Epitaxially overgrown tungsten features for current restriction applications in GaAs

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6.772 final project presentation

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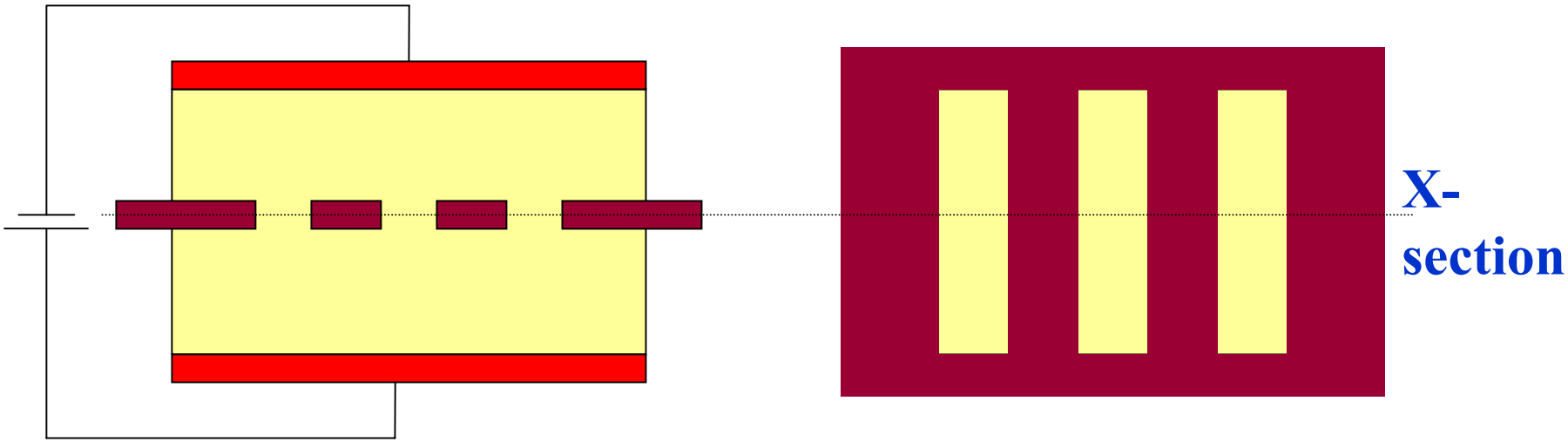
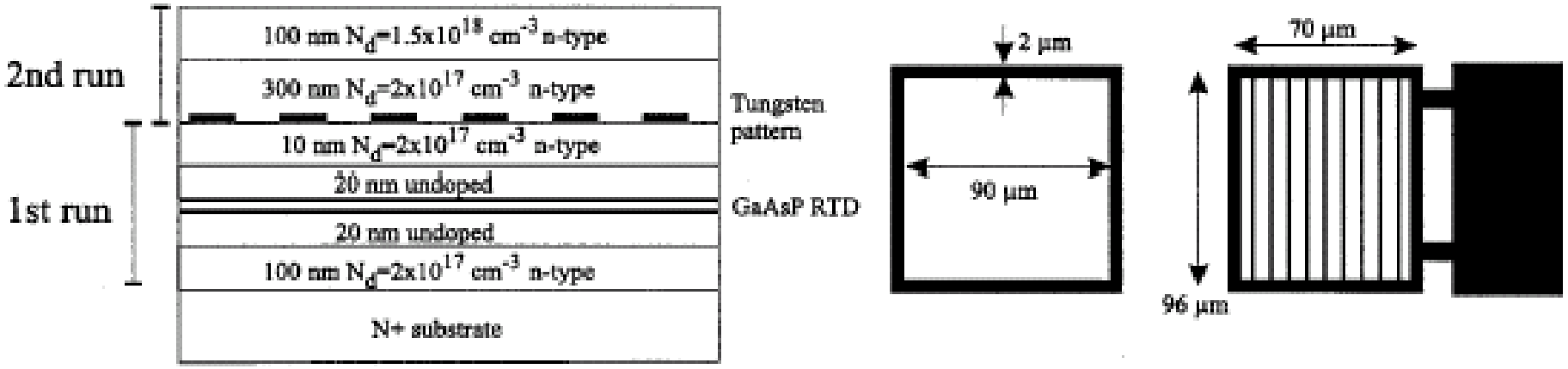
The Permeable Base Transistor (PBT) – epitaxially overgrown metallic gates



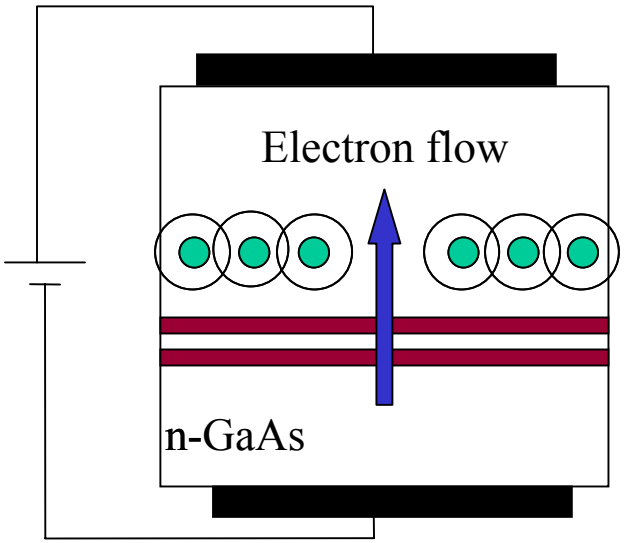
- Permeable base transistor: Device operation similar to a vertical channel MESFET
  - Short gate lenghts possible (improving current drive)
  - Two channels per grid line
  - Overgrowth of tungsten lines not trivial
  - [2] Bozler et al. 1980

The Permeable Base Resonant Tunneling Transistor



- Resonant Tunneling Barriers + PBT
  - RTTs are interesting for research since they utilize quantum mechanical phenomenon (tunneling) and enable multilevel logic to be investigated.
  - Related is the Resonant Tunneling Diode (RTD). Such diodes can also have buried metallic features for isolation purposes
  - [4], Lind et al. 2002

Resonant Tunneling Diodes with overgrown metallic features (tungsten)



Device area defined by opening

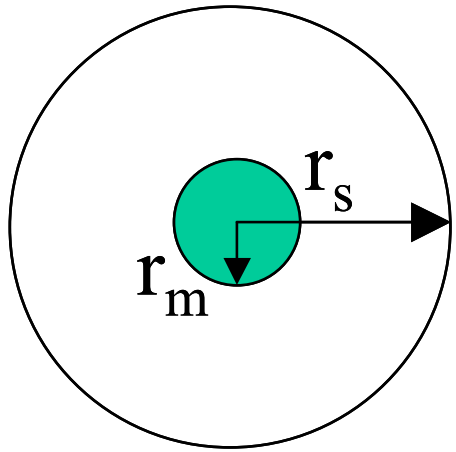
Resonance when bands aligned with well bound states, ref [3], Wernersson et al.

How does the current restriction work?

3D Schottky contacts (using a 1D spherically symmetric model)

Charge on metal sphere:

$$Q_m = qN_d \frac{4\pi}{3}\left(r_s^3 - r_m^3\right)$$



Gauss law (assume field to 0 at rs):

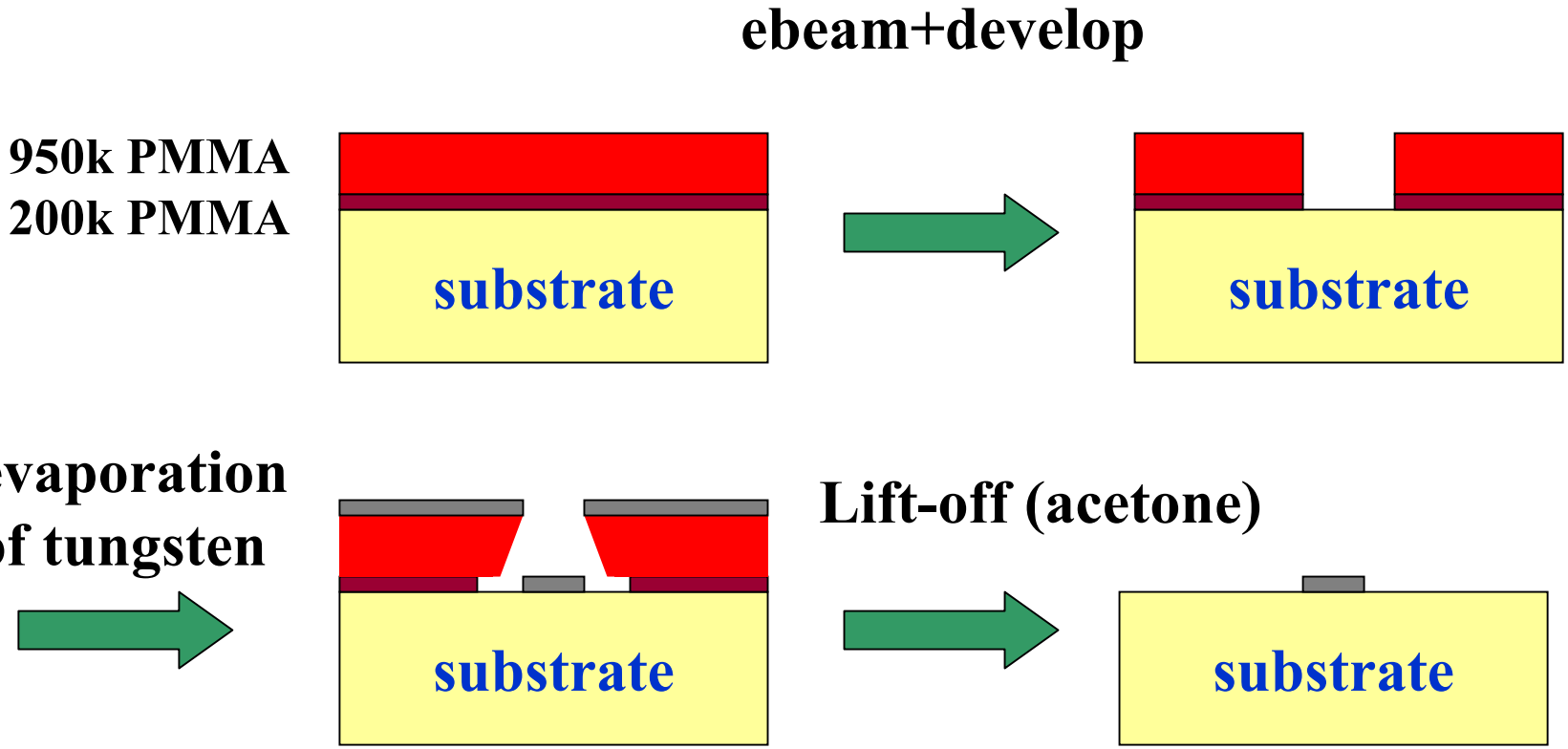
$$E(r) = \frac{qN_d}{3\varepsilon\varepsilon_0}\left(\frac{r_s^3}{r^2} - r\right), \quad r_m < r < r_s$$

Obtain potential by integration:

$$\Phi_b = \frac{qN_d}{6\varepsilon\varepsilon_0}\left(\frac{2r_s^3}{r_m} + r_m^2 - 3r_s^2\right).$$

Ref [6], Warren et al.

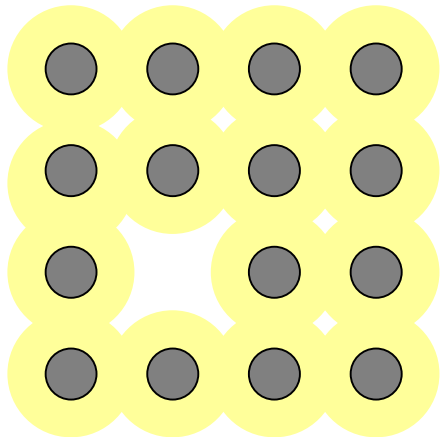
Traditional isolation approach: ebeam lithography evaporation of tungsten and lift-off



Thermal expansion and deformation of PMMA

PMMA=polymethyl methacrylate

Current restriction by a “traditional” grid

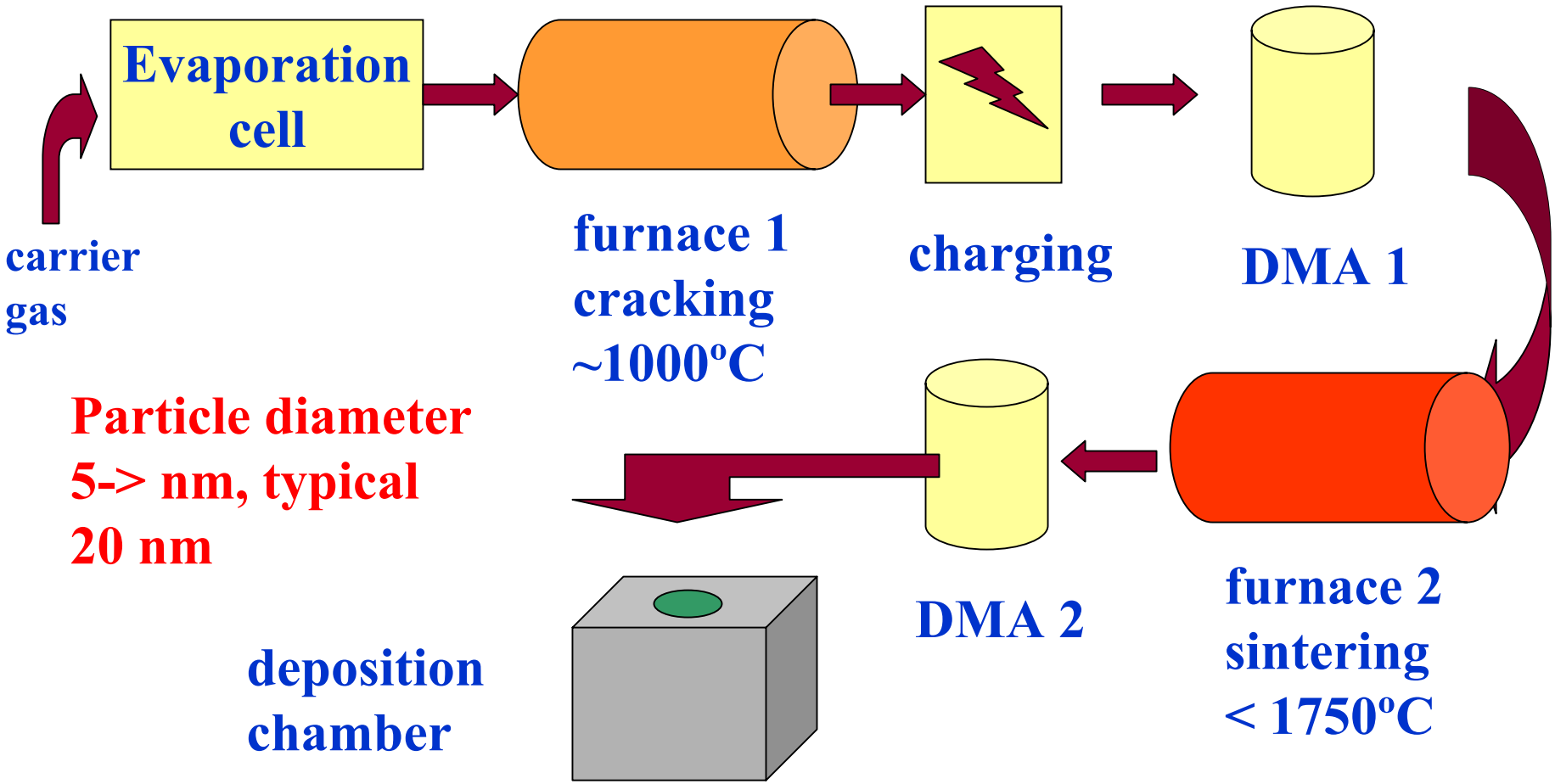


Conductance drops by 7 orders of magnitude!

Ref. [7]

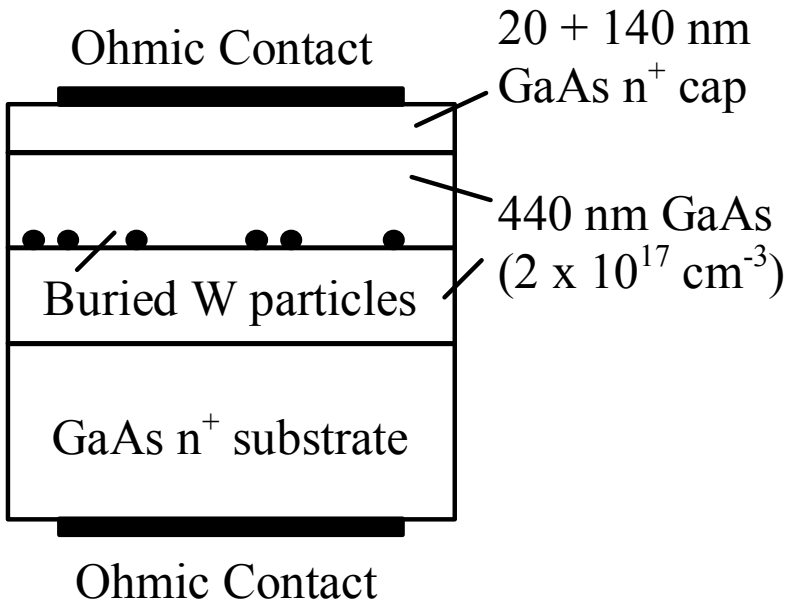
Random deposition, tungsten from an aerosol

$$W(CO)_6 \Rightarrow W + 6CO, \quad > 200^{\circ}C.$$



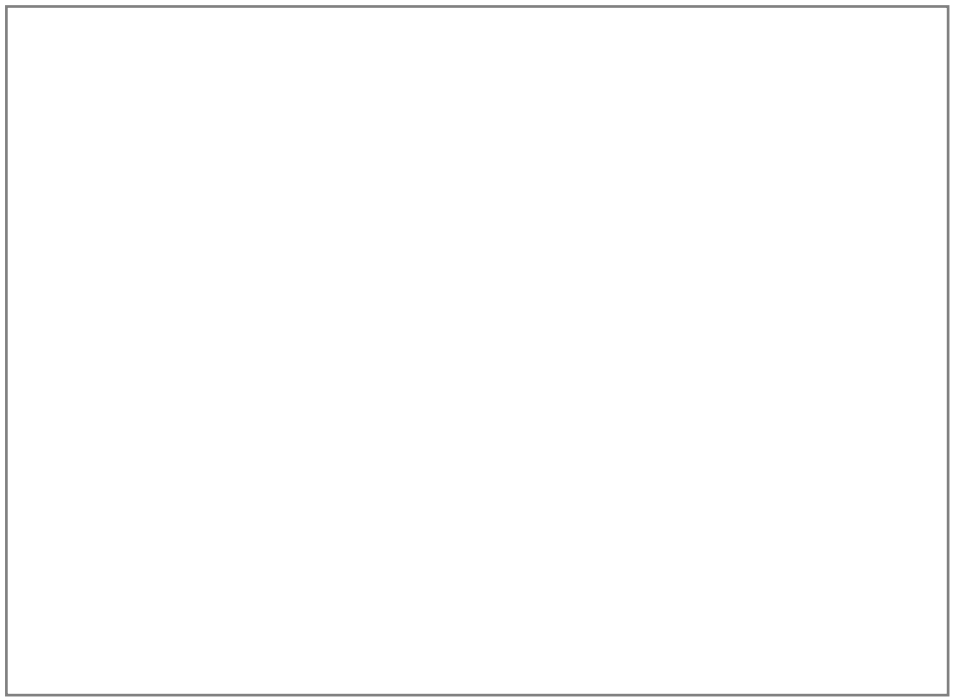
Ref [8]

Random deposition, tungsten from an aerosol



Particles range from 0 to 200 per micron sq.

Random deposition, tungsten from an aerosol



Conductance drop only factor 500 (compare with 7 orders of magnitude)!

Summary

- Lithographic method:
  - arbitrary patterns (can make transistors)
  - Throughput (bad), optical?
  - High level of current restriction
- Aerosol method:
  - Randomness (work in progress to counteract, see e.g. ref [9]), no gated structures
  - Throughput (good)
  - Insufficient level of current restriction (presently)

References

[1] S. M. Sze, *Physics of Semiconductor Devices*, Wiley (1981) and references therein

[2] C. O. Bozler and G. D. Alley, IEEE Trans. Electron Devices **27**, 1128 (1980)

[3] L.-E. Wernersson, N. Carlsson, B. Gustafson, A. Litwin, and L. Samuelson, Appl. Phys. Lett. **71**, 2803 (1997)

[4] E. Lind, L.-E. Wernersson, I. Pietzonka, W. Seifert, IEEE Transactions on Electron Devices **49**, 1066 (2002)

[5] I. Aberg, K. Deppert, M.H. Magnusson, I. Pietzonka, W. Seifert, L.-E. Wernersson, and L. Samuelson, Appl. Phys. Lett. **80**, 2976 (2002)

[6] A. C. Warren, J. M. Woodall, J. L. Freeouf, D. Grischowsky, D. McInturff, M. R. Melloch, and N. Otsuka, Appl. Phys. Lett. **57**, 1331 (1990)

[7] L.-E. Wernersson, A. Litwin, L. Samuelson, and W. Seifert, Jpn. J. Appl. Phys. **36**, L1628 (1997)

[8] M. H. Magnusson, K. Deppert, and J.-O. Malm, J. Mater. Res. **15**, 1564 (2000)

[9] T. J. Krinke, H. Fissan, and K. Deppert, Appl. Phys. Lett. **78**, 3708 (2001)