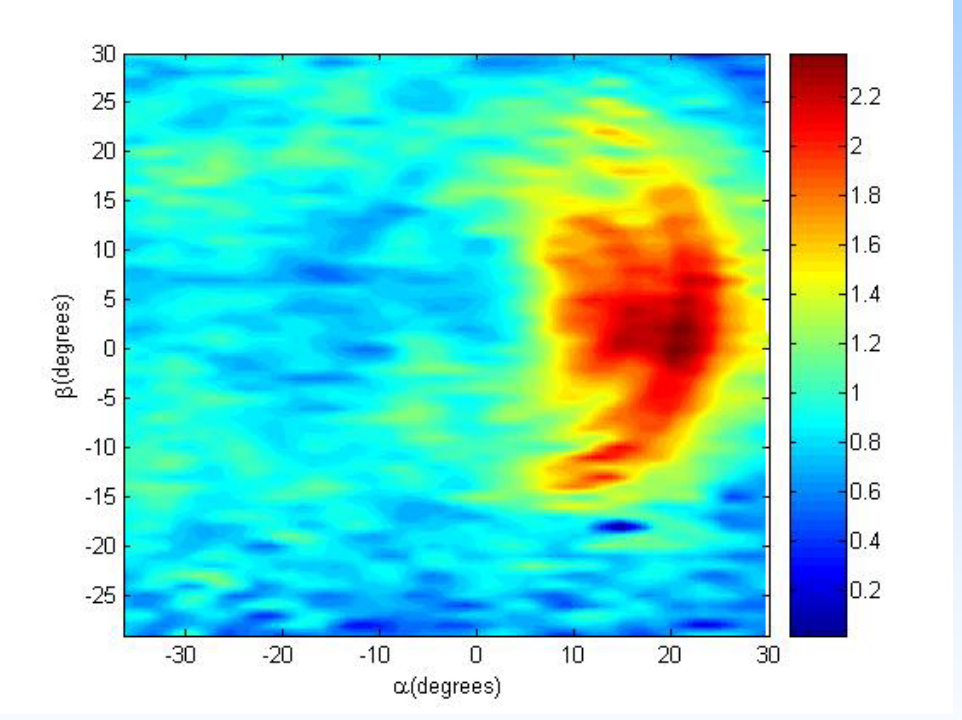

100um



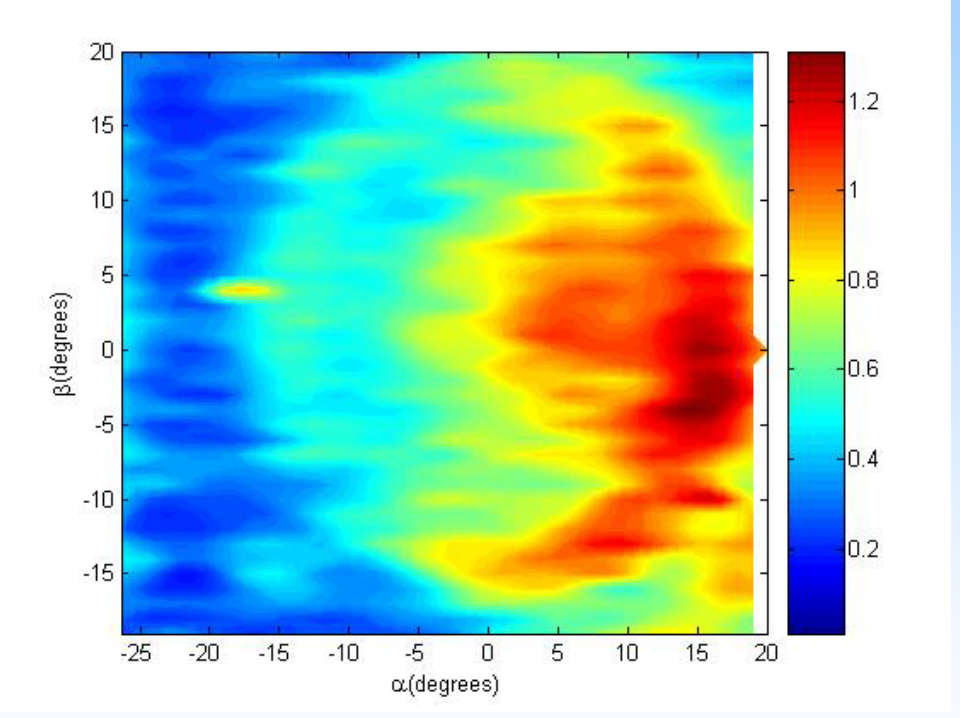
A2986l9 200umx1300 res x1 y2

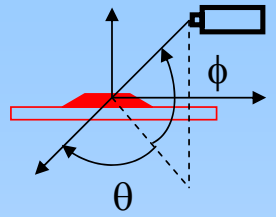


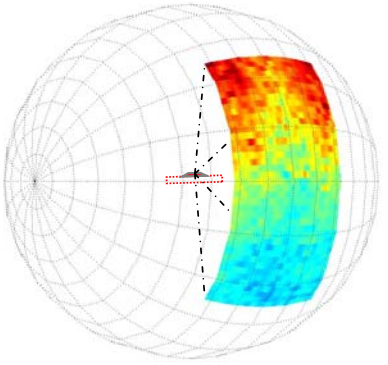
A2986l9 (1280) 100umx1300 res x2 y1

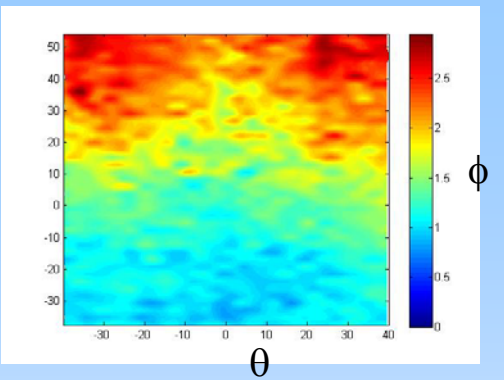


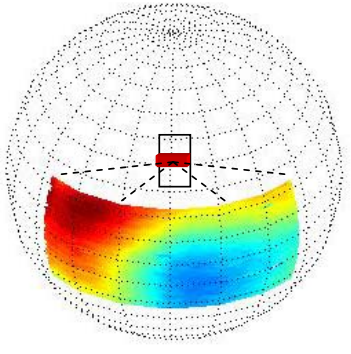
N760cartone 2000X100

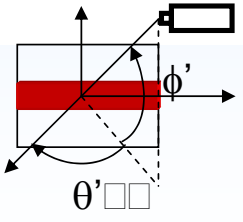


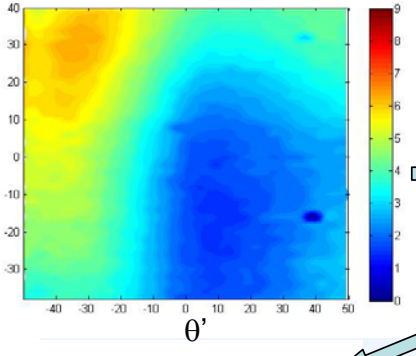

ϕ
θ

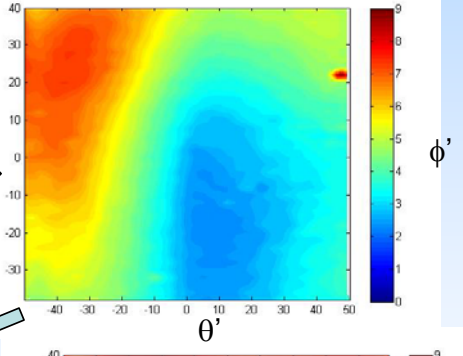


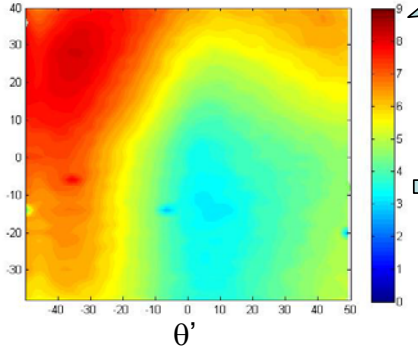

ϕ
θ

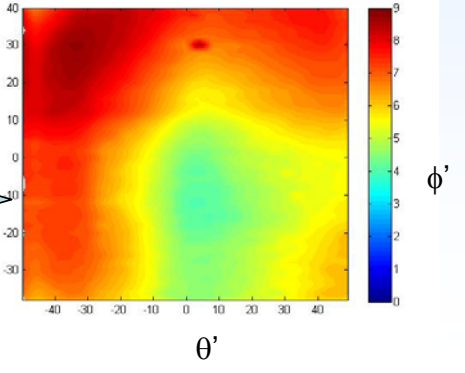


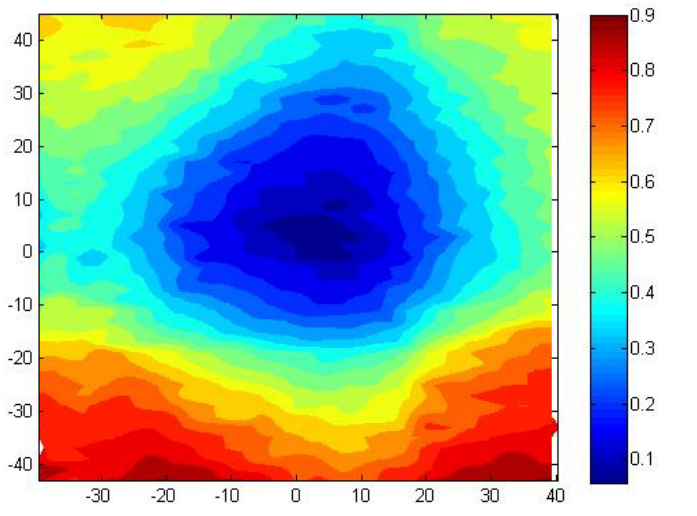

ϕ'
θ'□□

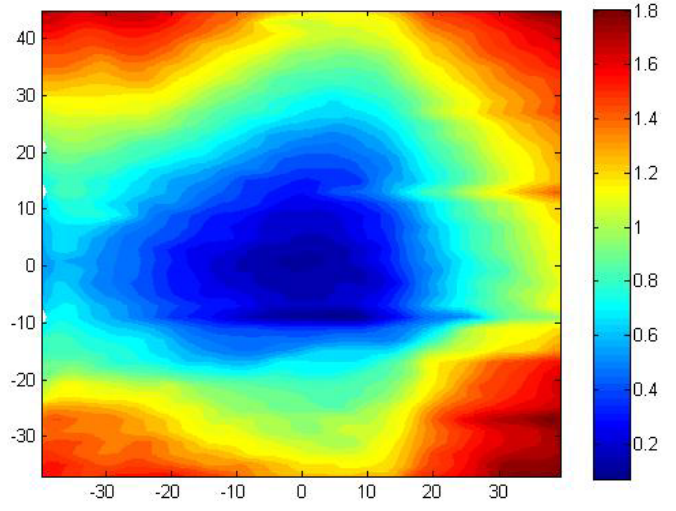

ϕ'
θ'

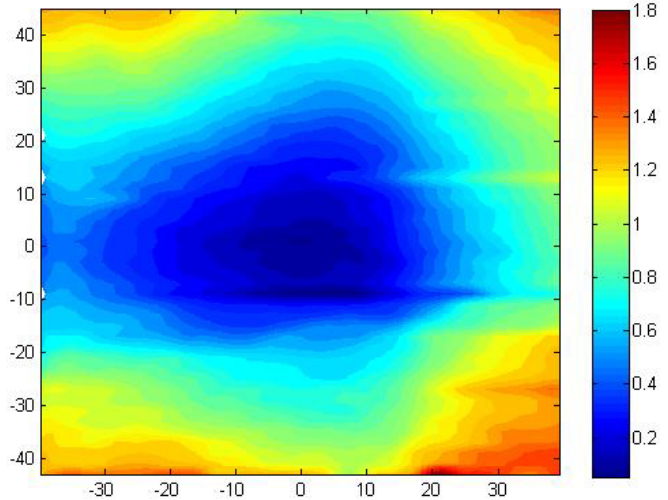

ϕ'
θ'

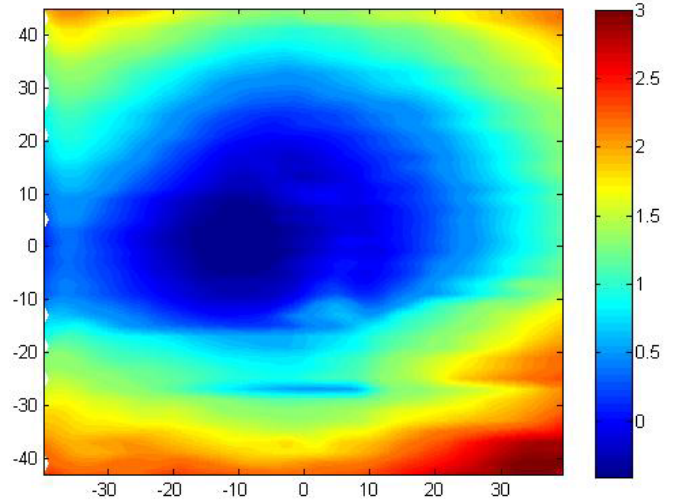

ϕ'
θ'


ϕ'
θ'

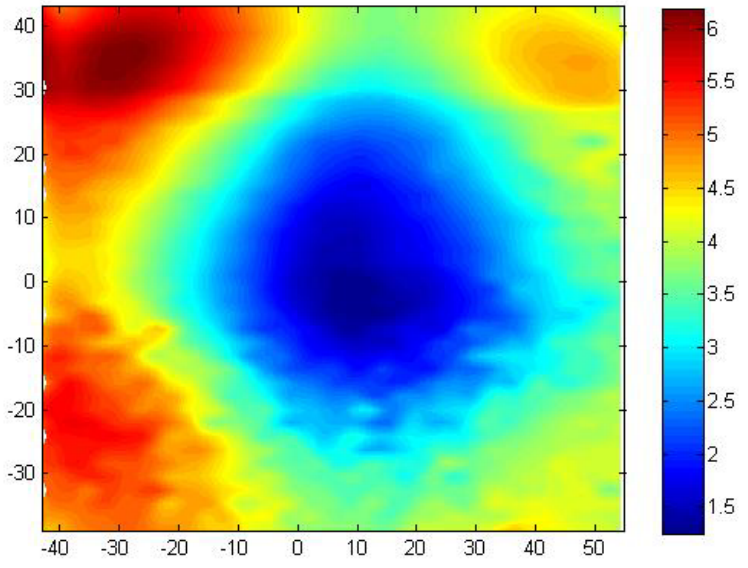

40
30
20
10
0
-10
-20
-30
-40
-30 -20 -10 0 10 20 30 40
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1


40
30
20
10
0
-10
-20
-30
-30 -20 -10 0 10 20 30
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2

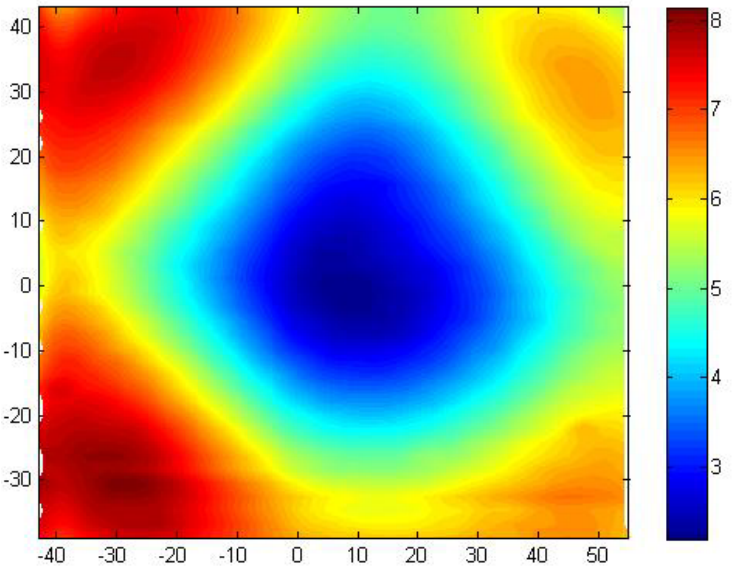

40
30
20
10
0
-10
-20
-30
-40
-30 -20 -10 0 10 20 30
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2


40
30
20
10
0
-10
-20
-30
-40
-30 -20 -10 0 10 20 30
3
2.5
2
1.5
1
0.5
0

12V




15V




Questo era il 18_3