



UNIVERSITÉ
CÔTE D'AZUR



Vers une source UV à partir de la génération d'harmonique dans des guides GaN.

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Outline

- Motivation
- History
 - Periodically oriented GaN (PO-GaN)
- Recent results
 - Modal phase matching
 - Low loss waveguides
 - SHG results
- Waveguides designed for UV
- Conclusions and perspectives

Motivation for the NLO in AlGaN semiconductors

Direct band gap
LED, laser diodes

Transparency
200nm - 7μm

$\chi^{(2)}$ nonlinearity
5-20pm/V

Combining nonlinear processes with the electrical injection.

Applications: electrically pumped nonlinear processes
in the Visible and near IR.

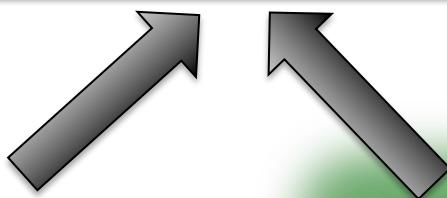
Nonlinear interactions in the Visible and the UV range.

Applications: frequency doubling 500nm → 250nm with AlN,
UV light for the medical application and water treatment.

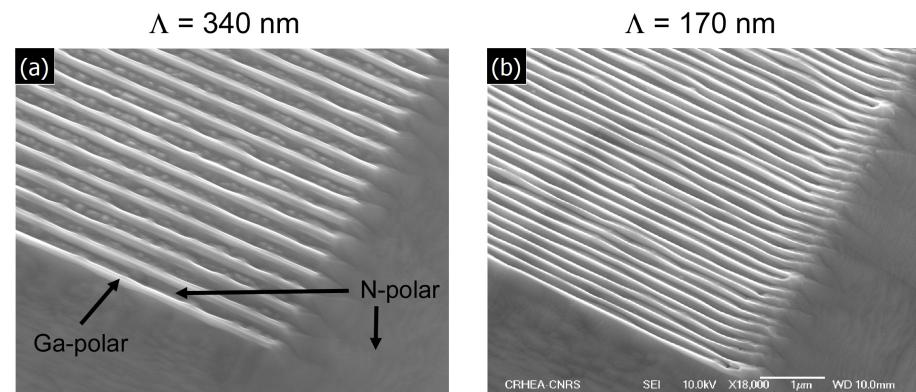
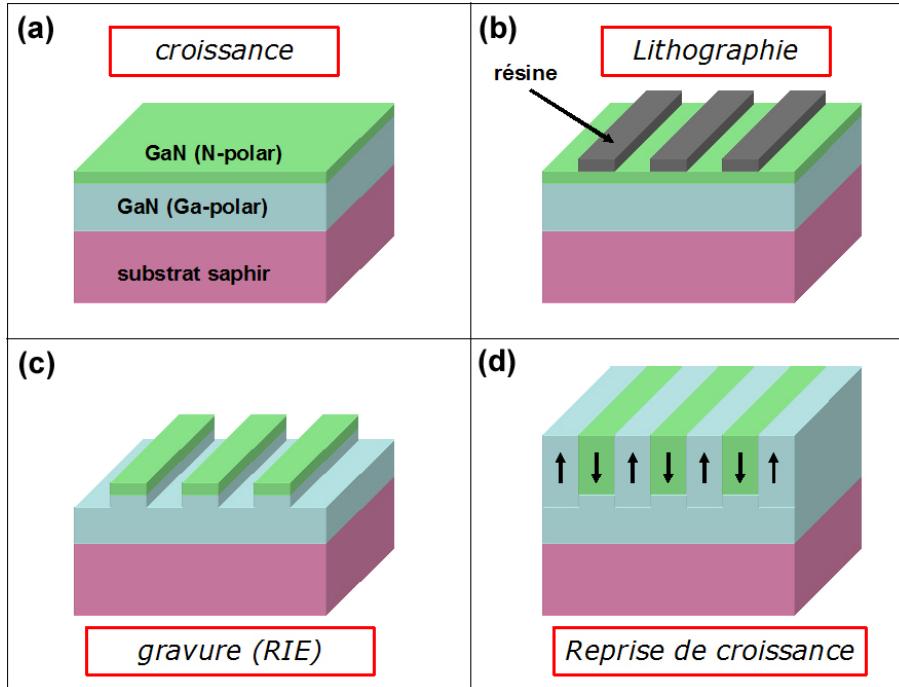
$\chi^{(2)}$ nonlinear
guided wave
interactions

low propagation
losses

phase-matching

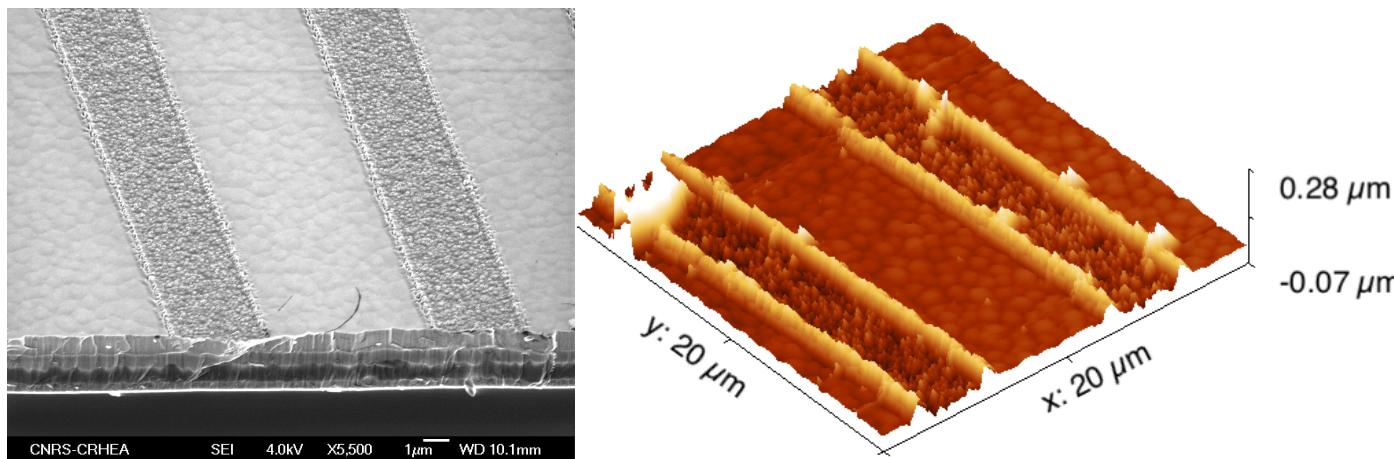


Periodically Oriented GaN (*S.Pezzagna 2005*)



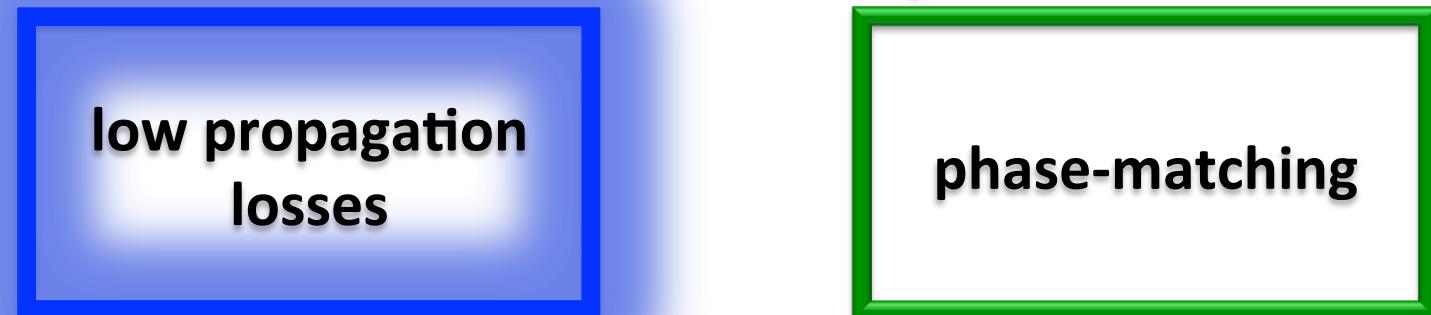
Sub-micron patterning for contra-propagative interactions

Technological limitation – macroscopic surface roughness

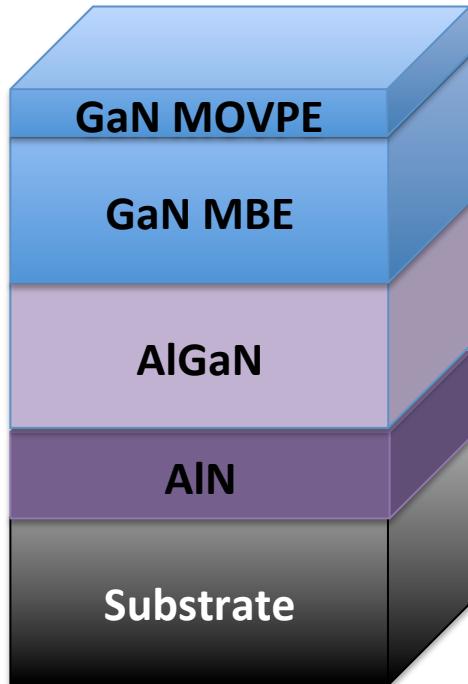


**SHG (Bell Labs)
0.1% conversion
1.2x10⁻⁴ % W⁻¹cm⁻²**

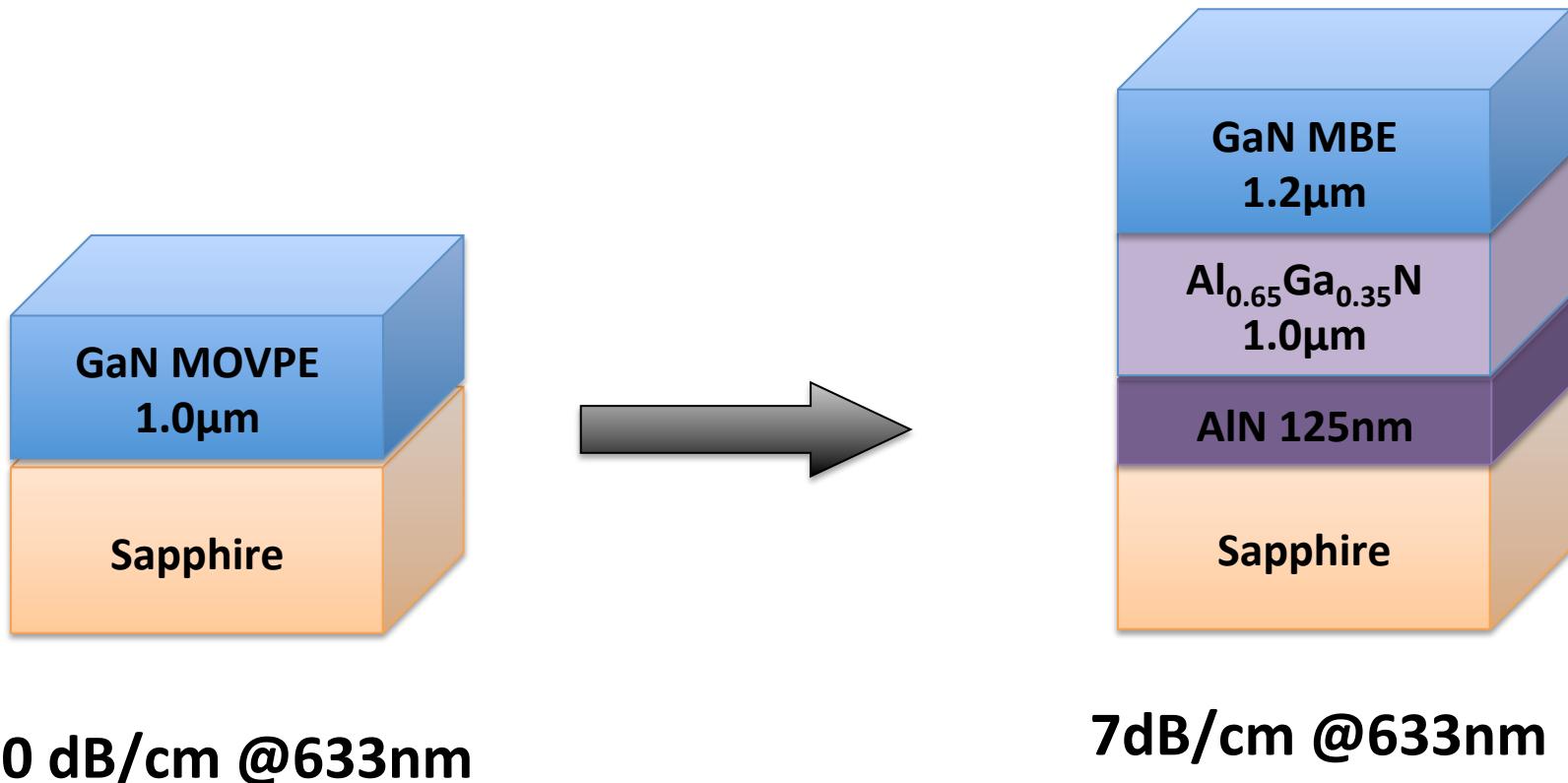
$\chi^{(2)}$ nonlinear
guided wave
interactions



Low loss planar waveguides = complex waveguides



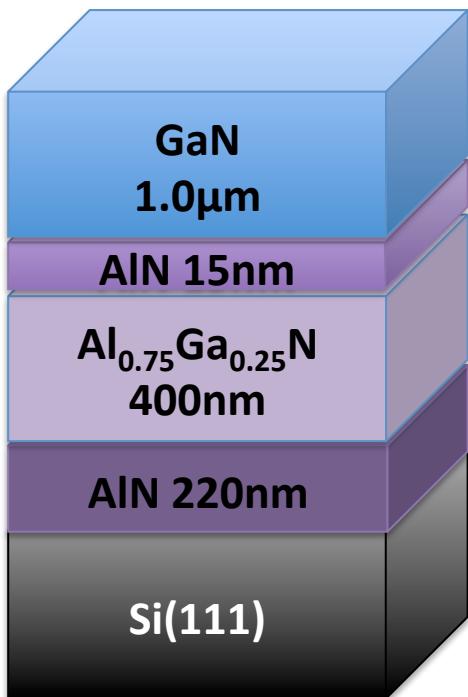
Low loss planar waveguides: buffer layer



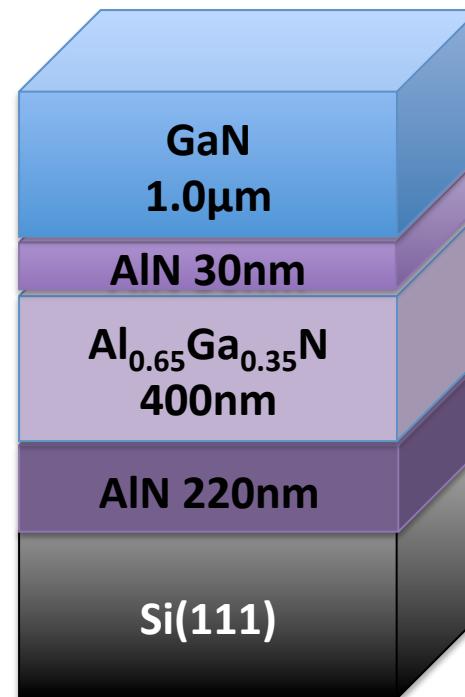
Low loss planar waveguides: MBE vs MOVPE

MBE and MOVPE are two main techniques used for growing crystalline AlGaN

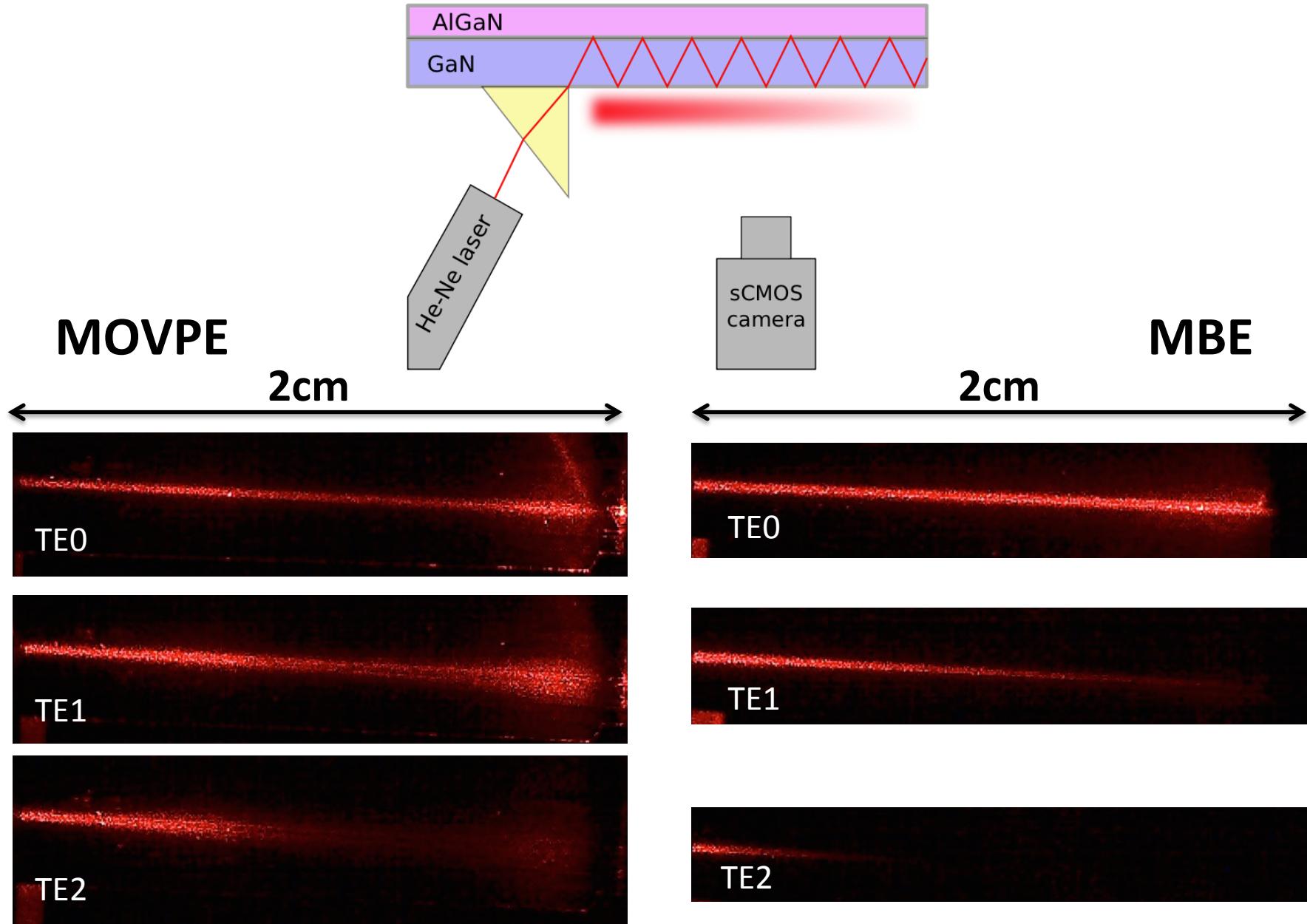
MOVPE



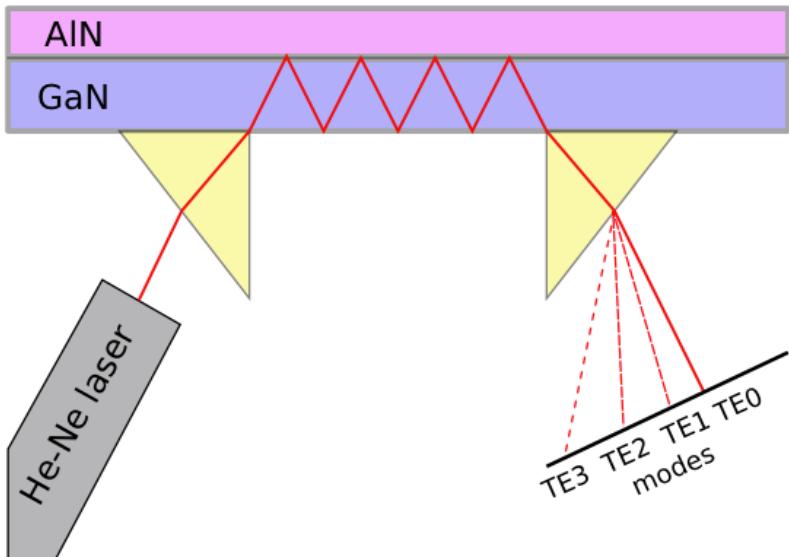
MBE



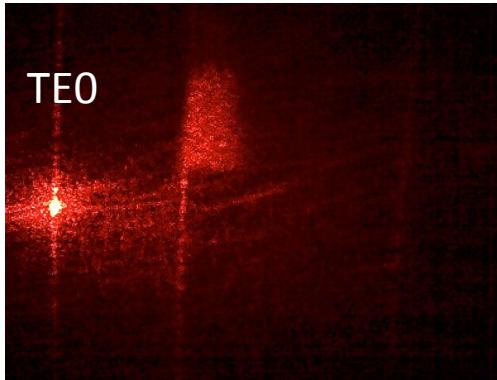
Low loss planar waveguides: MBE vs MOVPE



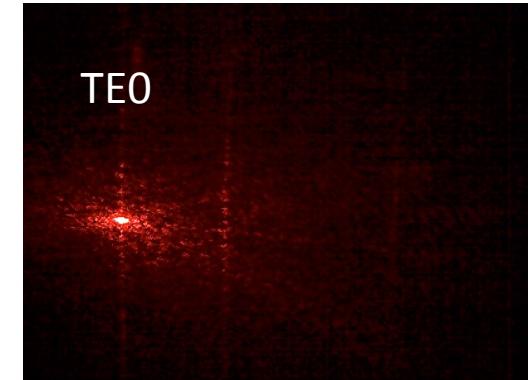
Low loss planar waveguides: MBE vs MOVPE



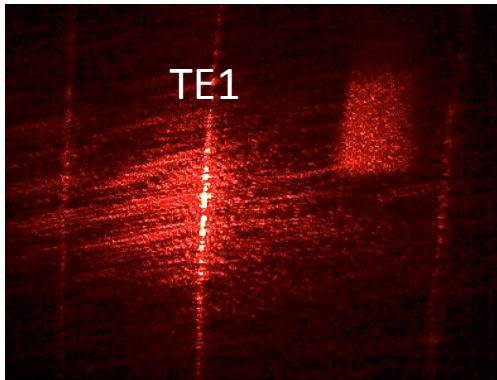
MOVPE



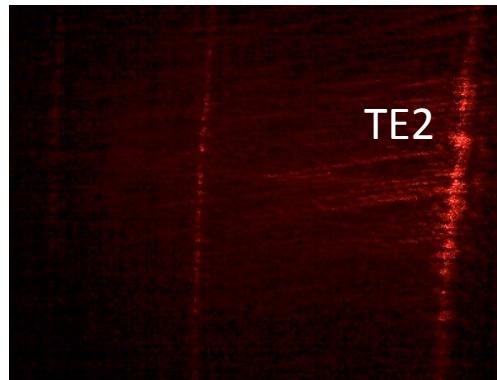
MBE



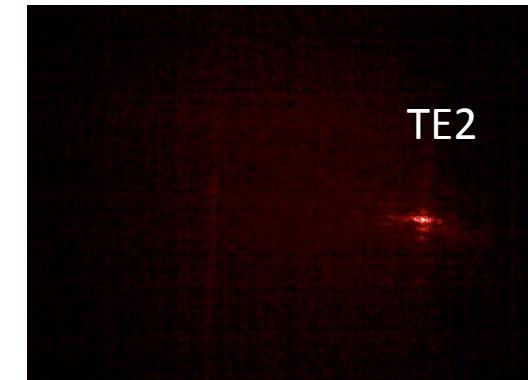
TE1



TE1

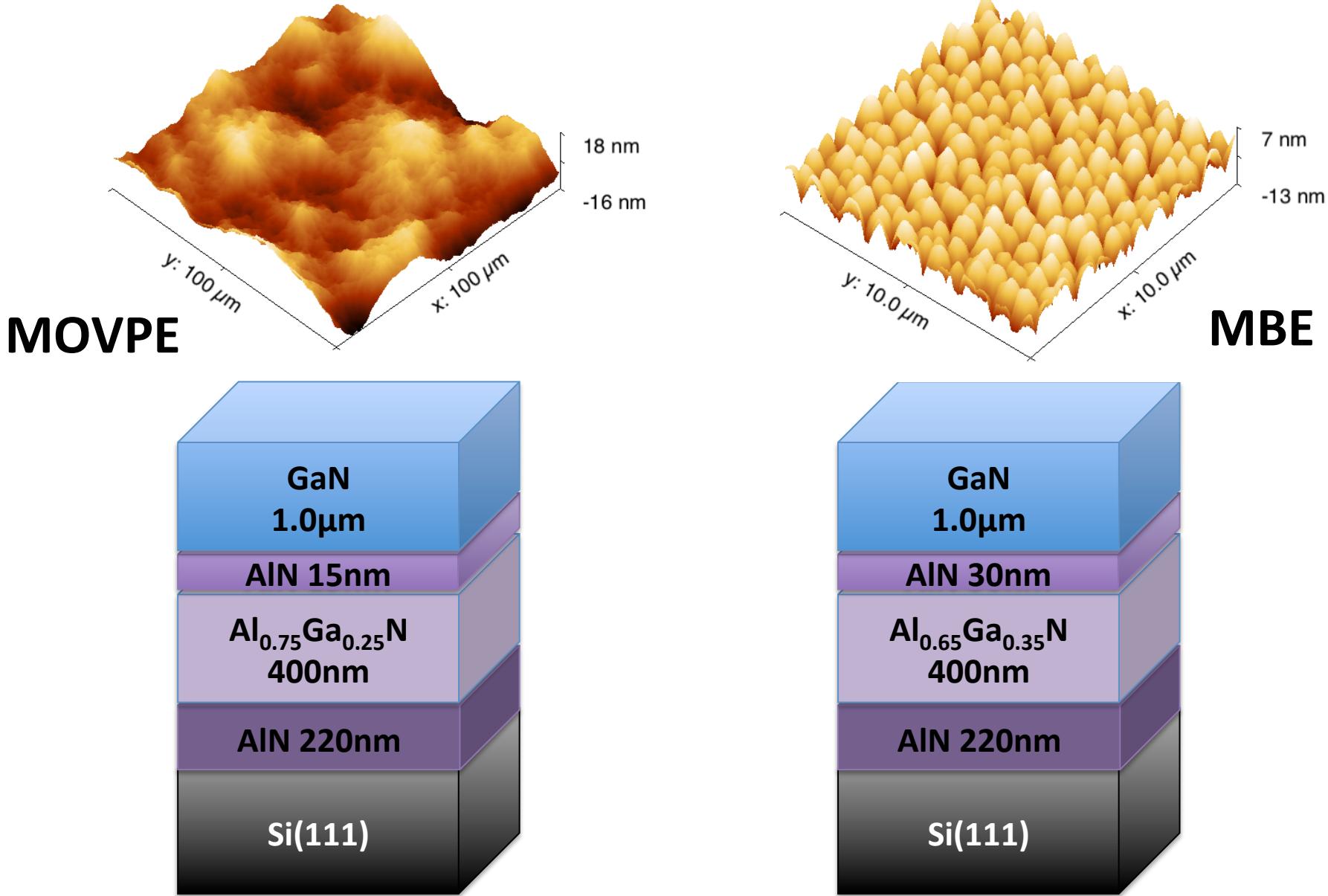


TE2

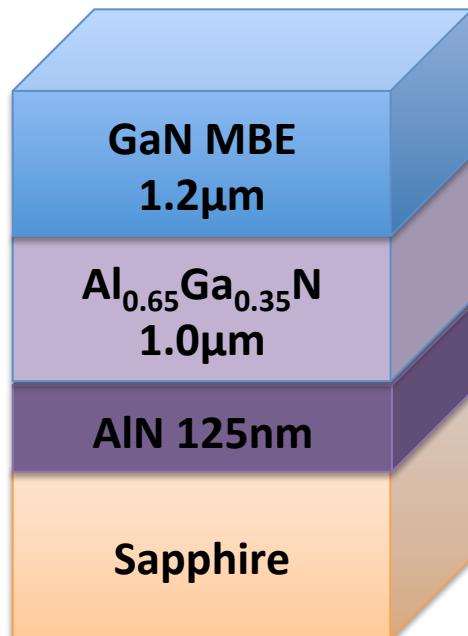
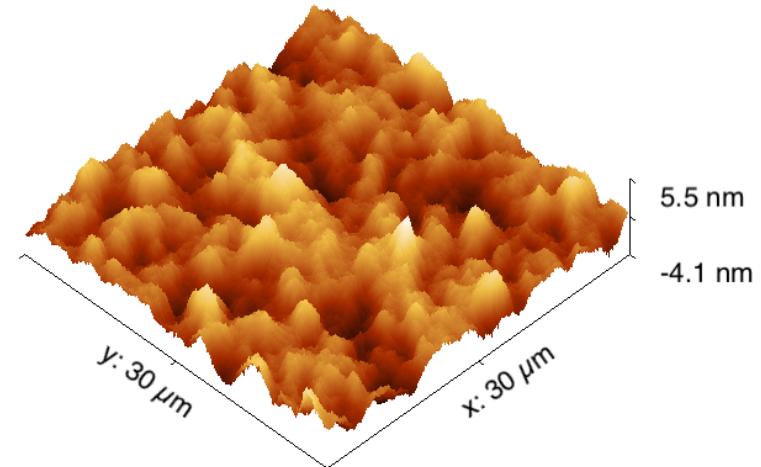
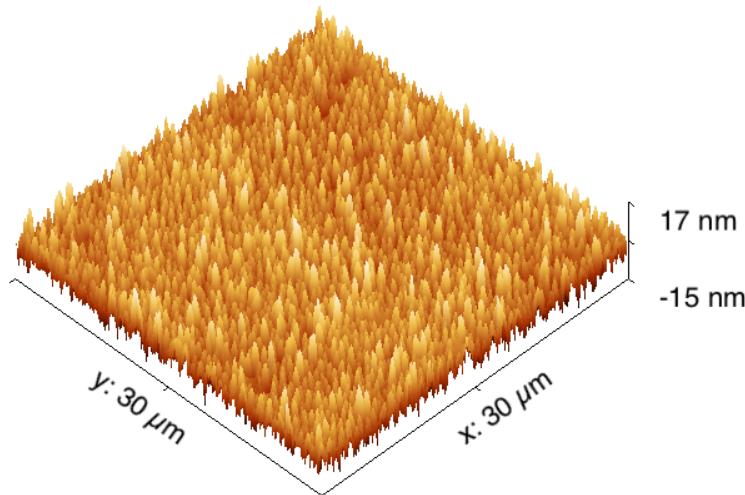


TE2

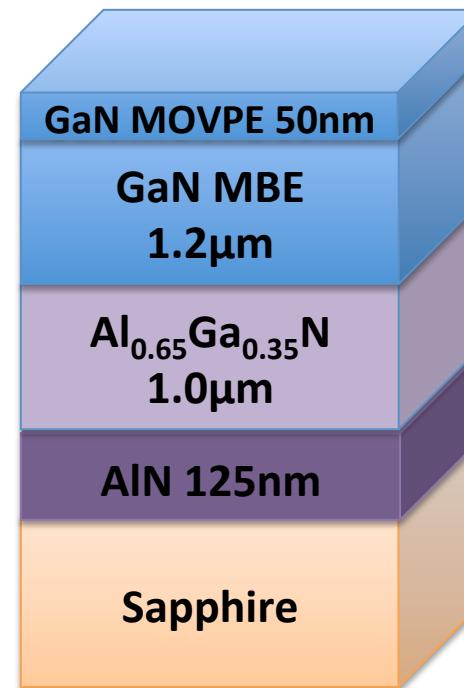
Low loss planar waveguides: MBE vs MOVPE



Low loss planar waveguides: surface roughness



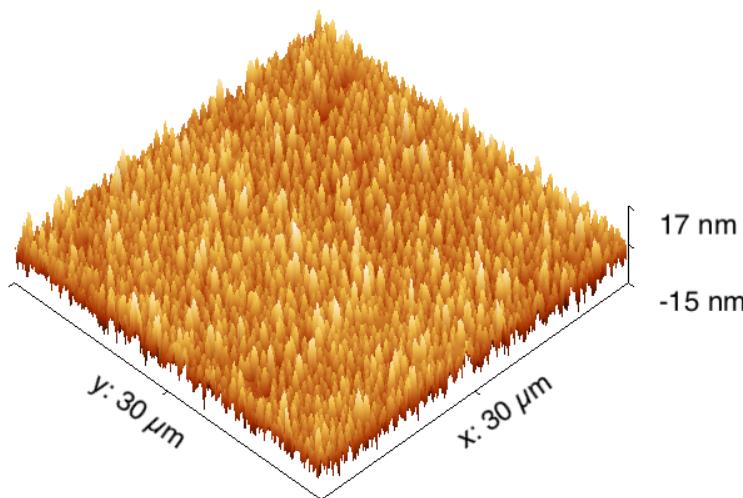
7dB/cm @633nm



1 dB/cm @633nm

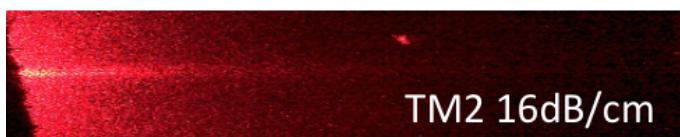
Low loss planar waveguides: surface roughness

MBE

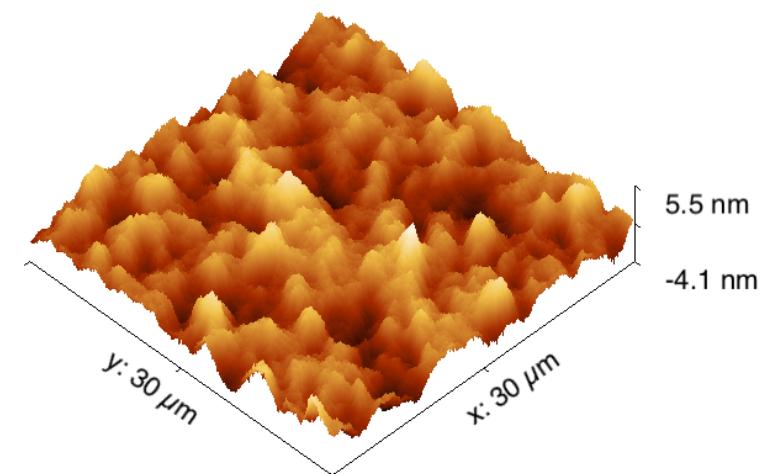


1 cm

Propagation losses @ 633nm

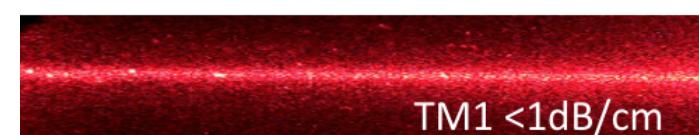
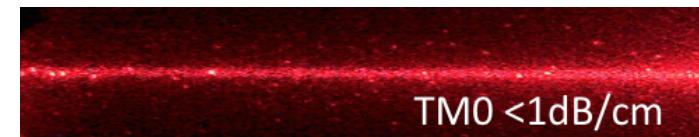


MBE+MOVPE



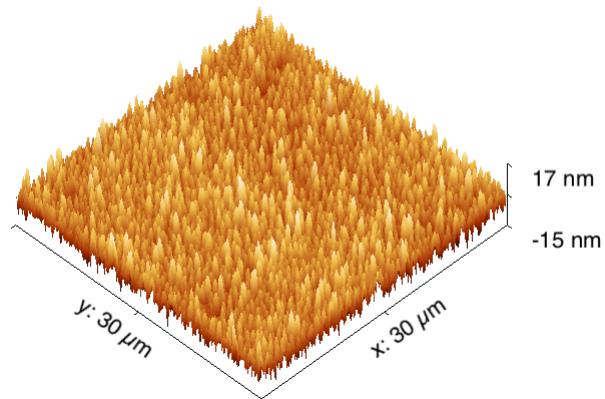
1 cm

← →

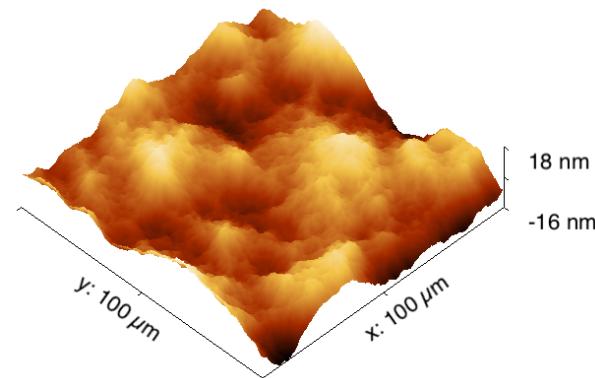


Low loss planar waveguides: surface roughness

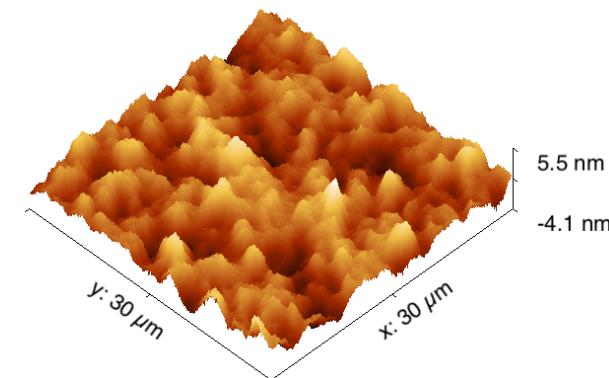
MBE



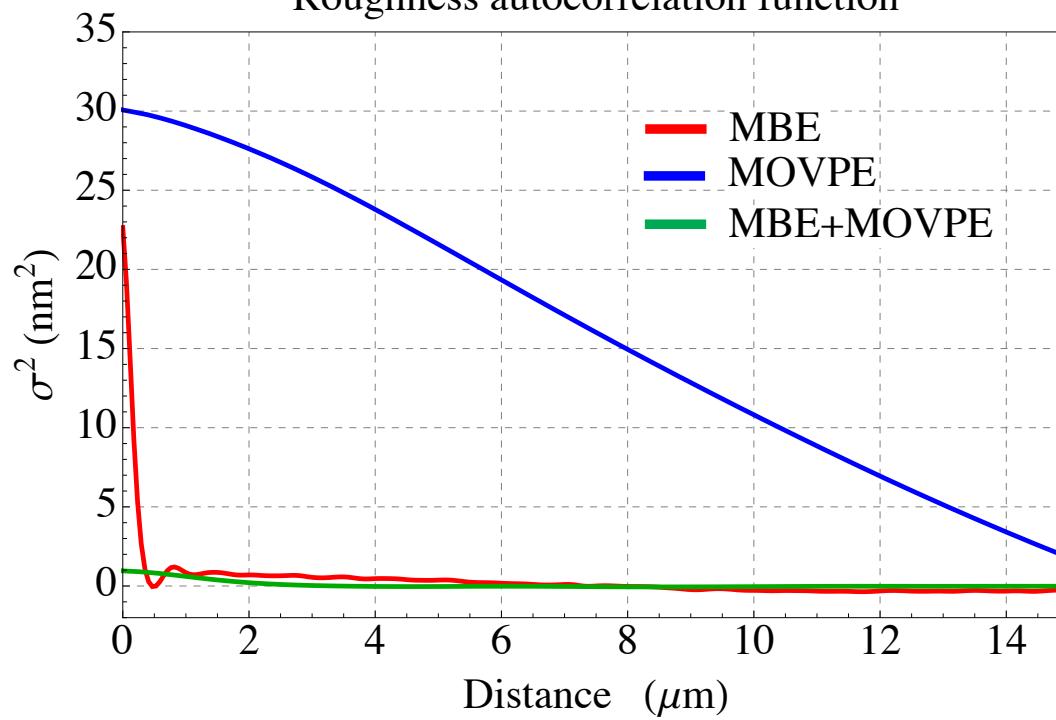
MOVPE



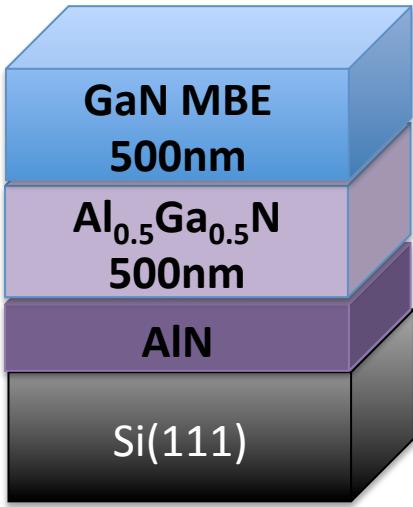
MBE+MOVPE



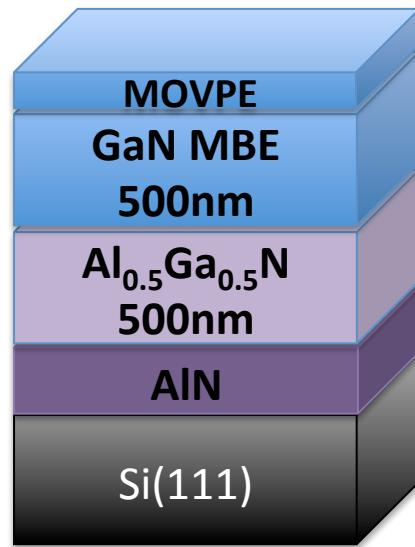
Roughness autocorrelation function



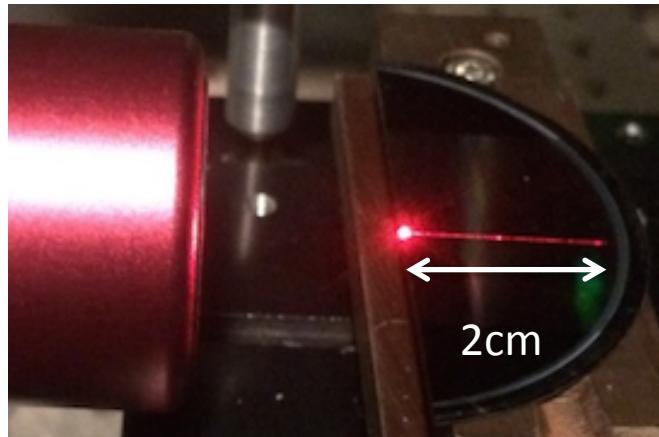
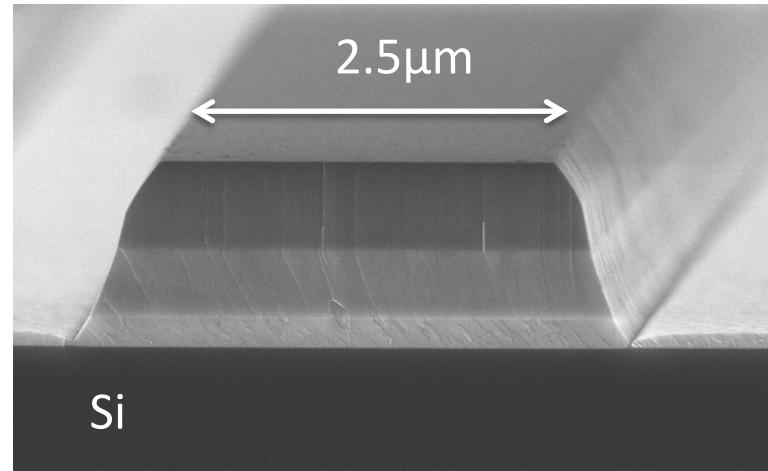
Ridge waveguide for higher power density



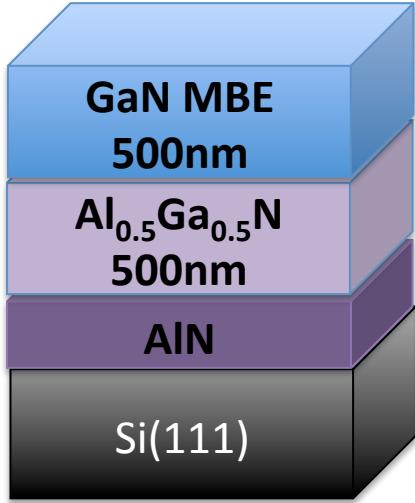
8dB/cm



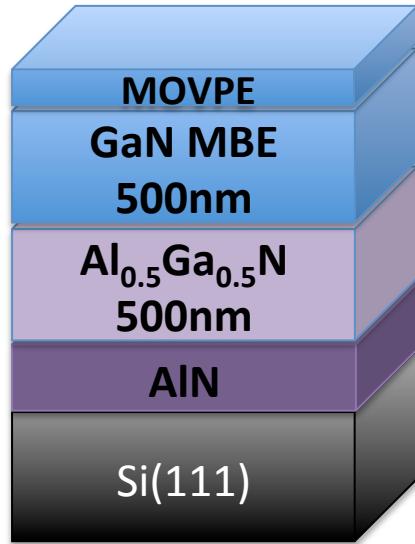
4dB/cm



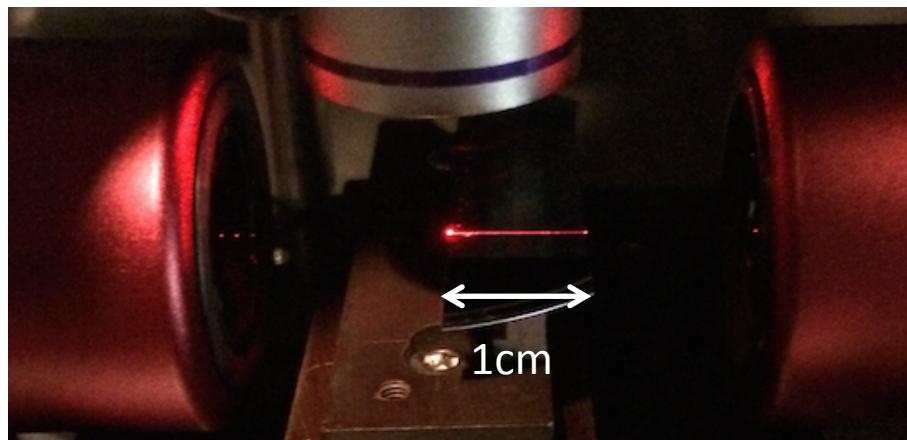
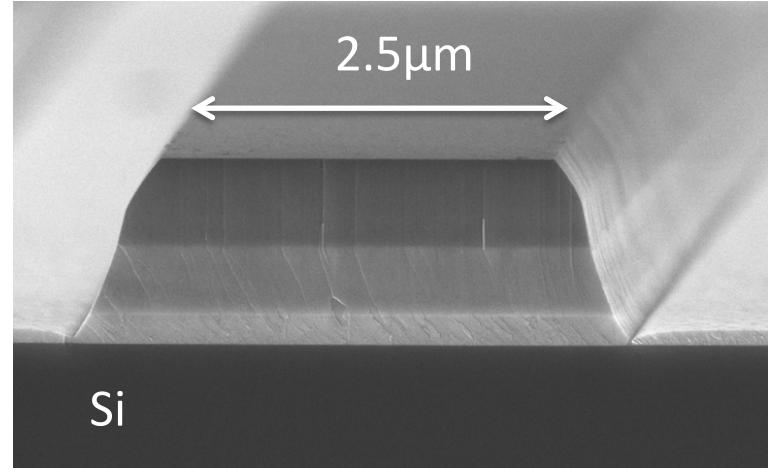
Ridge waveguide for higher power density



8dB/cm



4dB/cm

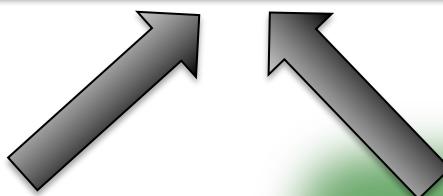


- light is injected in the **TM00** mode;
- intensity of the scattered light decreases at a rate **4±1 dB/cm**

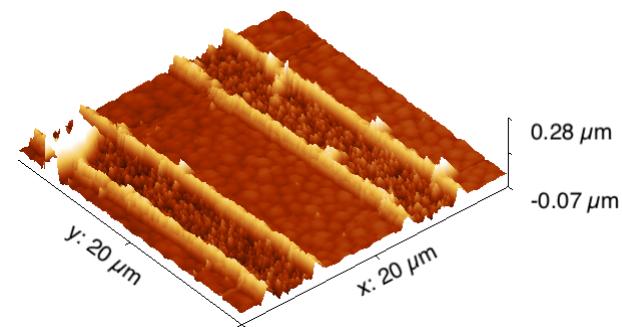
$\chi^{(2)}$ nonlinear
guided wave
interactions

low propagation
losses

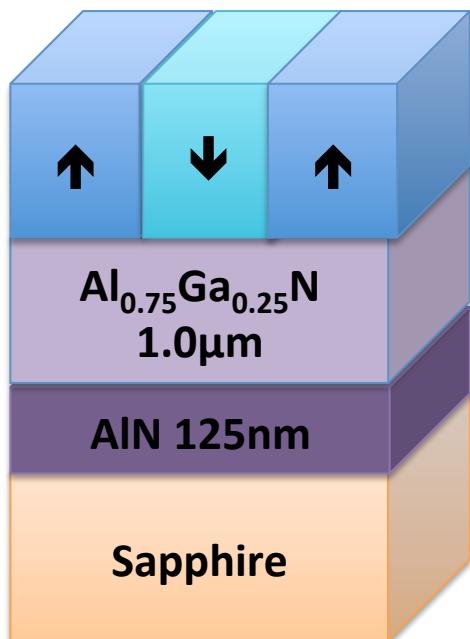
phase-matching



Modal (MPM) and quasi phase-matching (QPM)

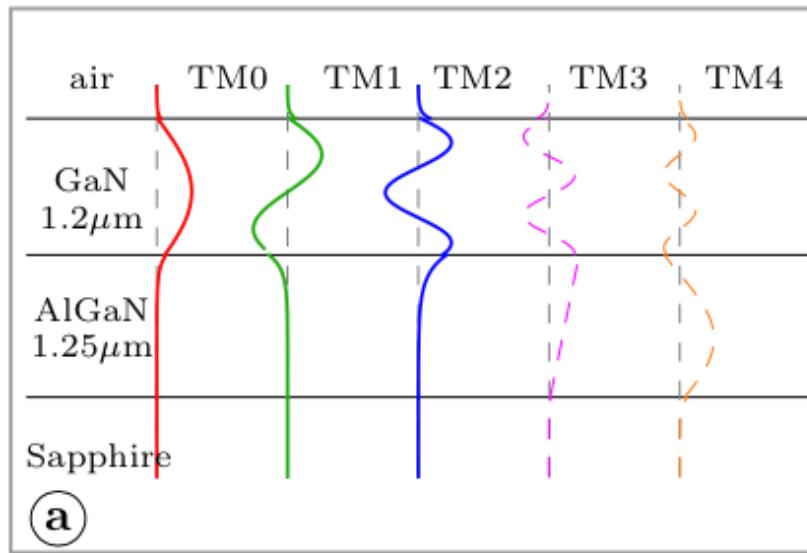


QPM

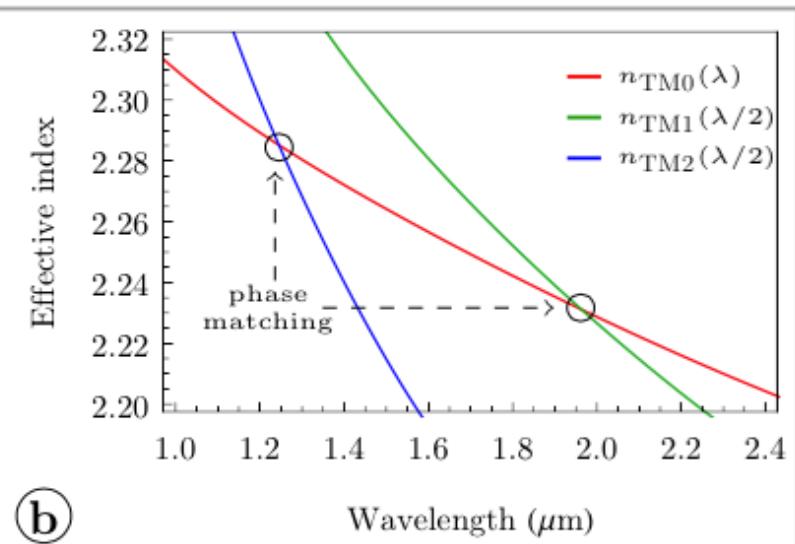


>30dB/cm @633nm

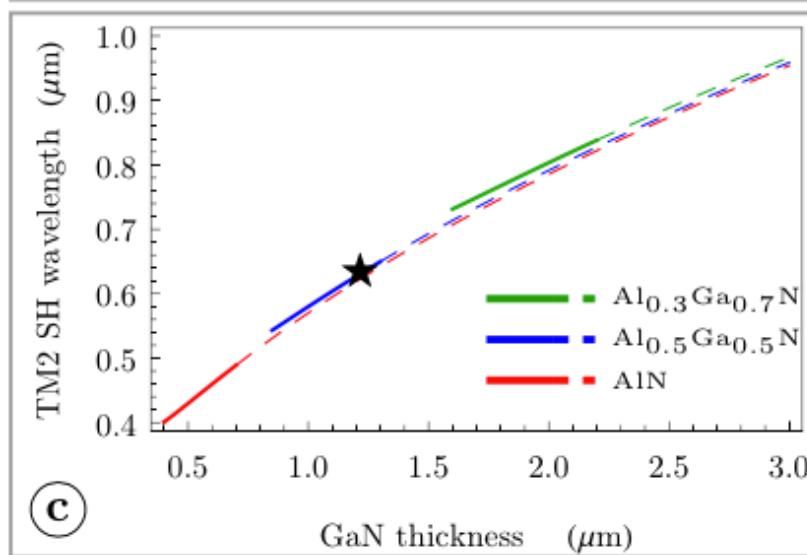
Modal phase matching



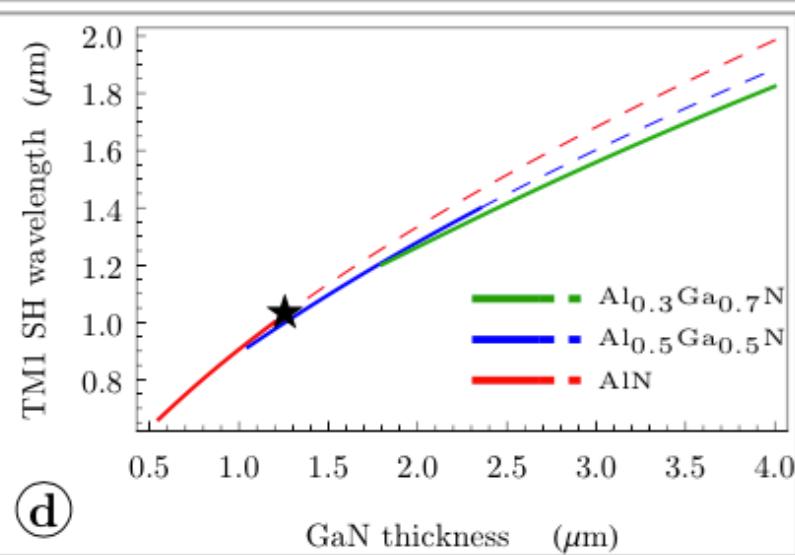
(a)



(b)



(c)



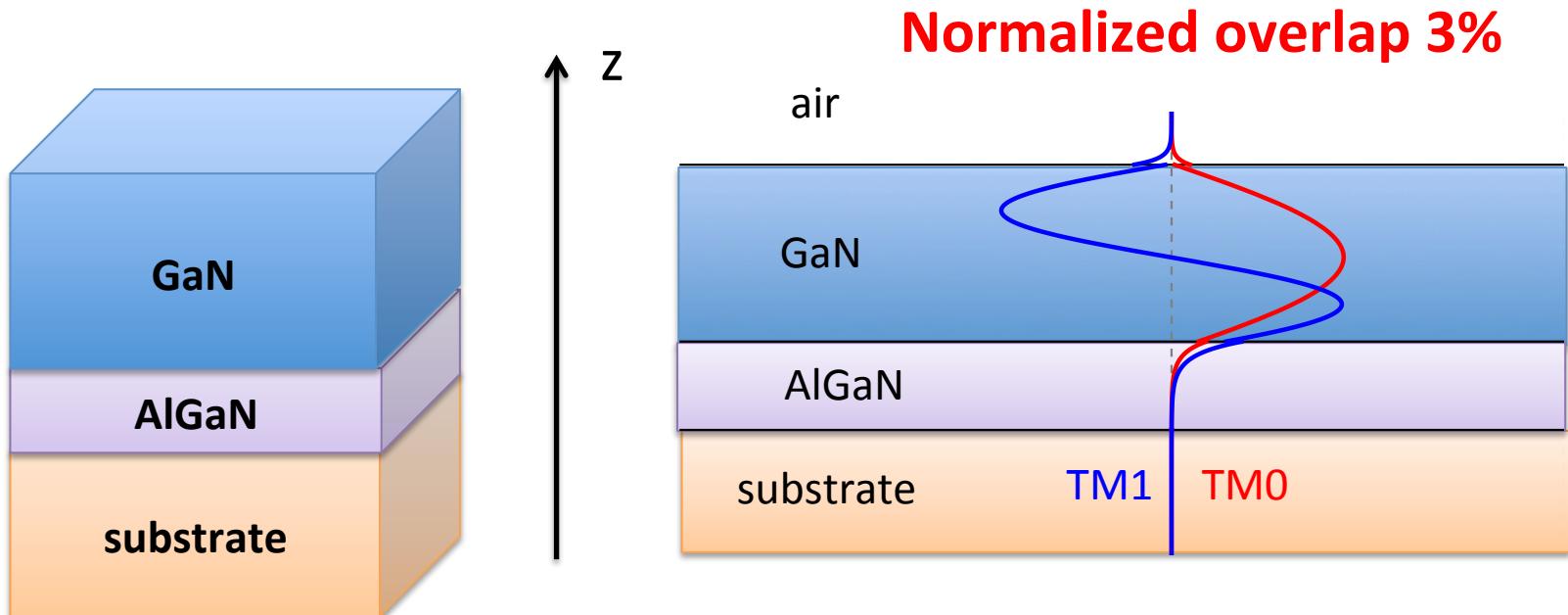
(d)

TM0/TM2 for near-IR to visible conversion

TM0/TM1 for mid-IR to near-IR conversion

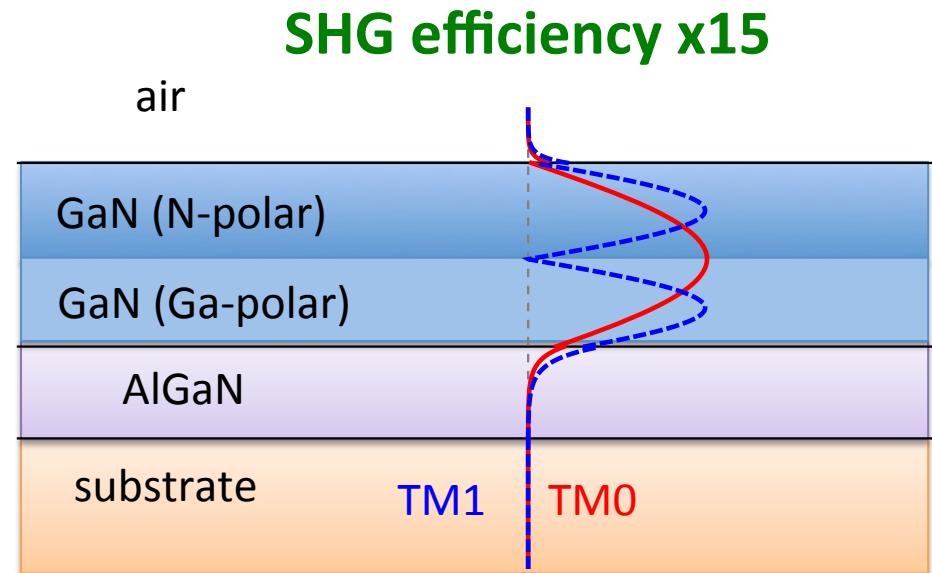
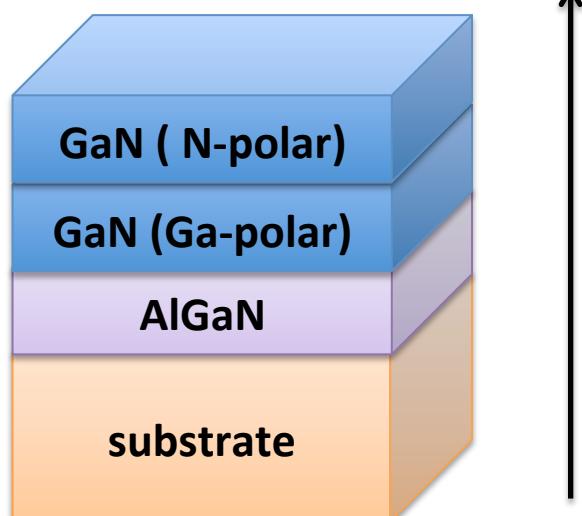
Modal Phasematching: overlap problem

$$K = \int_{-\infty}^{+\infty} d_{33}(z) \mathcal{E}_P^2(\omega, z) \mathcal{E}_{SH}(2\omega, z) dz$$



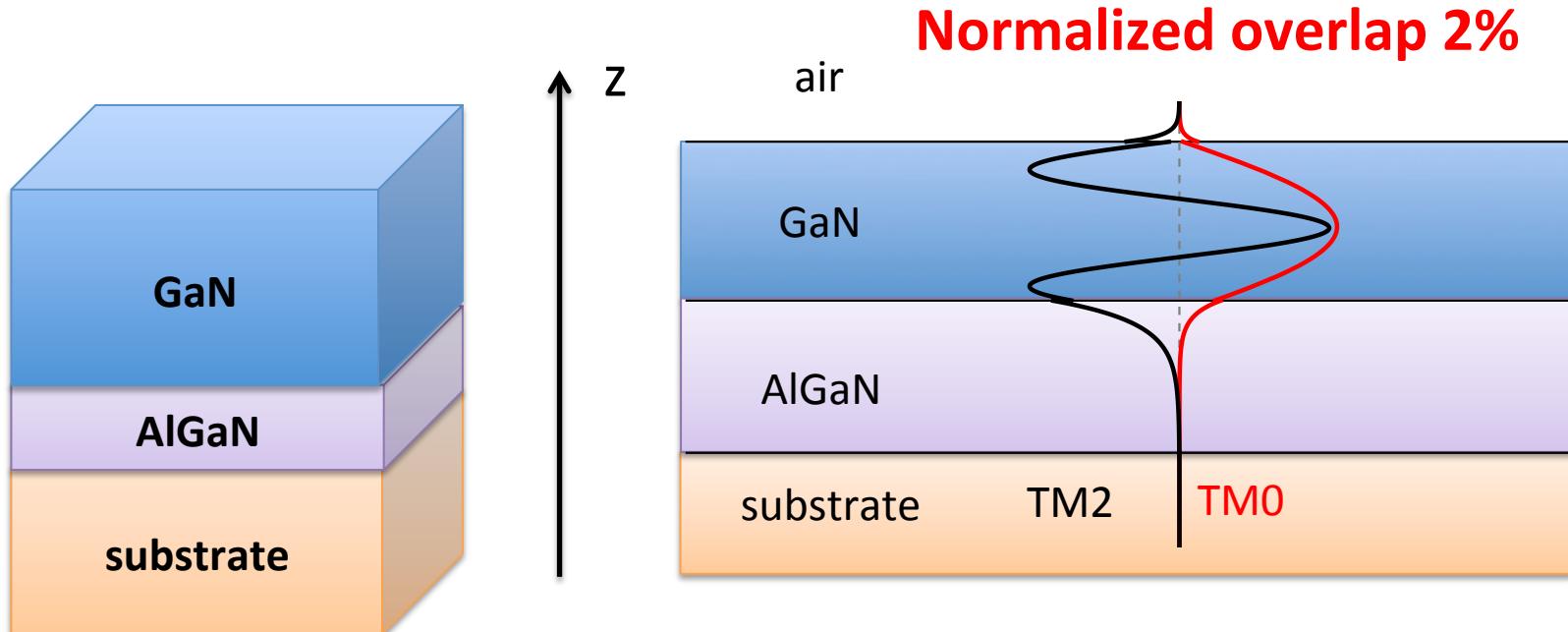
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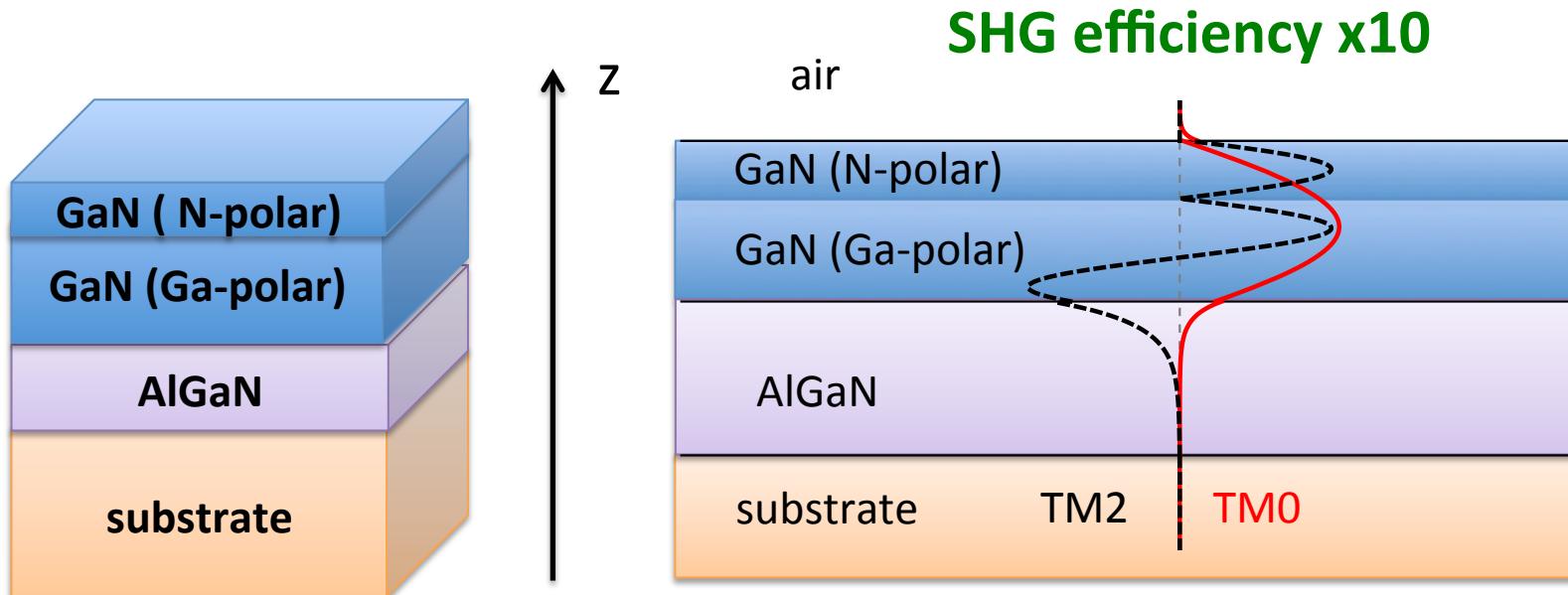
Modal Phasematching: overlap problem

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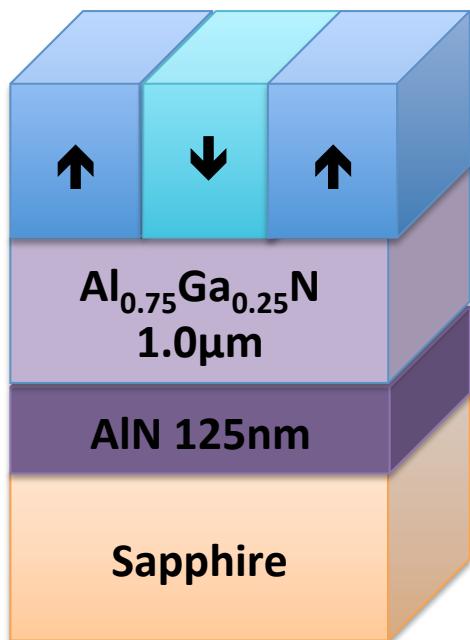
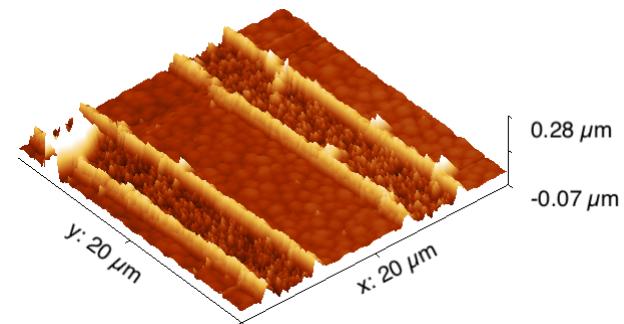


Modal Phasematching: overlap problem

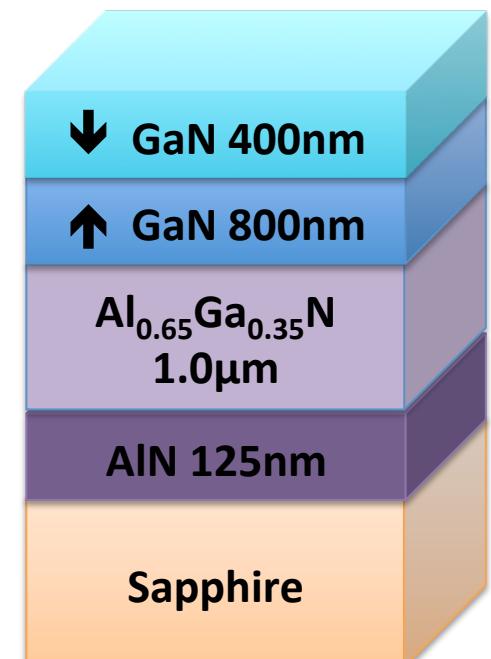
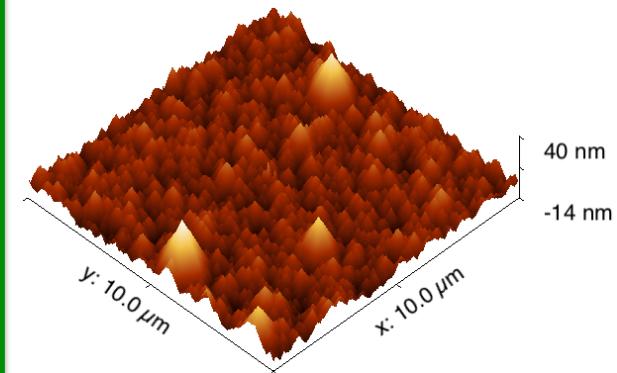
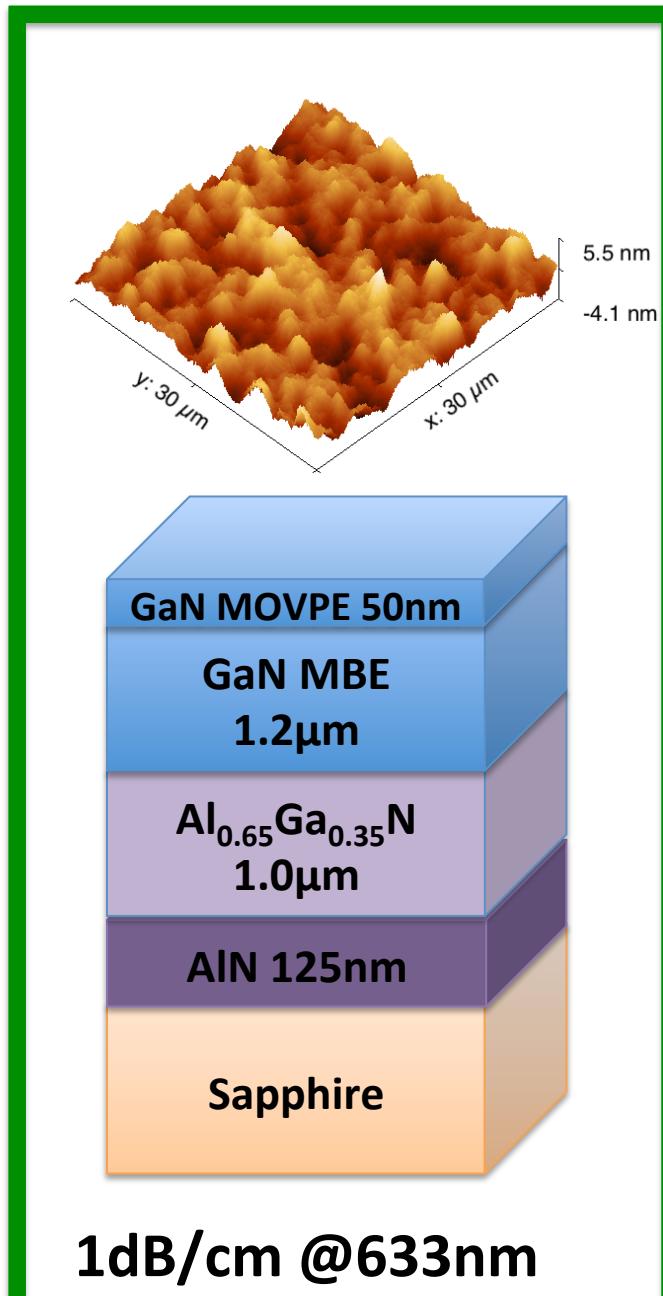
$$K = \int_{-\infty}^{+\infty} d_{33}(z) \mathcal{E}_P^2(\omega, z) \mathcal{E}_{SH}(2\omega, z) dz,$$



Modal and quasi phase-matching

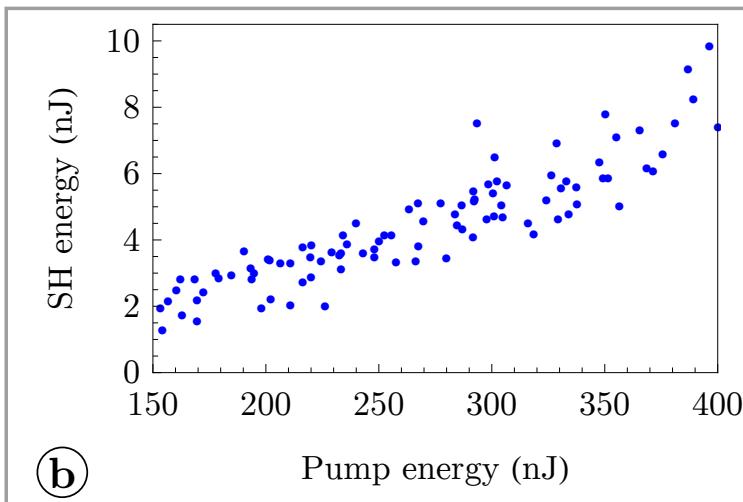
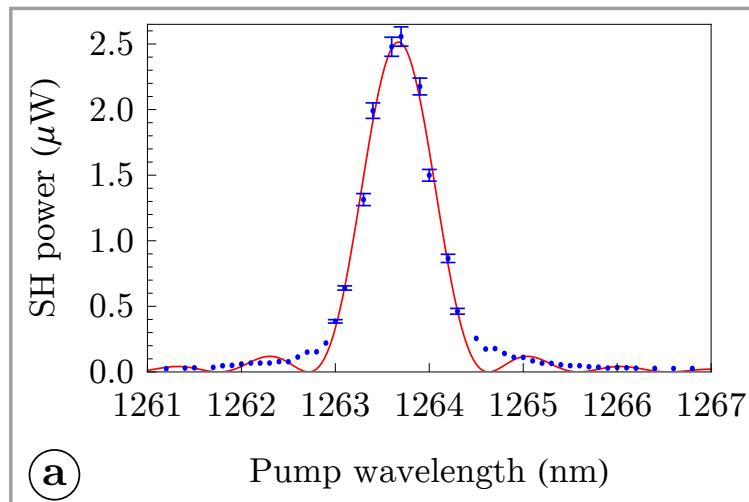
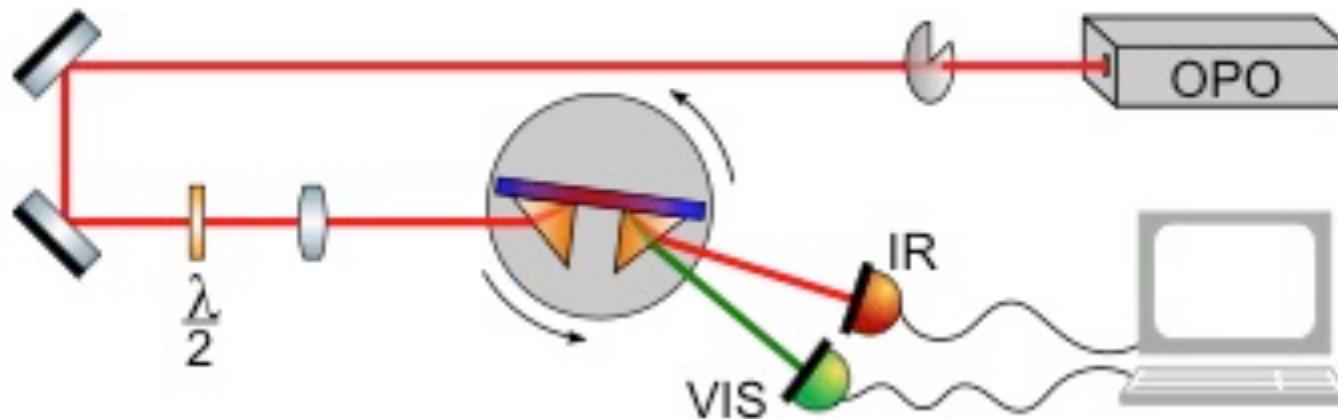


>30dB/cm @633nm



20dB/cm @633nm

Second harmonic generation results

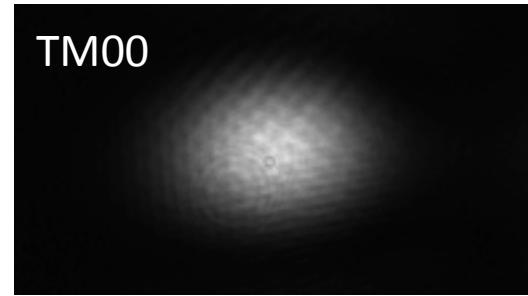
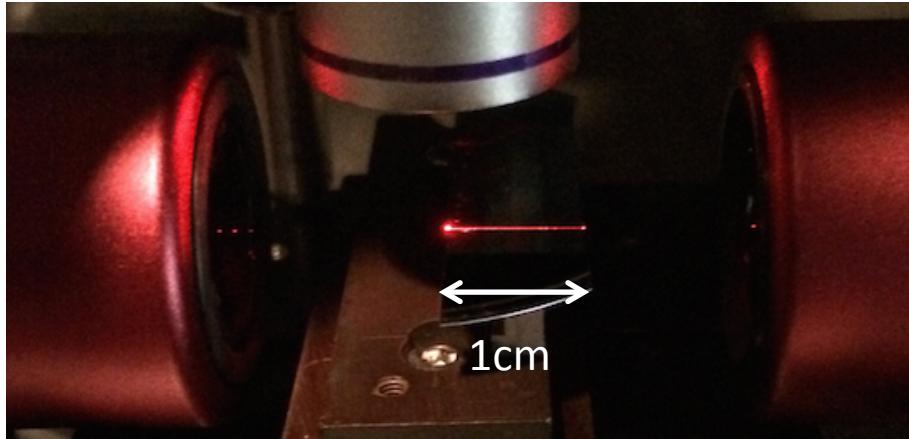
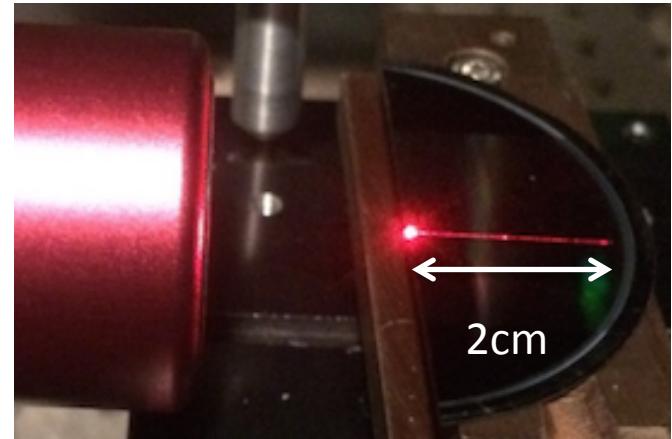
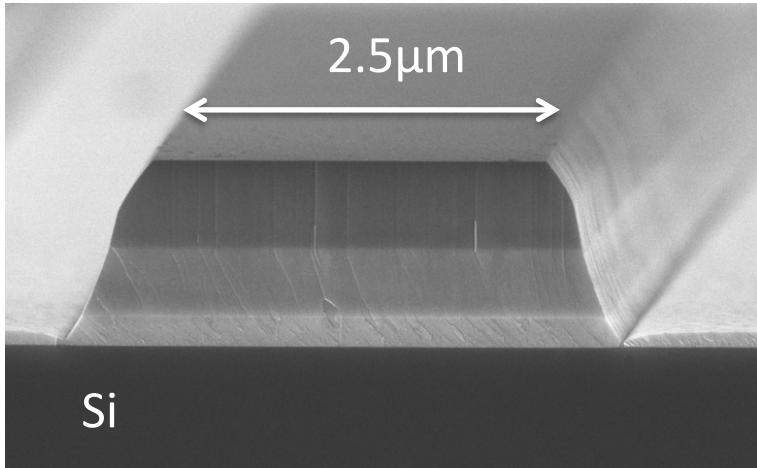


2% conversion is reached for 400nJ pump energy

Second harmonic generation results

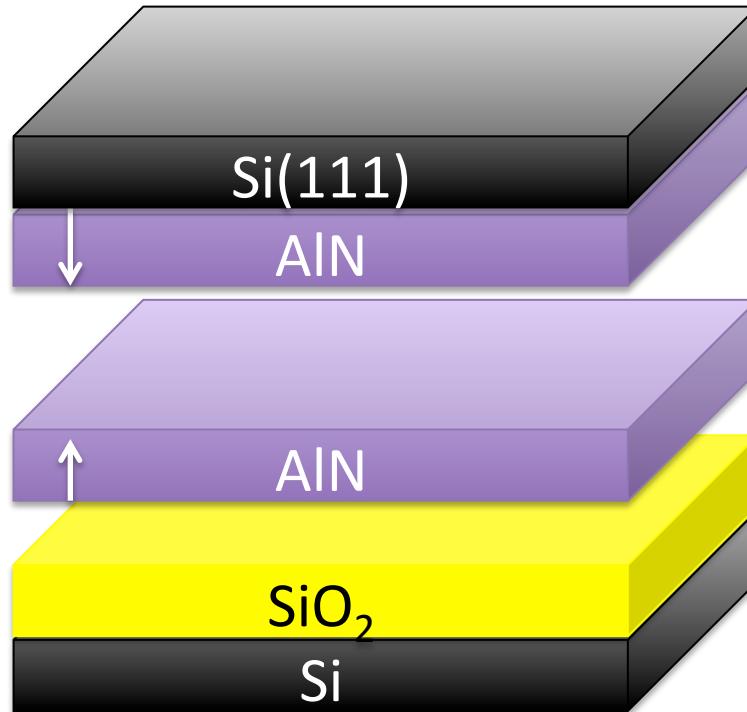
Harmonic wavelength	Harmonic power	Pump power	Conversion efficiency (%/W)	Type of the structure	Laboratory
750nm	0.7nW	0.8mW	0.24	PhC	EPFL Switzerland
633nm	2.5W	100W	$2.5 \cdot 10^{-2}$	GaN planar waveguide	CRHEA, LPMC France
760nm	2.2um	120mW	$1.5 \cdot 10^{-2}$	GaN μ -ring on SiO ₂	Yale, MIT USA
800nm	670mW	670W	$1.5 \cdot 10^{-4}$	PePo-GaN planar	Bell Labs USA

Ridge waveguide for higher power density



- light is injected in the **TM00** mode;
- intensity of the scattered light decreases at a rate of **$4\pm1\text{ dB/cm}$**

Perspectives: AlN for the VIS to UV conversion (collaboration with CEA-LETI, Grenoble)



VIS 500nm → UV 250nm
conversion with 100%W⁻¹cm⁻² theoretical efficiency

Conclusions and perspectives

- We have made an important progress in understanding propagation losses in AlGaN waveguides.
- Low propagation losses allowed us to demonstrate AlGaN potential for efficient nonlinear interactions using modal phase matching.
- Further improvements are required to realize a the structures with polarity inversion.
- Report is one solution.
- Report allows realizing structures for UV generation.

THANK YOU
for your
ATTENTION!
Any
QUESTIONS?