

Potential of nanoparticle technologies for next generation rare earth doped fibers

S. Tammela, M. Hotoleanu, K. Janka, P. Kiiveri, M. Rajala,
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The logo for Liekki Oy, featuring the word "LIEKKI" in a stylized, white, sans-serif font. The letters are bold and have a modern, geometric feel. The background of the slide is a blue gradient with a pattern of light blue circles of varying sizes, creating a bokeh effect.

THE INDUSTRIAL PRODUCER OF HIGH QUALITY DOPED OPTICAL FIBERS

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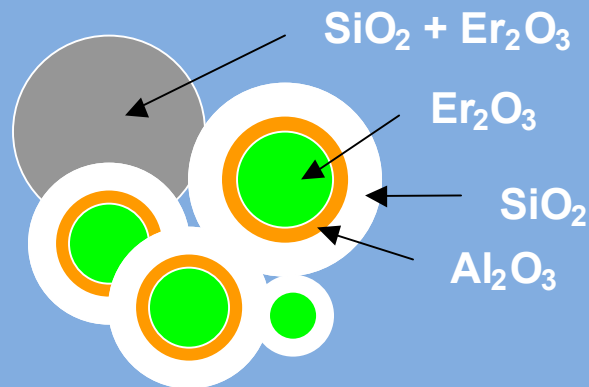
Content

- Motivation
- What nanoparticle technology provides
- Direct Nanoparticle Deposition (DND)
- Properties of the DND glass
- DND fibers: properties
- Conclusions

Motivation for the search on new approach

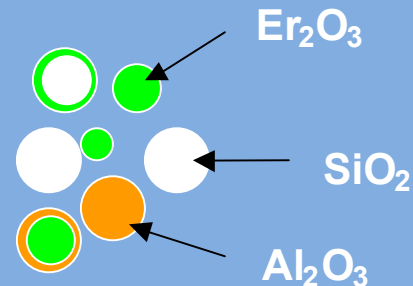
OVD / VAD

- laborous doping during soot deposition
- flame hydrolysis => large particles



MCVD

- doping after soot deposition
- oxidation => small particles

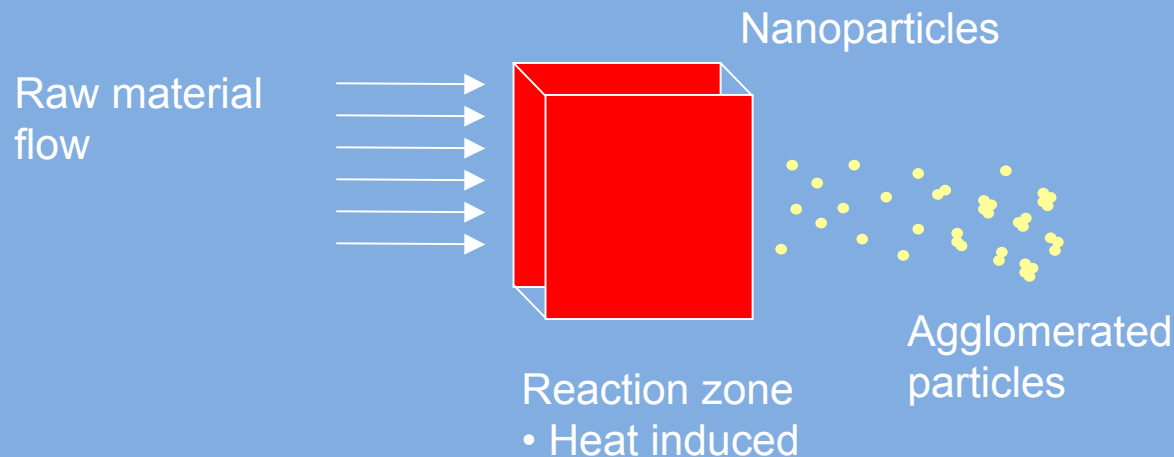


What nanoparticle technology provides

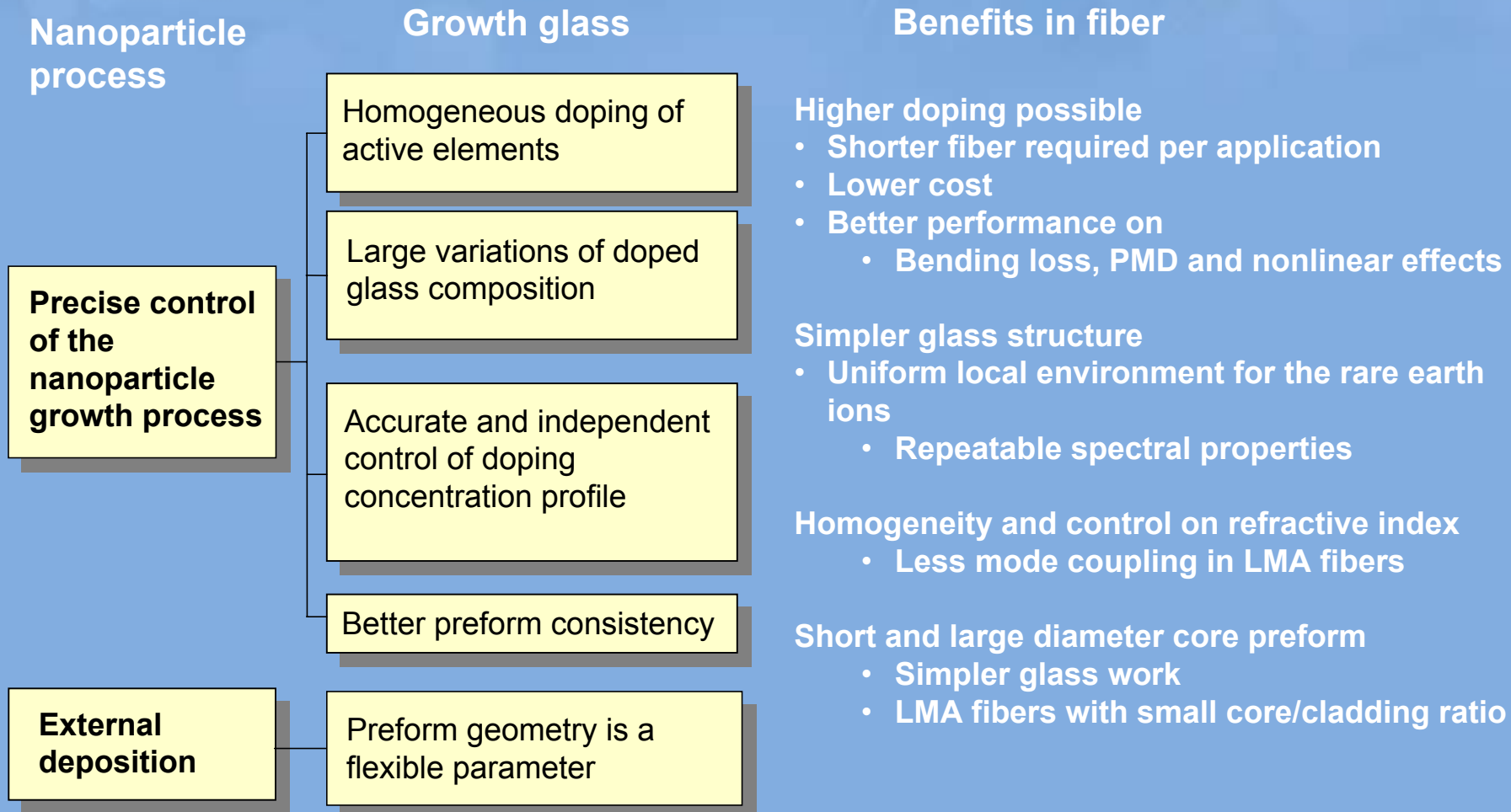
- Possibility to use high and low vapor pressure raw materials
- Good homogeneity of the sintered glass
- Homogeneous sites for the rare-earth ions

Some drawbacks

- Agglomeration limits the nanoparticle generation speed
- Small particle size results moderate growth rate



What nanoparticle technology provides

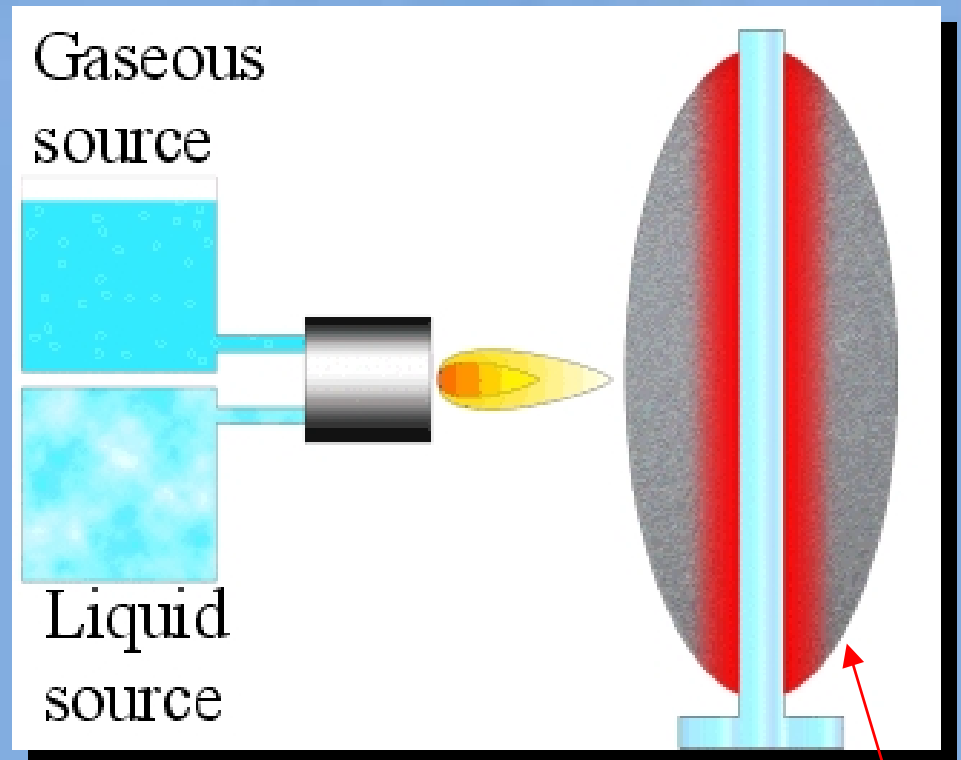


Direct Nanoparticle Deposition (DND)

Liekki has developed a disruptive, propriety nanoparticle generation and deposition process

DND process

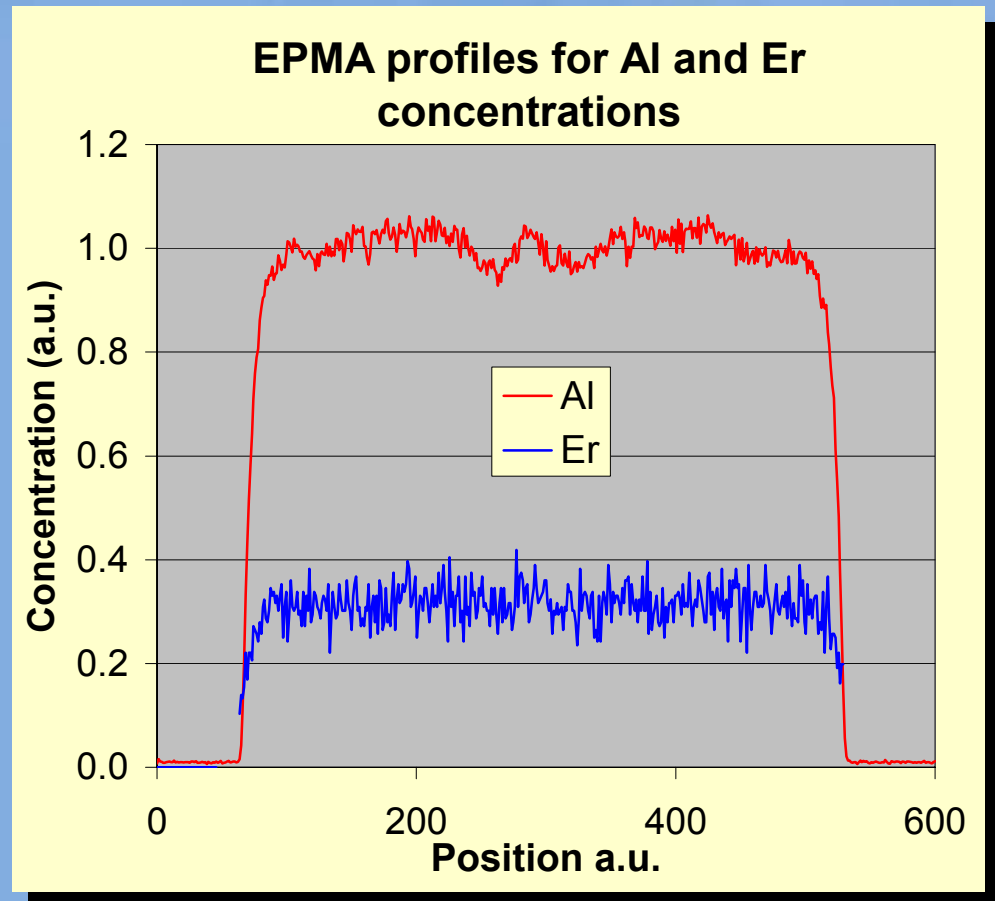
- Combustion of gaseous and atomized liquid raw materials
- Deposition immediately after particle generation



Rare earth
doped
glass soot

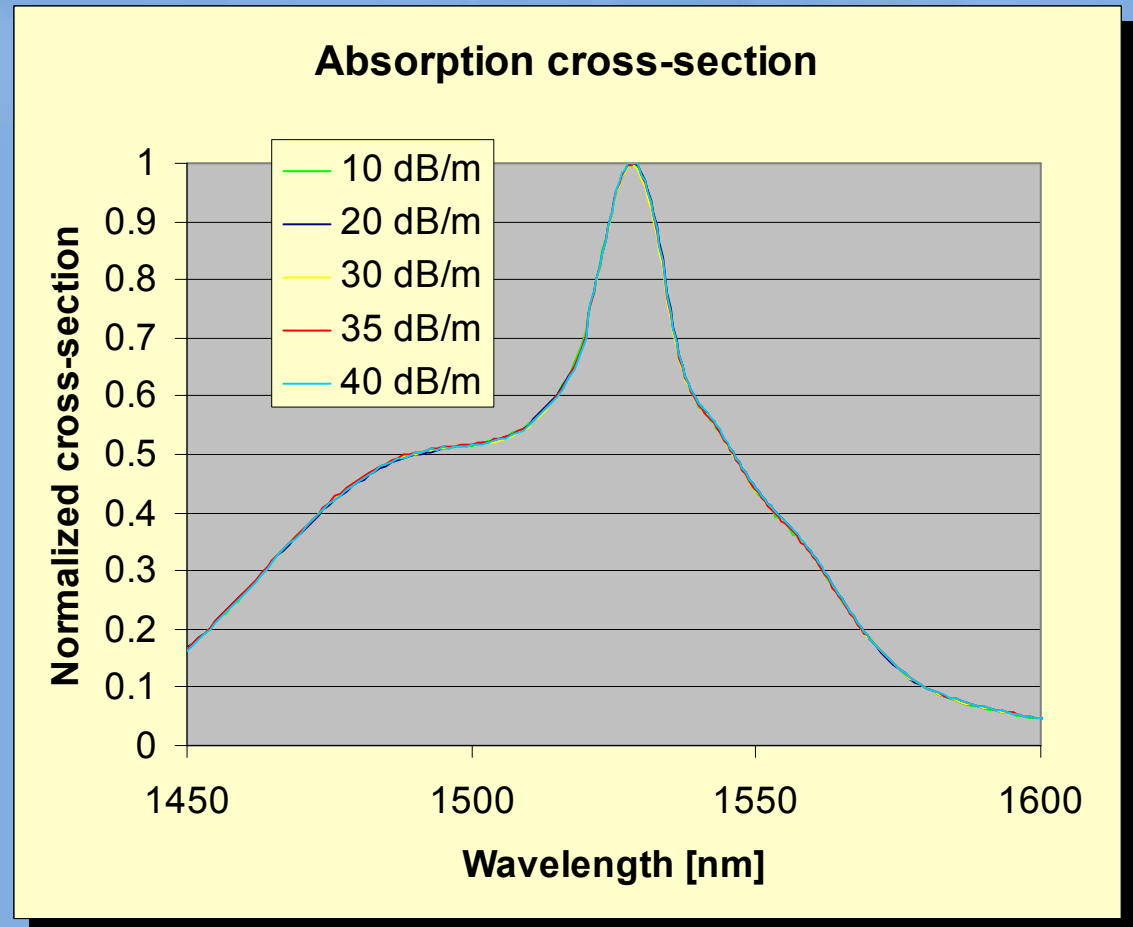
DND: doping uniformity in preform

- Core consists of about 100 layers
- The concentration variation within $\pm 5\%$
 - Temperature non-uniformity in the reaction volume
 - Process controlling at process start



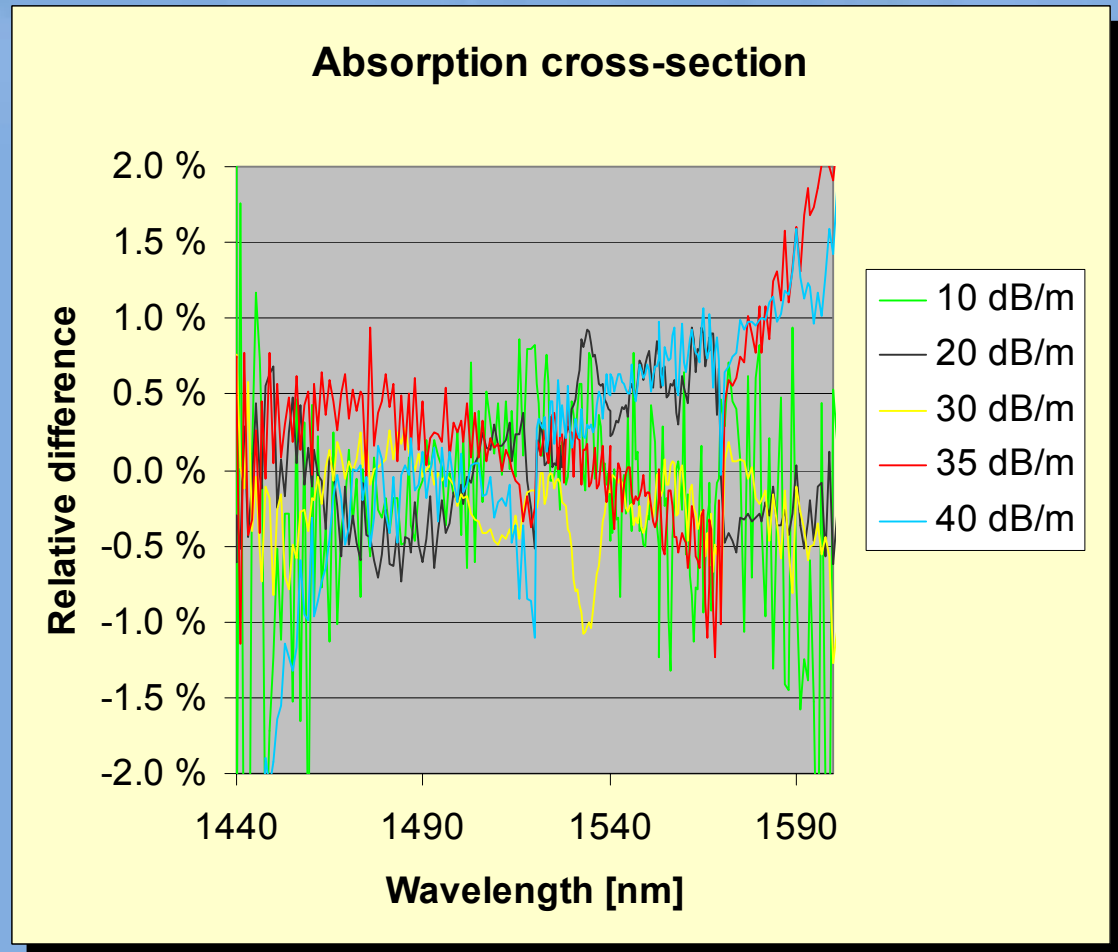
DND: Rare-earth local environment

- The cross-section is calculated from fiber absorption measurement
- In the cross-section calculus the different cut-off wavelengths of the fiber is taken account



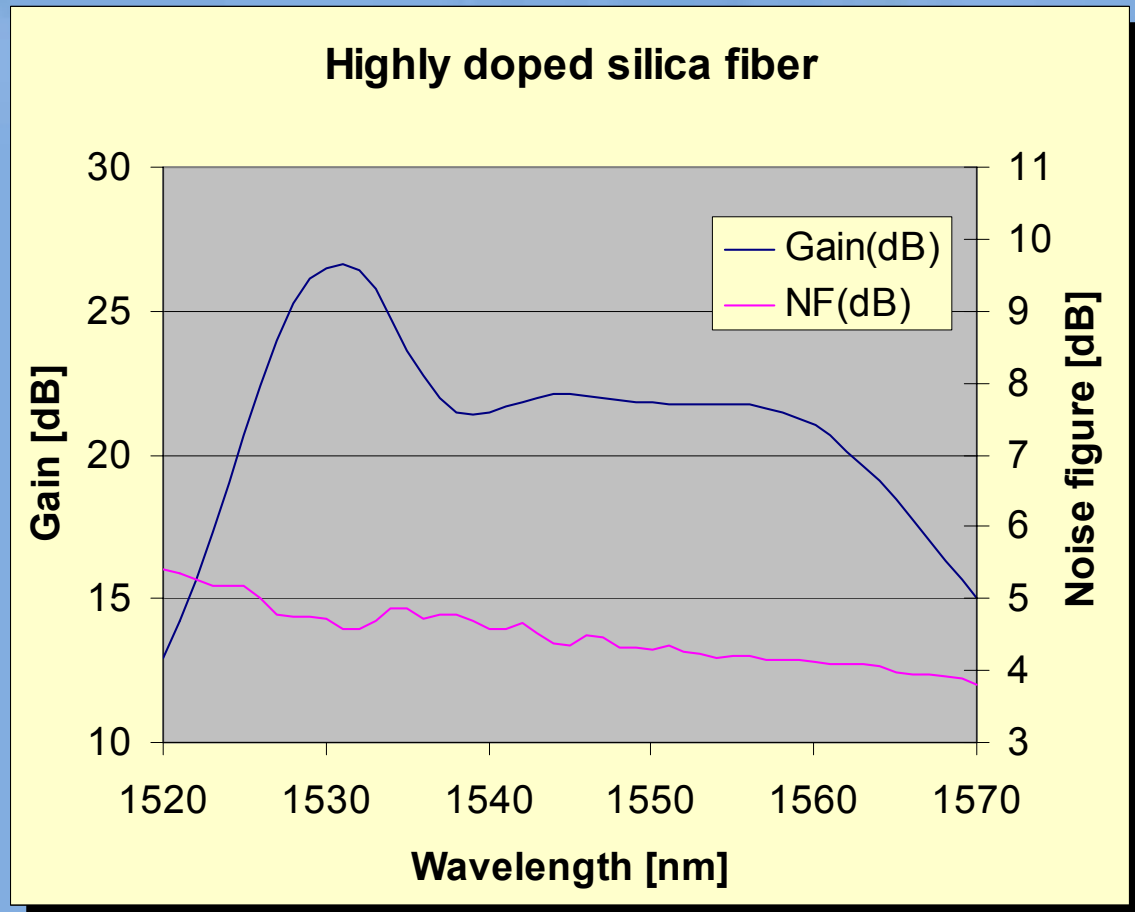
DND: Rare-earth local environment

- The differences on absorption cross-sections result mainly from inaccuracies in fiber coupling loss and cut-off variation
- The local environment for the rare-earth can be considered similar



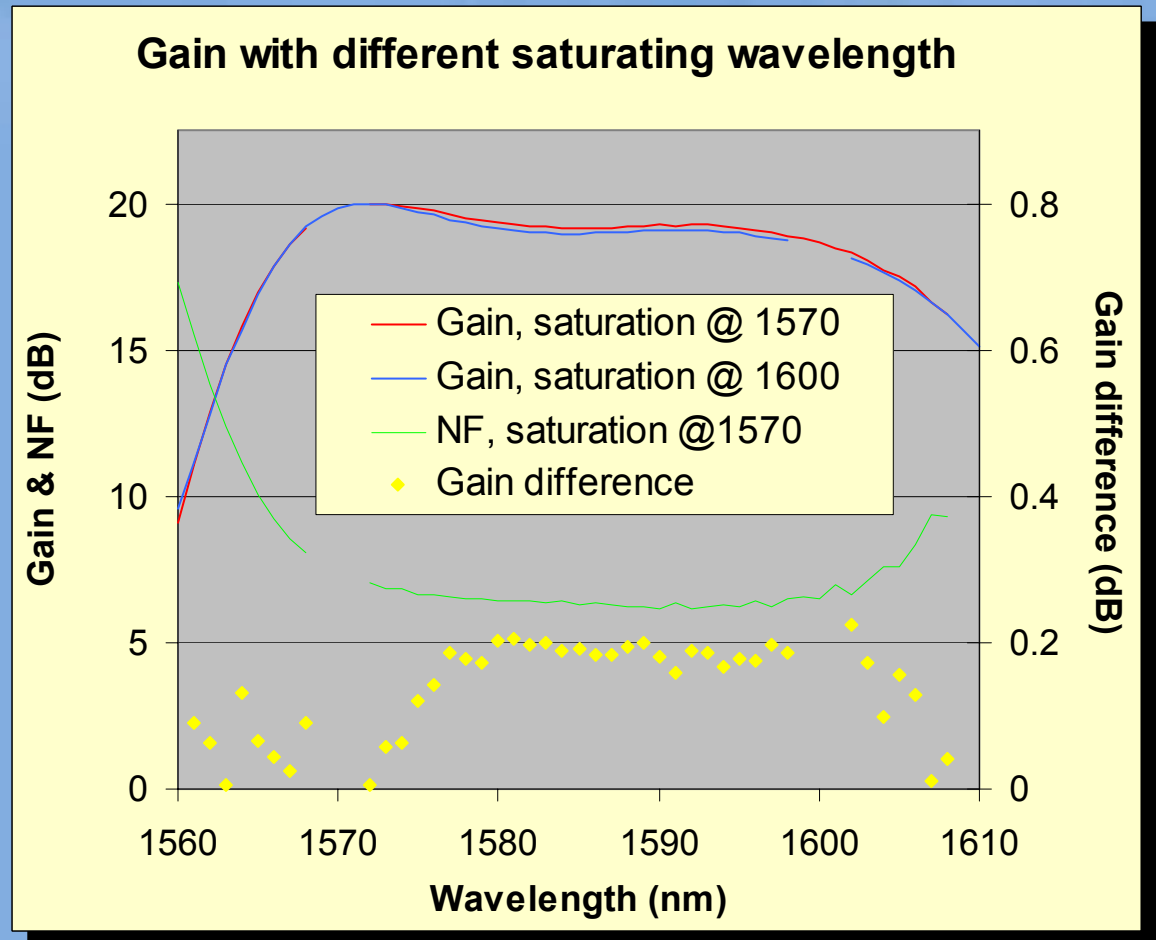
DND fibers: very short C-band fiber

- Uniform doping enables high doping with moderate up-conversion
- Absorption 100 dB/m @ 1530 nm
- Fiber length 0.58 m
- Pump 110 mW @ 980 nm
- QCE 21 % @ 0dBm input



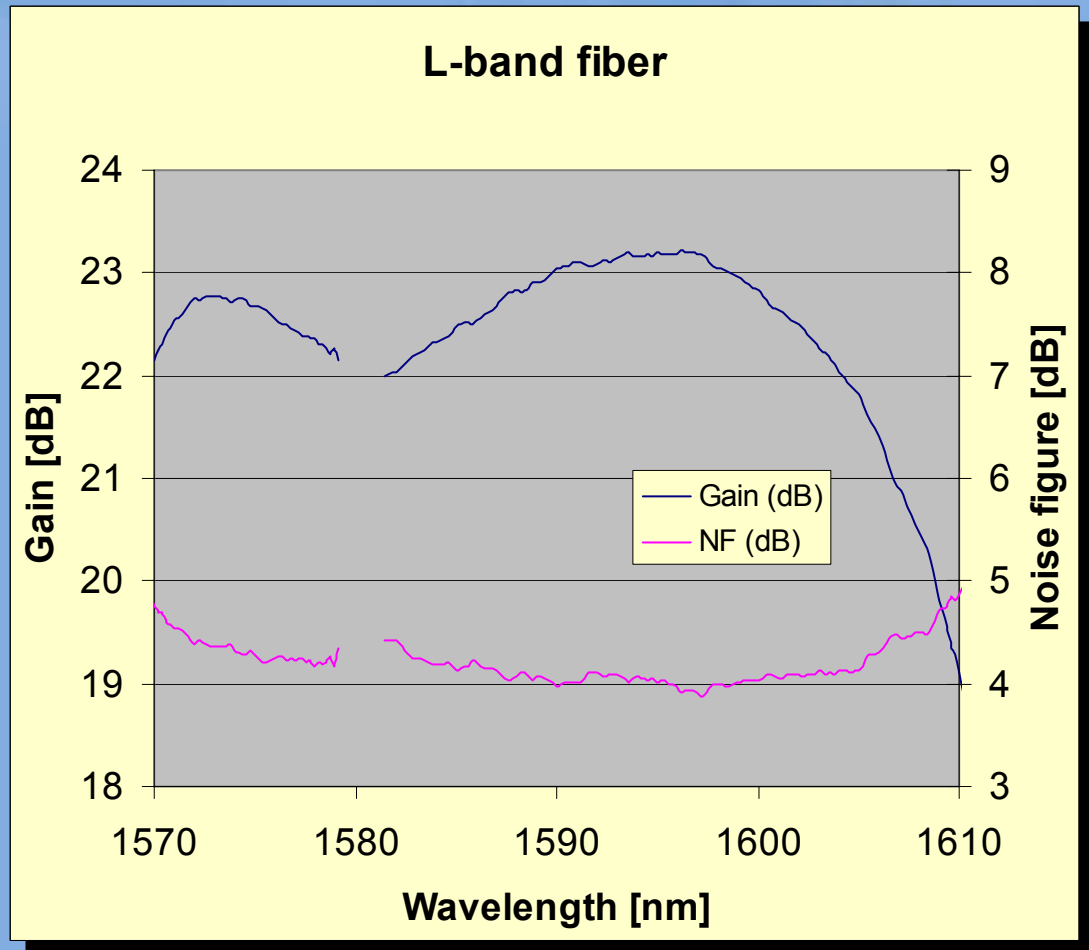
DND fibers: L-band fiber

- Small spectral hole burning
- Fiber Length=13.3m
- Saturating power 0 dBm
- Pump power:
forward 100mW
@977.5nm,
backward 135mW
@1475nm
- QCE 45 %



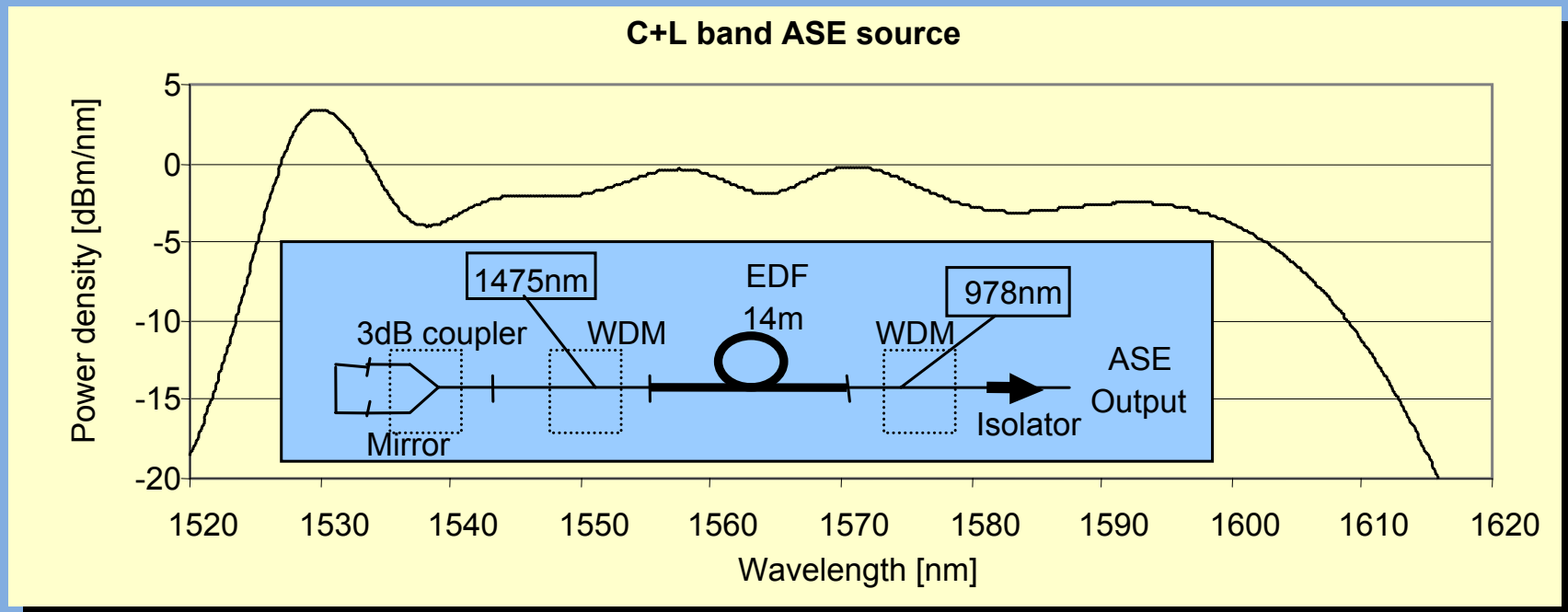
DND fibers: improved efficiency L-band

- Absorption 30 dB/m @ 1530 nm
- Cut-off @ 1100 nm
- 22 m long fiber
- Saturating signal 0dBm @ 1580 nm
- Pump forward 100 mW @ 976.7 nm
- "Pump backward 145 mW @ 1476 nm
- QCE 65%



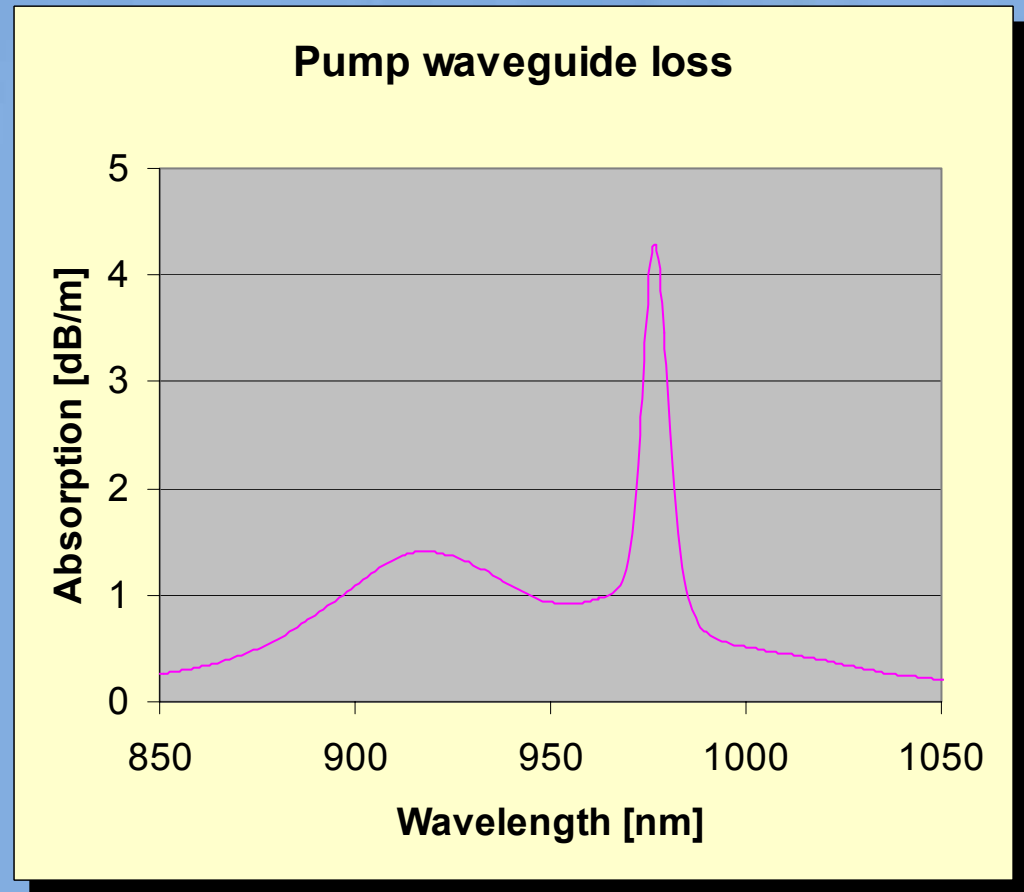
DND fibers: ASE source

- The broad band gain bandwidth results also broad ASE sources
- When the gain at C and L band are close enough it is possible to make C+L band ASE source using one active fiber



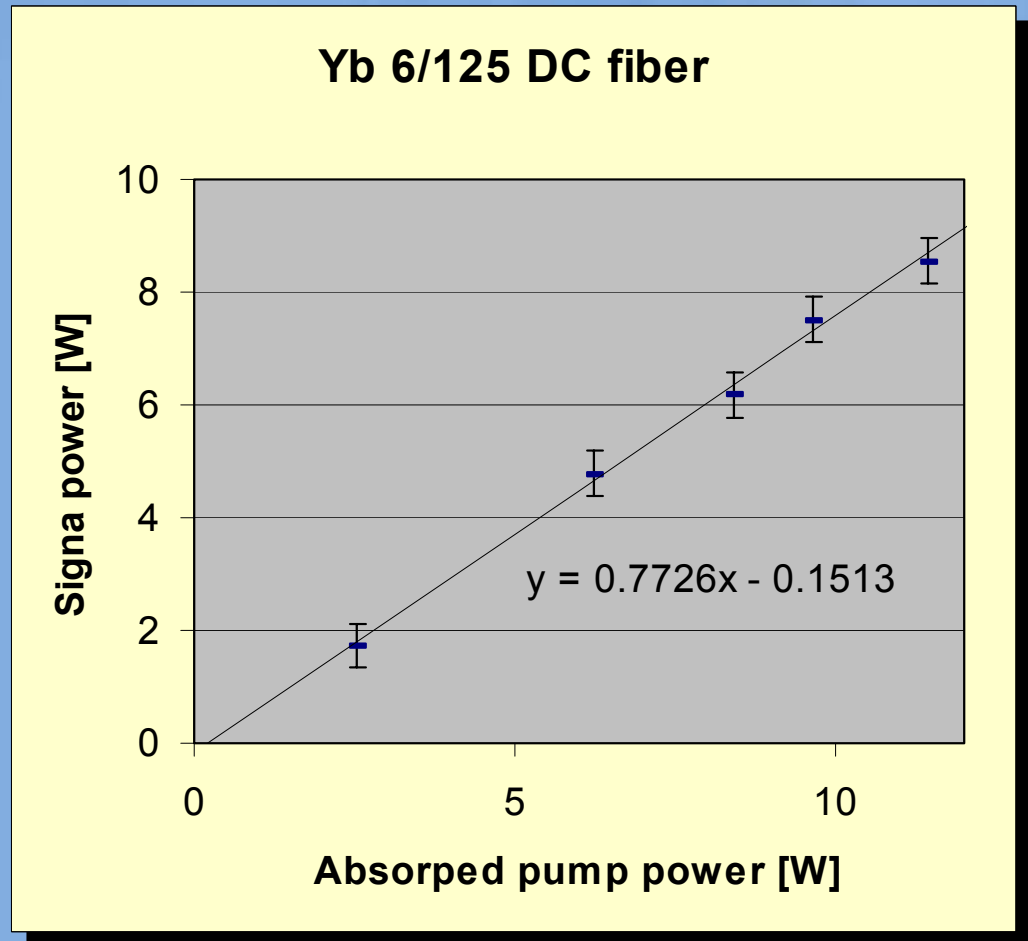
DND fibers: Yb doped fibers

- Core / Cladding ratio is 6/125
- Core absorption about 2000 dB/m
- Pump absorption 1.4 dB/m @ 920 nm



DND fibers: Yb DC fibers for lasers

- End pumping measurement
- 10 m of Yb fiber
- Core diameter 6 μm
- Cladding 125 μm
- Low n polymer cladding
- Core absorption: 2300 dB/m @ 978 nm



Conclusion

Nanoparticle technology provides

- Possibility to use high and low vapor pressure materials simultaneously
- Possibility to produce uniform material both in nano- and macroscopic scale
- Independent selection of deposition process and preform geometry
- Scalability

To rare-earth doped fibers this means

- Higher concentrations, shorter fibers, less optical non-linearity and dispersion
- Better uniformity in doping and in spectral properties
 - Within fiber, both in lateral and longitudinal
 - From fiber to fiber
- Simpler preform glass work
- Wide range of core/cladding ratios (small to large)

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The logo for LIEKKI is rendered in a bold, white, sans-serif font. The letters are stylized, with the 'L' and 'I' being simple vertical bars, the 'E' having three horizontal bars, and the 'K' having a distinctive shape with a wide base and a narrow top. The 'I' at the end is also a simple vertical bar.

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