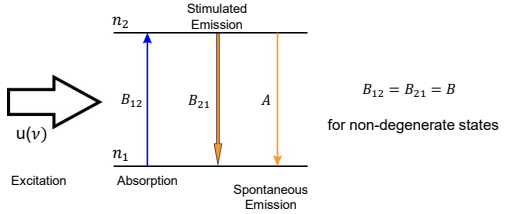
4. Nano-optics using far-field optical techniques

Stimulated Emission



$B_{12} = B_{21} = B$

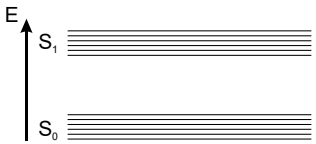
for non-degenerate states

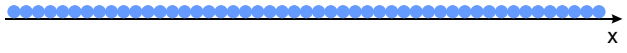
$$\dot{n}_2 = B\,u(\nu)\,n_1 - B\,u(\nu)\,n_2 - A\,n_2$$

The coefficient *A* (spontaneous emission) depends on the density of states:

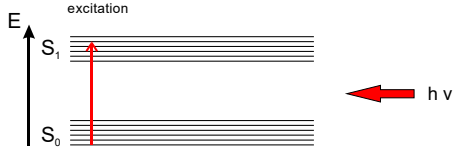
$$\frac{A}{8\pi\,\nu^2/c^3} = B \cdot h\nu$$

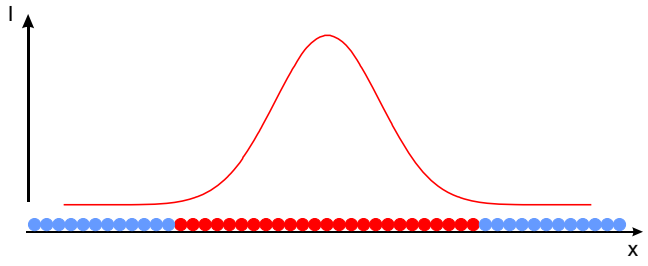
Stimulated Emission Depletion



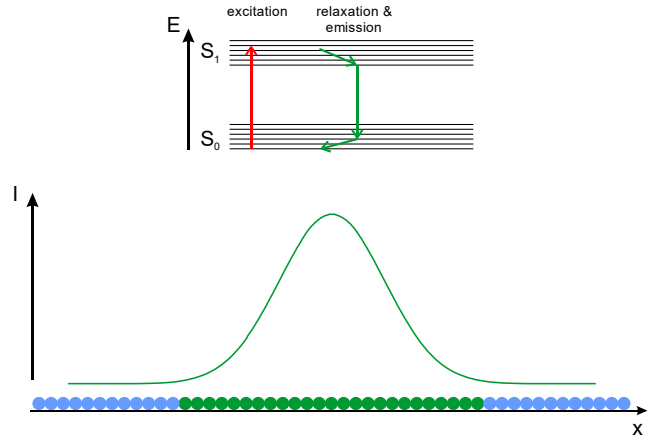


Stimulated Emission Depletion

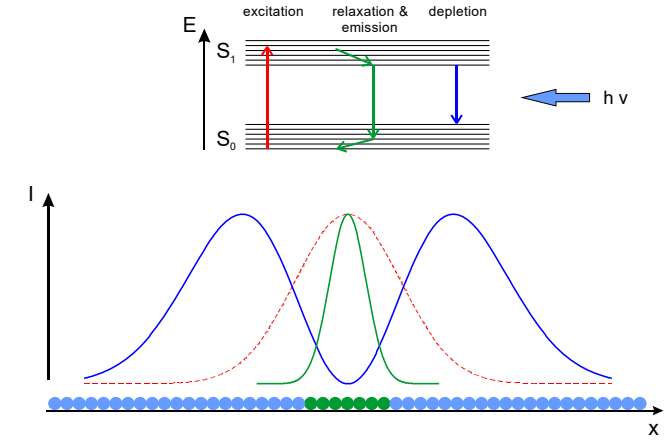




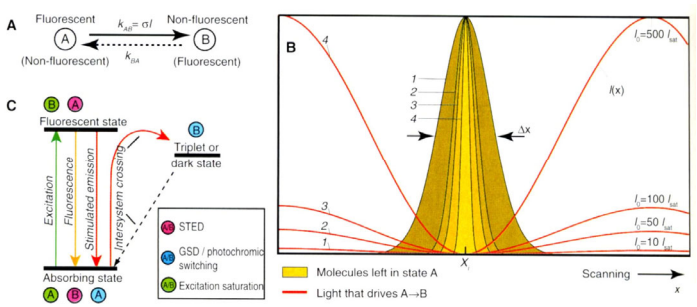
Stimulated Emission Depletion



Stimulated Emission Depletion

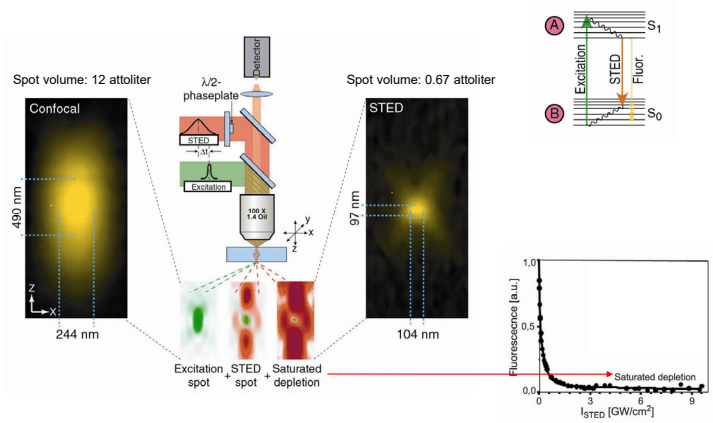


STED: Confinement by "Inverse Saturation" or "Saturated Depletion"



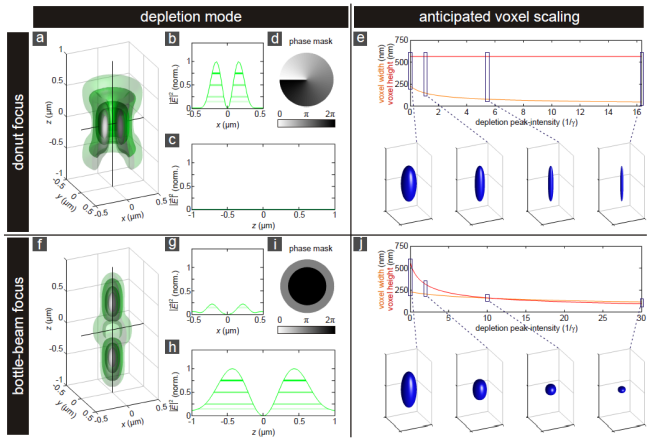
Hell et al., in Pawley (ed.), Biological Confocal Microscopy (2006)

STED Microscopy



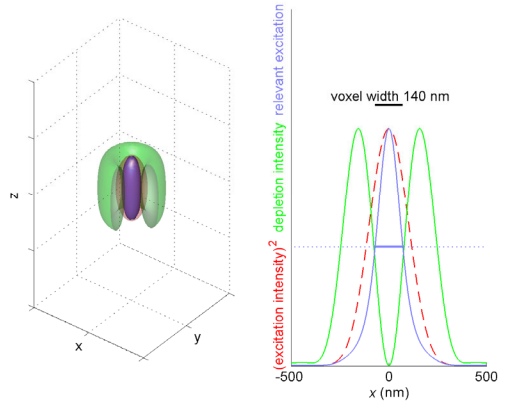
S.W. Hell, J. Wichmann (1994), *Opt. Lett.* **19**, 780.
T.A. Klar, S. Jakobs, M. Dyba, A. Egner, S.W. Hell (2000), *PNAS* **97**, 8206.
S.W. Hell, M. Dyba, S. Jakobs (2004), *Curr. Opin. Neurobiol.* **14**, 599.

Phase masks for STED beam



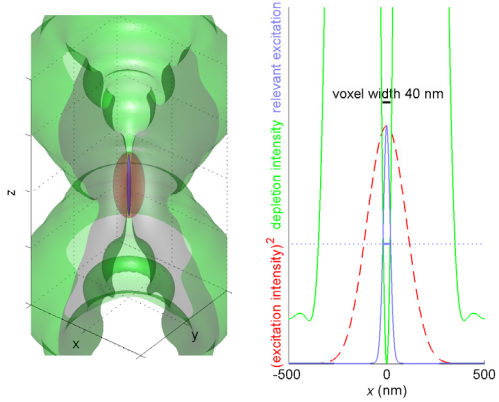
Joachim Fischer, Dissertation

The Depletion Idea



Joachim Fischer

The Depletion Idea



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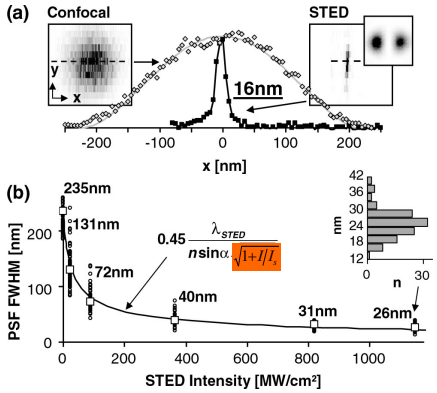
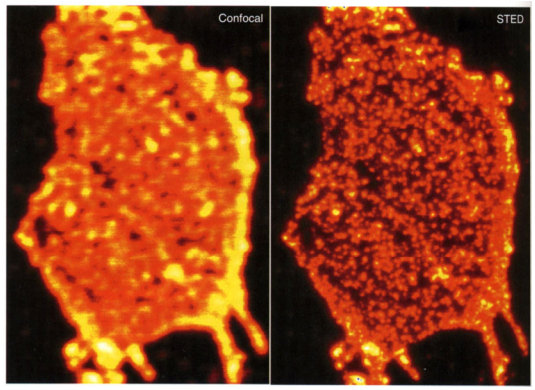
STED – Optical resolution capability

measured subdiffraction *single molecule* PSF:



V. Westphal, S.W. Hell (2005), *Phys. Rev. Lett.* **94**, 143903.

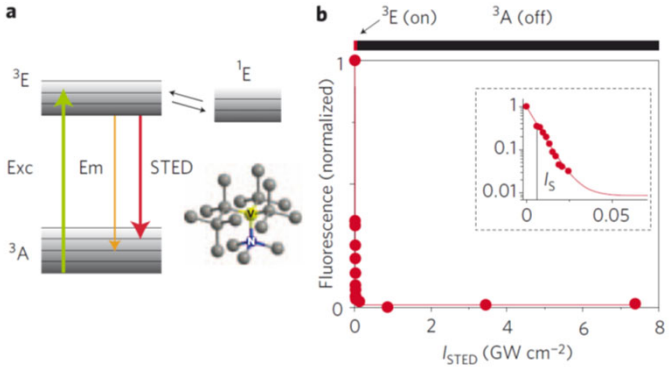
Comparison: Confocal microscopy and STED



Plasma membrane patch immuno-stained against SNARE protein SNAP25; secondary antibody Atto532-NHS; STED at 615 nm (Pawley, Biological Confocal Microscopy, 2006).

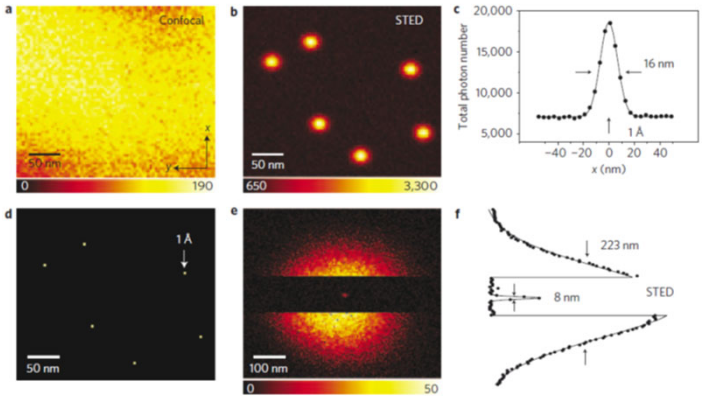
Hell et al., in Pawley (ed.), Biological Confocal Microscopy (2006)

N-V Color-Center in Diamond



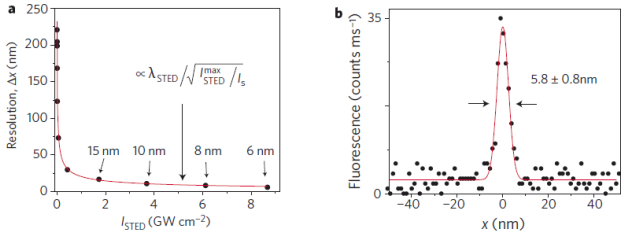
Rittweger et al., Nature Photonics (2009)

N-V Color-Center in Diamond



Rittweger et al., Nature Photonics (2009)

N-V Color-Center in Diamond

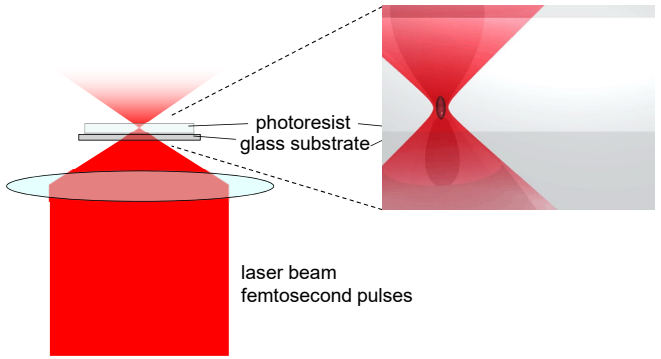


Rittweger et al., Nature Photonics (2009)

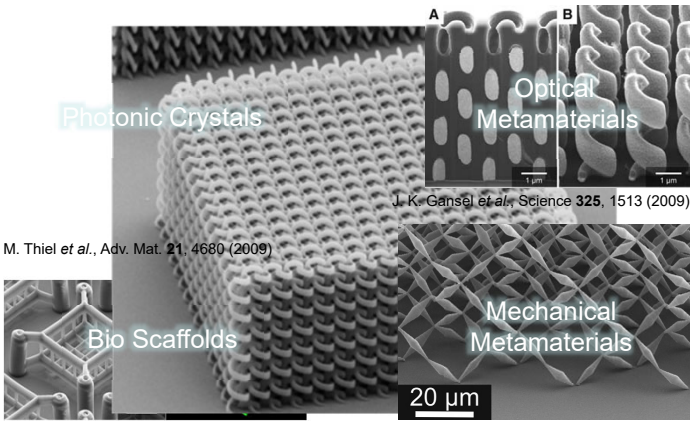
4. Nano-optics using far-field optical techniques

   4.1 Introduction: single-molecule methods in biology
   4.2 Single-molecule tracking (SMT)
   4.3 Stochastic optical reconstruction microscopy (STORM)
   4.4 Stimulated emission depletion (STED)
   4.5 3D laser lithography using STED

Motivation – 3D Direct Laser Writing



Motivation – 3D Direct Laser Writing



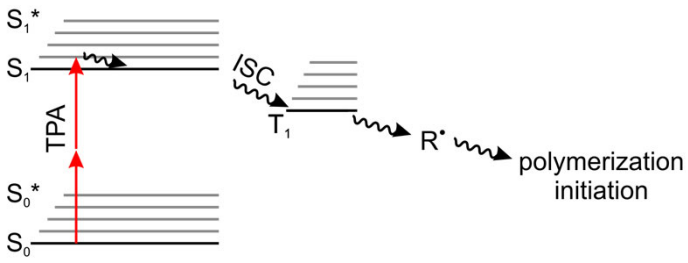
J. K. Gansel *et al.*, Science **325**, 1513 (2009)

M. Thiel *et al.*, Adv. Mat. **21**, 4680 (2009)

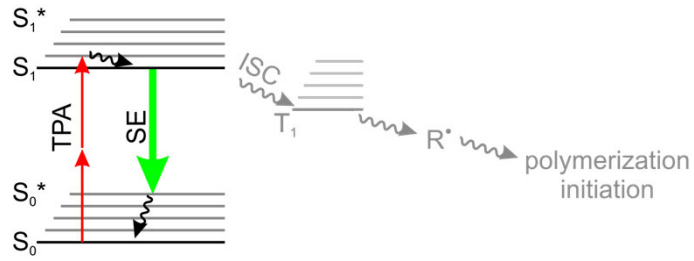
F. Klein *et al.*, Adv. Mat. **22**, 868 (2010)

M. Kadic *et al.*, Appl. Phys. Lett. **100**, 191901 (2012)

The Depletion Idea



The Depletion Idea



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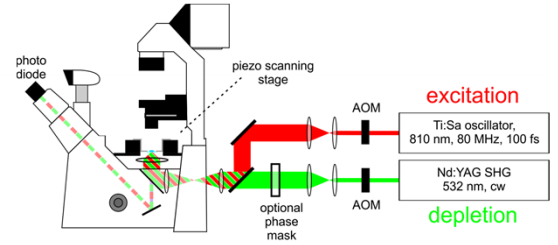
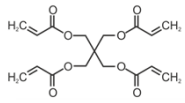
STED-DLW – Setup



Photoresist

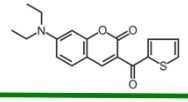
monomer:

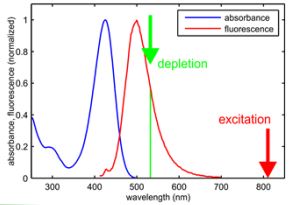
pentaerythritol tetraacrylate (99.75% wt)



photoinitiator:

7-diethylamino-3-thenoylcoumarin (0.25% wt)





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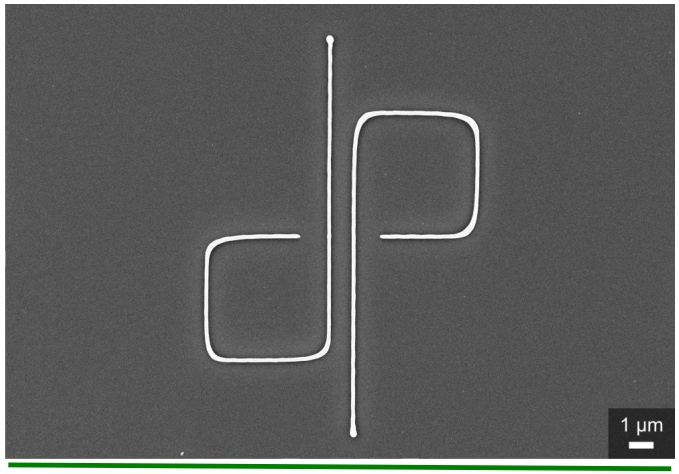
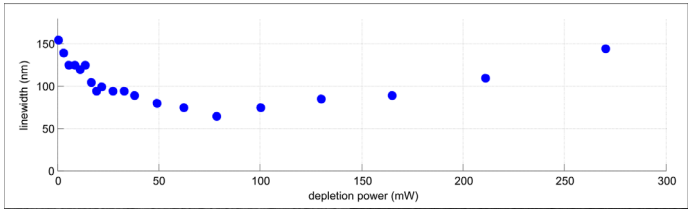
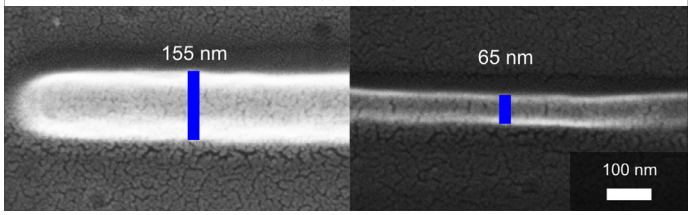
Results – Polymerization Suppression



J. Fischer et al., Adv. Mat. **22**, 3578 (2010)

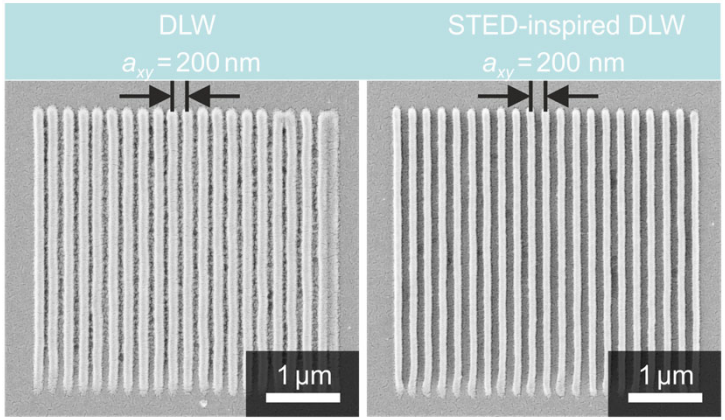
Results – Lateral Linewidth & Resolution





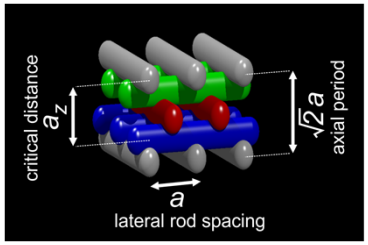
J. Fischer et al., Adv. Mat. **22**, 3578 (2010)

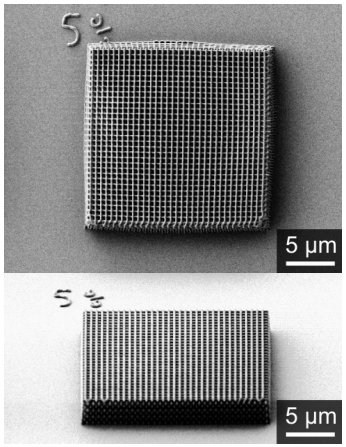
Results – Lateral Linewidth & Resolution



J. Fischer et al., Opt. Mater. Express **1**, 614 (2011)

Results – Axial Resolution





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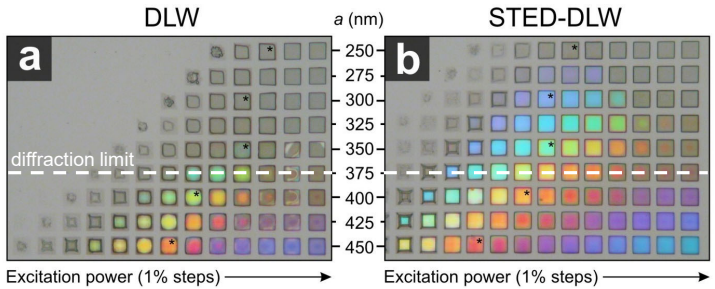
Results – Axial Resolution



J. Fischer et al., Opt. Mater. Express **1**, 614 (2011)