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Characterization of III-Nitride Nanowires

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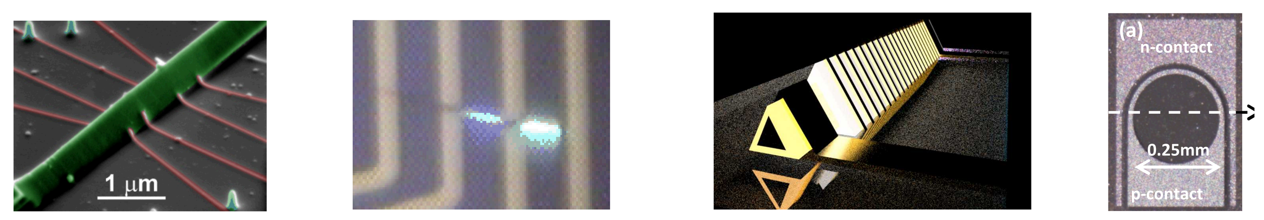
Motivation

The III-nitrides (AlGaInN) are technologically important direct band-gap semiconductors which absorb and emit over a very broad and attractive energy range from the UV to the infrared wavelengths, and are the materials used for many commercial products like visible light-emitting diodes (LEDs) and blue laser diodes. Nanowires (NWs) based on the III-nitride materials system have attracted attention as potential ultra-compact building blocks in future generation optoelectronics, sensing, photovoltaics, and electronics. Advantages of nanowires due to elastic strain relaxation and their unique geometries *may lead to novel physics and enhanced performance devices with new functionalities.*



high speed electronics *LEDs* *nanolasers* *solar cells*

Advantages due to size and geometry of nanowires

Nanowire attribute	Benefit
Vertical 3D device integration (radial)	High surface/device area = lower cost;
Non-polar, semi-polar facets	Reduced polarization effects (IQE)
2D arrangements, e.g. photonic crystals	Enhanced/controlled light extraction, wavelength tuning, rad. recombination (IQE)
Nanolasers	Lower threshold lasers; reduced eff. droop
Discrete; (and all of the above)	Scientific test system

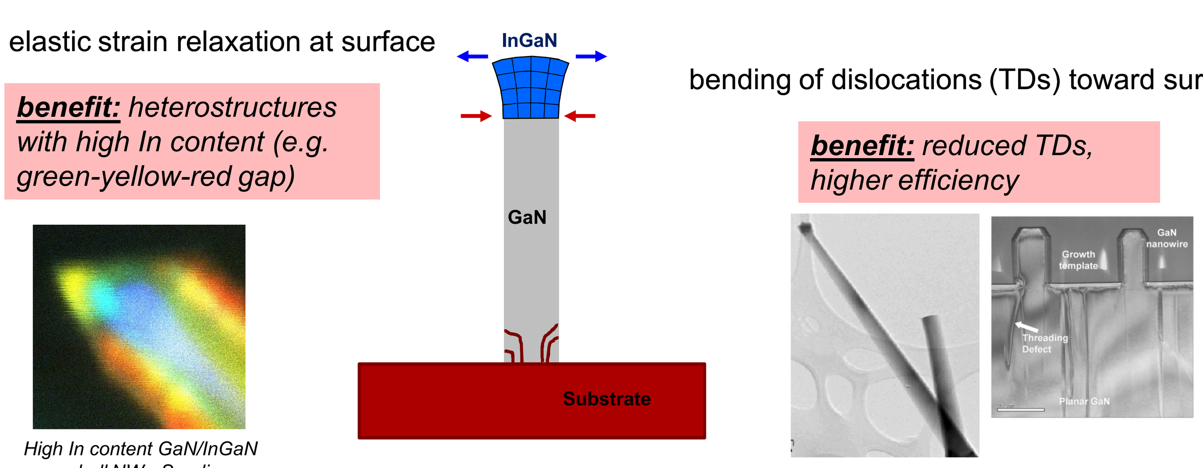
Advantages due to enhanced strain accommodation in nanowires

elastic strain relaxation at surface

benefit: *heterostructures with high In content (e.g. green-yellow-red gap)*

bending of dislocations (TDs) toward surface

benefit: *reduced TDs, higher efficiency*

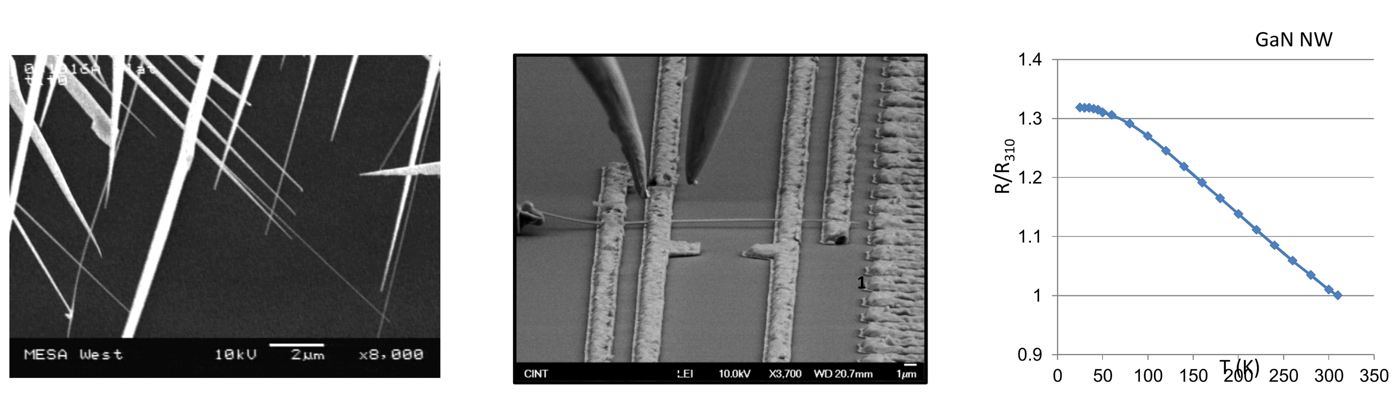


High In content GaN/InGaN core-shell NW - Sandia
Q. M. Li, G. T. Wang, *Appl. Phys. Lett.*, 97, 181107 2010.

small interfacial area

benefit: *can grow on cheaper, lattice mismatched substrates; integration with Si devices*

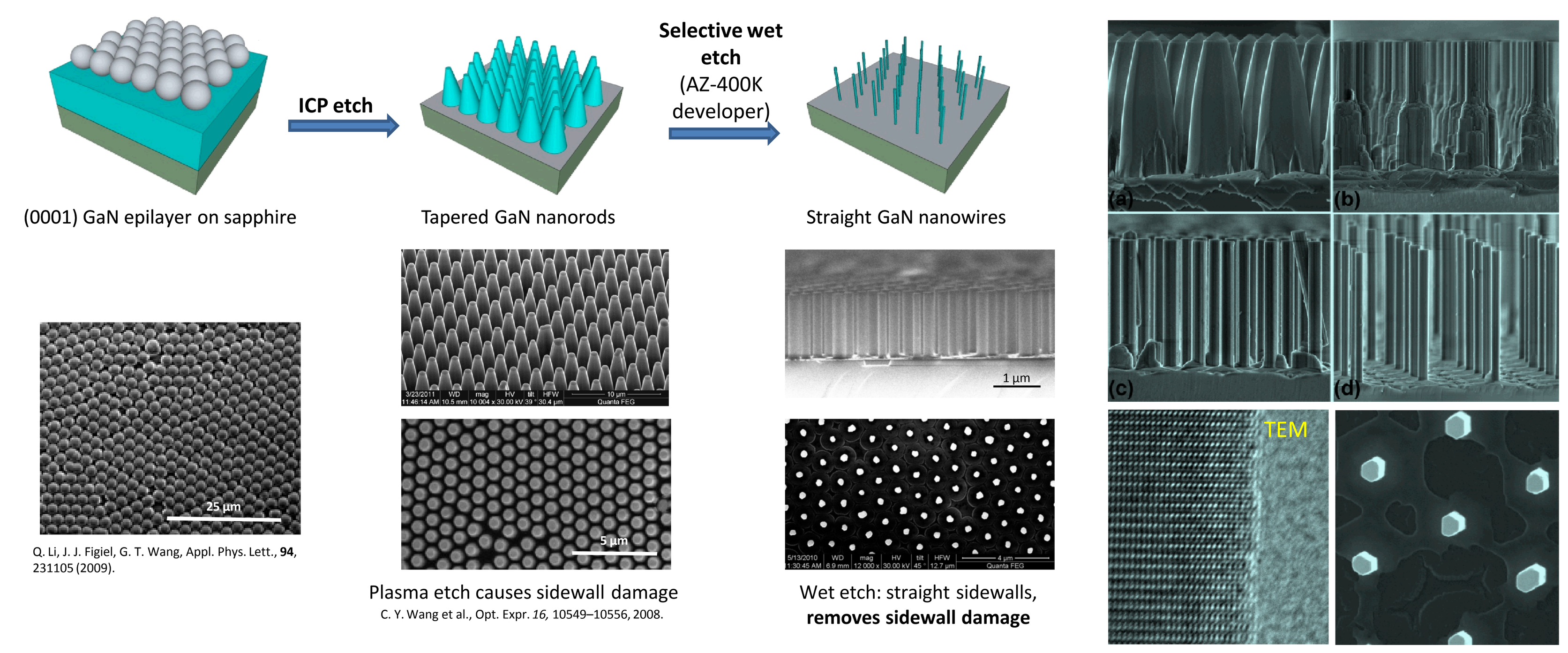
Nanowire Electrical Characterization



- Tested a platform for single nanowire 4-terminal electrical characterization.
- Resistance saturates at low temperatures (metallic-like behavior) indicating high material quality (bottom-up GaN NW).

Nanowire Synthesis

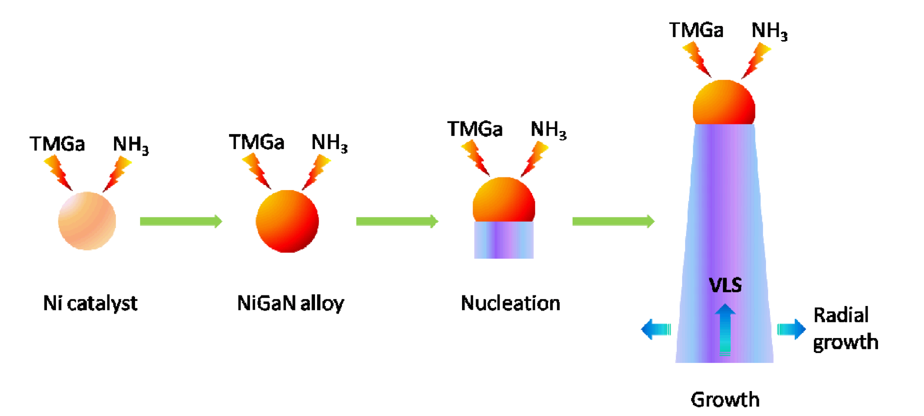
Top-down method (originated at Sandia)



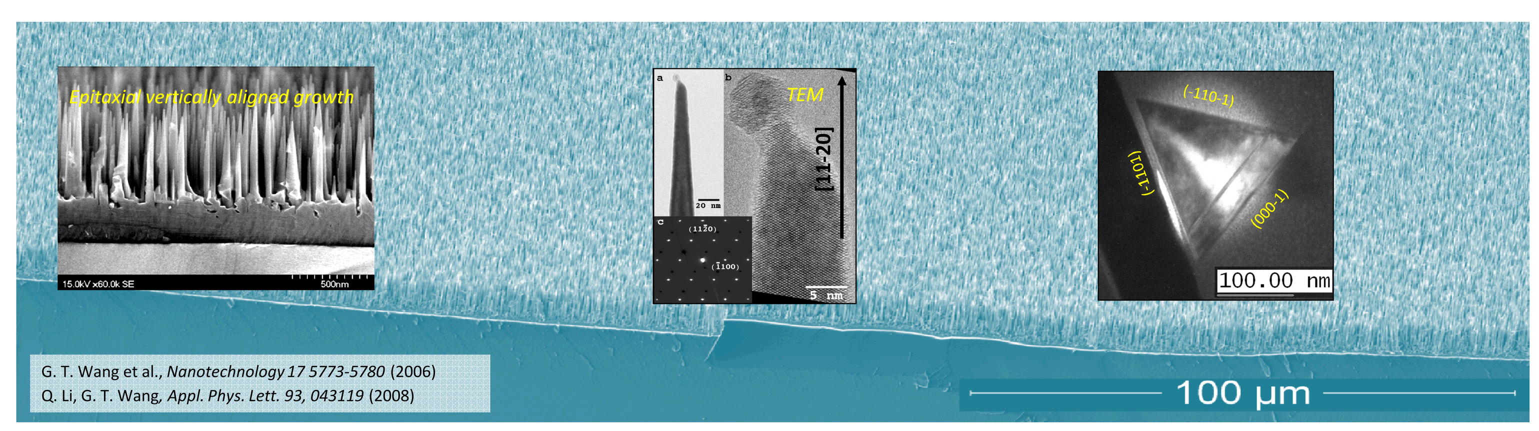
Q. Li, J. J. Figiel, G. T. Wang, Appl. Phys. Lett., 94, 231105 (2009).
C. Y. Wang et al., Opt. Expr. 16, 10549–10556, 2008.

Wet etch rate negligible for top c-face & fast for [10-10], leads to hexagonal NWs with **straight & smooth** *m*-facets

Bottom-up nanowire fabrication method

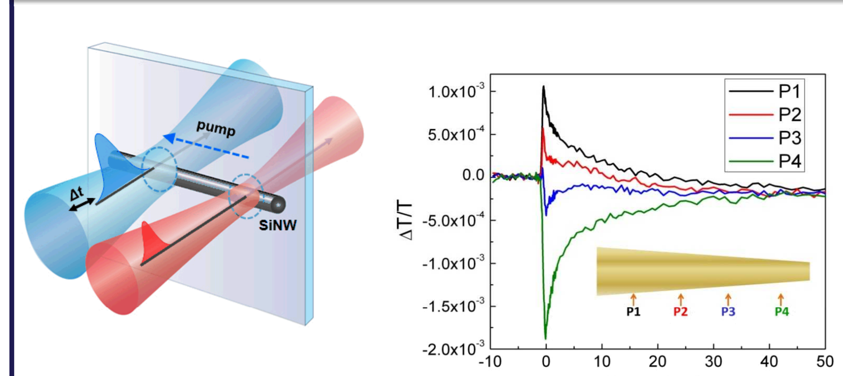


- Dislocation-free nanowires grown by Ni-catalyzed MOCVD (VLS)
- Highly-aligned vertical growth over large areas (2" r-sapphire wafer)
- Controllable densities as high as ~150 nanowires μm^{-2}



G. T. Wang et al., *Nanotechnology 17 5773-5780* (2006)
Q. Li, G. T. Wang, *Appl. Phys. Lett. 93, 043119* (2008)

Ultrafast Optical Microscopy

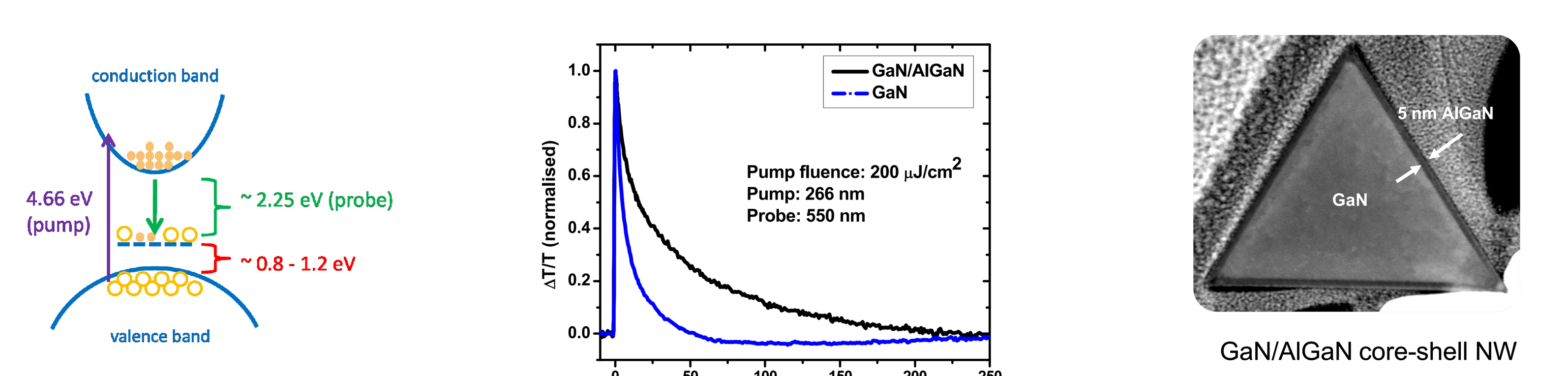


Position-dependent carrier relaxation in a single GaN NW

Ultrafast optical microscopy (UOM) can track carriers through space and time after photoexcitation in a single semiconductor nanowire

- Examined spatially-dependent carrier relaxation in single tapered GaN NWs

Surface Passivation with AlGaN shell layers

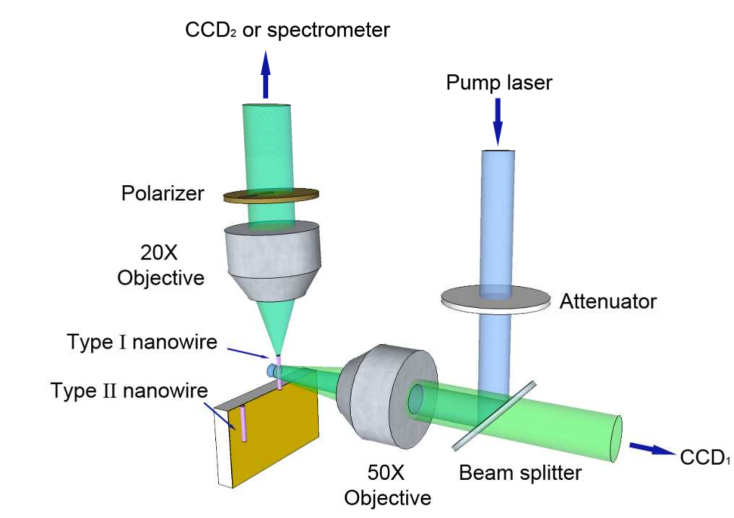


GaN/AlGaN core-shell NW

Kar, A., et al., *Appl. Phys. Lett.*, ***101***, 143104 **(2012).**

Microphotoluminescent Characterization

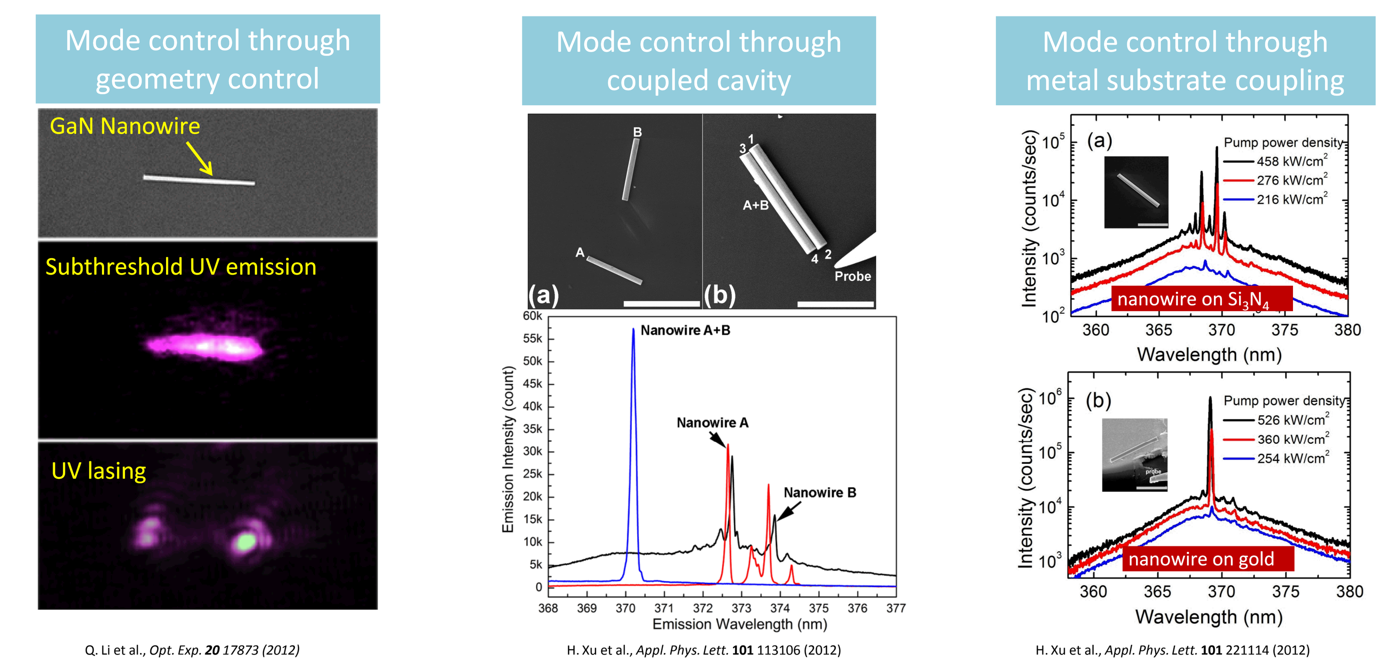
Photoluminescent Microscope



- Pump spot is tunable in size and power density.
- Light can be collected from the end-facet or back scatter

Modal control of nanowire lasers

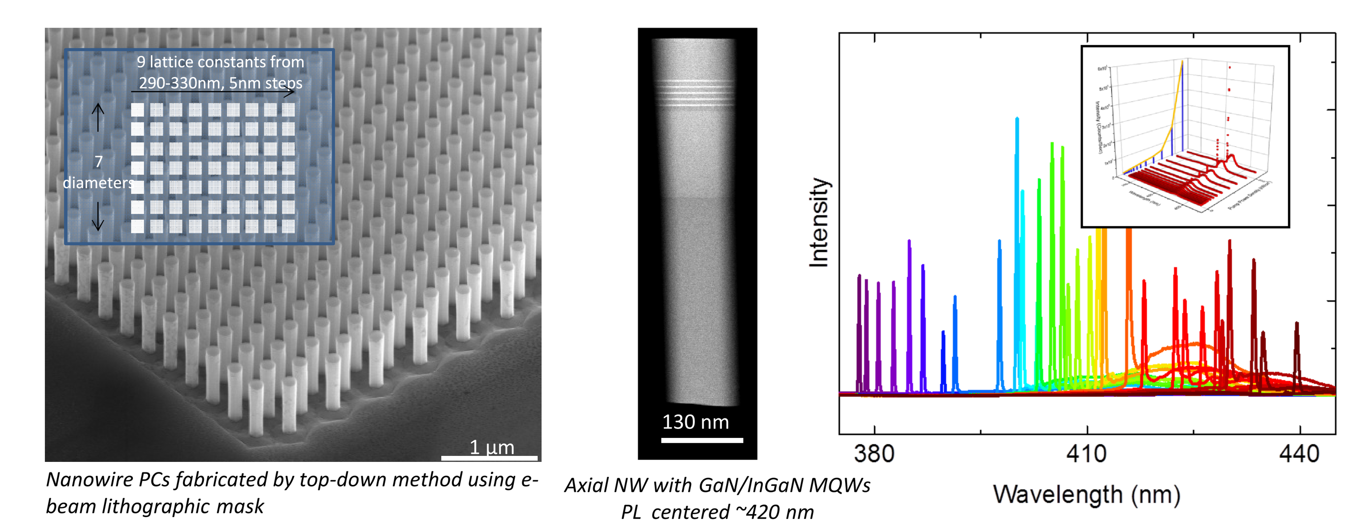
Motivation: NW lasers could serve as low-power, ultra-compact coherent light sources. Single-mode operation is desired for highest beam quality and resolution.



Q. Li et al., *Opt. Exp.* 20 17873 (2012)
H. Xu et al., *Appl. Phys. Lett.* 101 113106 (2012)
H. Xu et al., *Appl. Phys. Lett.* 101 221114 (2012)

Tunable photonic crystal nanowire lasers

Motivation: Achieve single-mode, tunable lasing on same chip. Applications in optical information processing, biology, solid state lighting, displays, etc.



Nanowire PCs fabricated by top-down method using e-beam lithographic mask

Axial NW with GaN/InGaN MQWs PL centered ~420 nm

Spectral coverage from 380-440nm on a single chip!

Publication in review

Publications from C2012A0024

H. W. Xu, J. B. Wright, A. Hurtado, Q. M. Li, T. S. Luk, J. J. Figiel, K. Cross, G. Balakrishnan, L. F. Lester, I. Brener, G. T. Wang, "Gold substrate-induced single-mode lasing of GaN nanowires", *Appl. Phys. Lett.*, ***101***, 221114 **(2012)**.

Kar, A., Q. Li, P. C. Upadhya, M. Seo, J. B. Wright, T. S. Luk, G. T. Wang, R. P. Prasankumar, "The influence of radial heterostructuring on carrier dynamics in gallium nitride nanowires", *Appl. Phys. Lett.*, ***101***, 143104 **(2012).**

X., H., J. B. Wright, L. Ting-Shan, J. J. Figiel, K. Cross, L. F. Lester, G. Balakrishnan, G. T. Wang, I. Brener, L. Qiming, "Single-mode lasing of GaN nanowire-pairs", *Appl. Phys. Lett.*, ***101***, 113106 **(2012)**.

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