
*High-Power
(Kilowatt-Level?)
Gain-Guided
Fiber Lasers*

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The basic objective

- ***High-power (kW-level), high-beam-quality (single-transverse-mode) fiber lasers***
 - *Oscillators or amplifiers*
 - *Pulsed or CW*
 - *Nd, Yb, maybe Er*
 - *Defense, industrial & scientific applications*

Fundamental limitations

- ***In conventional index-guided fiber lasers:***
 - ***Limited mode size***
 - ***‡10 micron core diameter to constrain oscillation to a single transverse mode***
 - ***leads to limited power capability***
 - ***‡ few tens of watts in this 10 micron core to stay below stimulated Brillouin or Raman thresholds***

A possible solution

Use cladding pumped fiber lasers having

- ***Large core diameters (≈ 100 microns)***

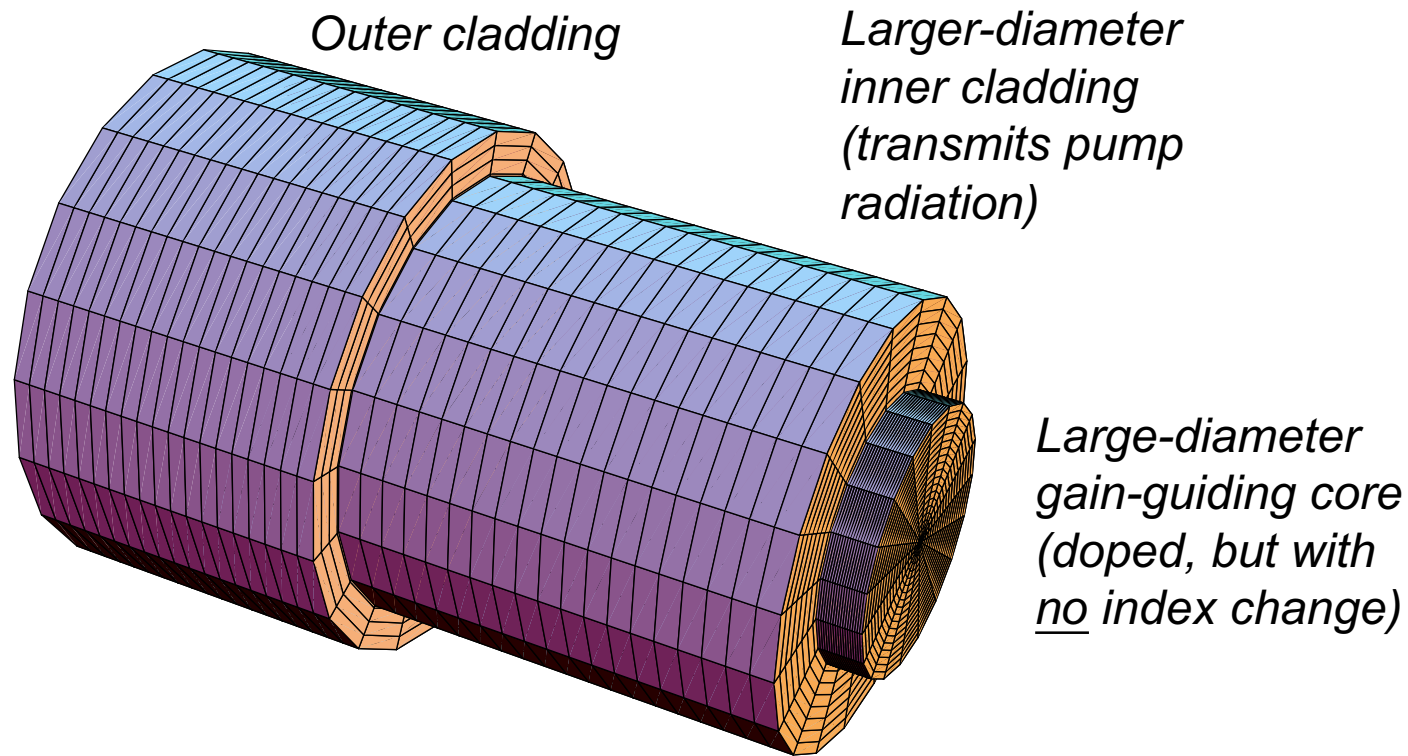
In combination with some variation of

- ***Pure gain guiding (no index step)***
- ***Gain guiding plus index guiding***
- ***Gain guiding plus index anti-guiding***

How to obtain strong gain guiding

- ***Very heavy active-ion doping in core only***
- ***No index step in core relative to cladding***
 - ***Or possibly negative (anti-guiding) index step***
- ***Laser pumping creates gain-guiding core***
- ***Leads to gain-guided single-mode propagation***

Gain-guided fiber laser structure



Gain and index-guiding analysis

Fiber modes can be guided by an index profile, a gain profile, or both.

$$\begin{aligned} & \exp \left[-j \frac{2 \pi (n_0 + \Delta n)}{\lambda_0} z + g z \right] \\ & = \exp \left[-j \frac{2 \pi n_0}{\lambda_0} z - j \frac{2 \pi}{\lambda_0} \left(\Delta n + j \frac{\lambda_0}{2 \pi} g \right) z \right] \end{aligned}$$

Gain coefficient g acts like an imaginary-valued index change.

Gain-guiding effects are weak: $g = 1/\text{cm}$ corresponds to $\Delta n \sim 10^{-5}$

Summary of basic concepts

- **Strongly gain-guided optical fibers**
 - *(with or without index guiding or anti-guiding)*
- **Heavily doped, heavily pumped, high gain fibers**
 - *Power gain coefficients of 0.1 to 1.0 cm⁻¹*
- **Large diameter gain cores (100 to 200+ microns)**
 - *But small or zero index step ($\Delta n \dagger 10^{-5}$)*
- **Gain guiding is a weak effect (poor bending tolerance)**
 - *But, this produces single-mode operation in large fibers*
 - *And, fibers can be short (10 s of cm or less)*
- **Large core area leads to kilowatt level possibilities**

Typical doping profiles

- **1. *Parabolic doping profile***
 - *Parabolic active ion doping & possibly parabolic index profile also*
- **2. *Step doping profile***
 - *Step profile for active ion doping & possibly for index profile also*
- **3. *Other profiles***
 - *To be analyzed later*

Parabolic doping profiles

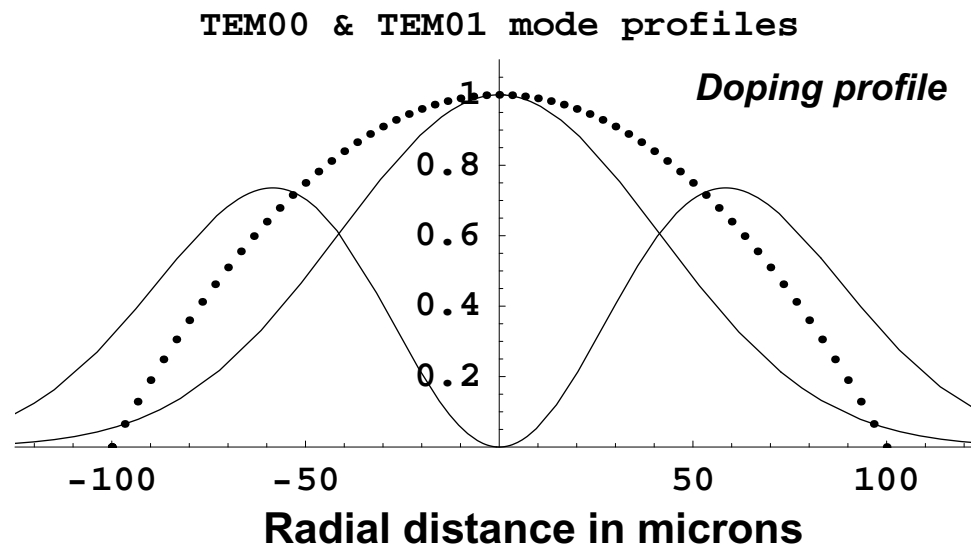
- Assume parabolic doping profile in core
 - May have parabolic index profile also
- Analytic solutions for complex-valued parabolic profiles are complex-valued Hermite-gaussian modes
- Solutions are valid for positive gain guiding, plus positive or negative index guiding
- Analysis fails if mode size exceeds duct size
- A few examples shown in following slides

Parabolic doping example

Doping diameter = 200 microns

On-axis gain = 1/cm (4.34 dB/cm)

TEM00 mode gain = 2.86 dB/cm



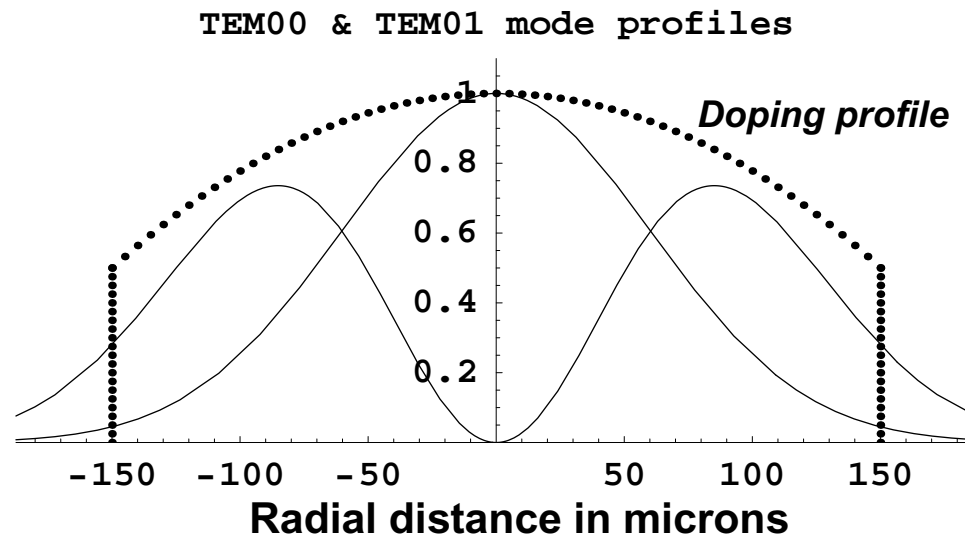
Parabolic doping example

Doping diameter = 300 microns

On-axis gain = 1/cm (4.34 dB/cm)

TEM00 mode gain = 3.64 dB/cm

TEM01 mode gain = 2.24 dB/cm



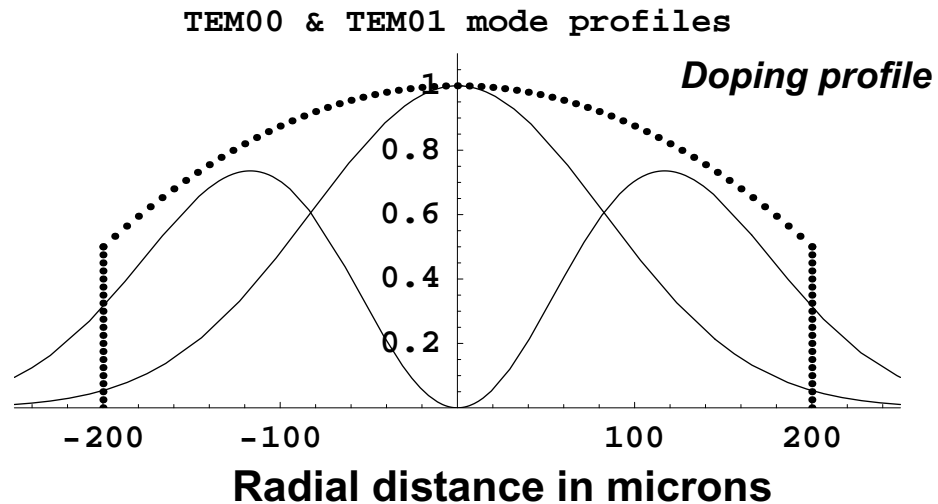
Parabolic doping example

Doping diameter = 400 microns

On-axis gain = 0.5/cm (2.2 dB/cm)

TEM00 mode gain = 1.8 dB/cm

TEM01 mode gain = 1.06 dB/cm



Step doping profiles

- Assume uniform doping profile in core
- May also have a uniform index step (positive or negative)
- Must carry out numerical solutions to find mode or modes
 - Complex-valued version of usual fiber mode analysis
- For pure gain guiding and large enough core diameters, obtain purely step-gain-guided single-mode solutions
- Following slides show a few examples
- Have also obtained gain-guided + index-anti-guided solutions

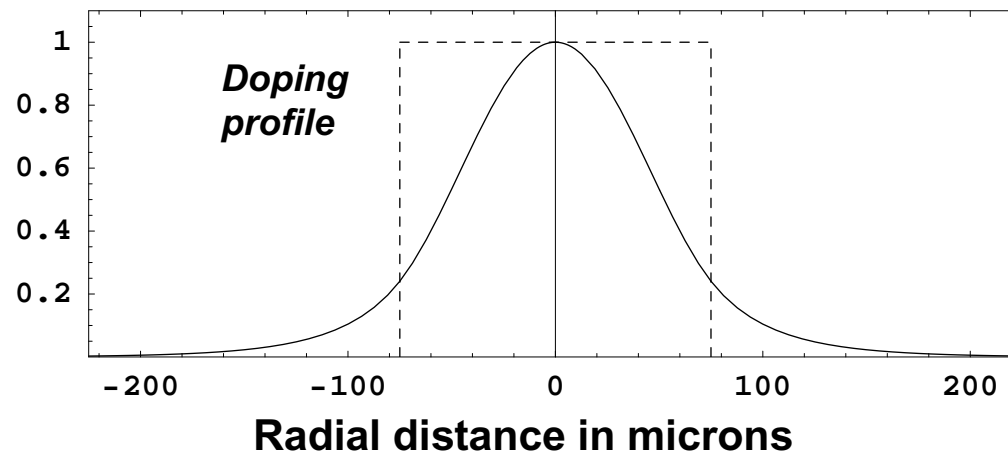
Step gain-guided example

Doping diameter = 150 microns

On-axis gain = 1/cm

TEM00 mode gain = 0.65/cm

Percent power in core = 65%



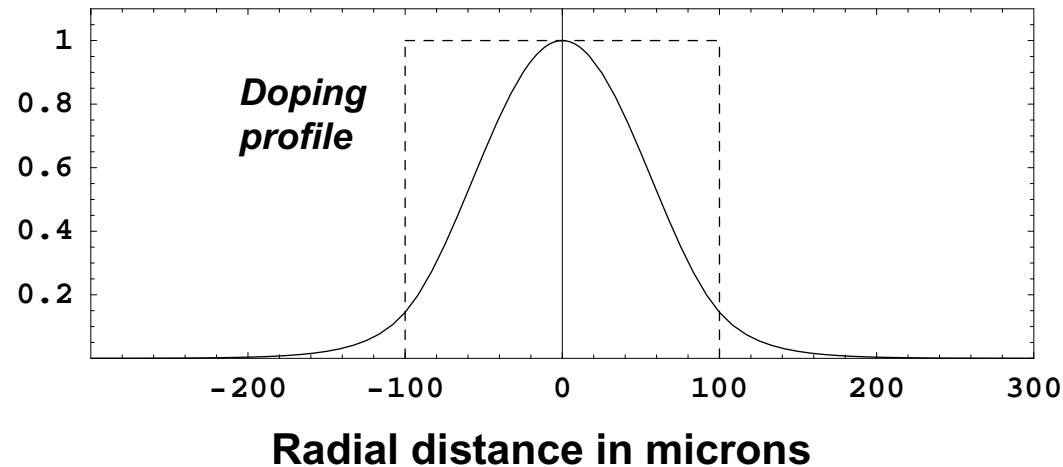
Step gain-guided example

Doping diameter = 200 microns

On-axis gain = 1/cm

TEM00 mode gain = 0.82/cm

Percent power in core = 82.4%



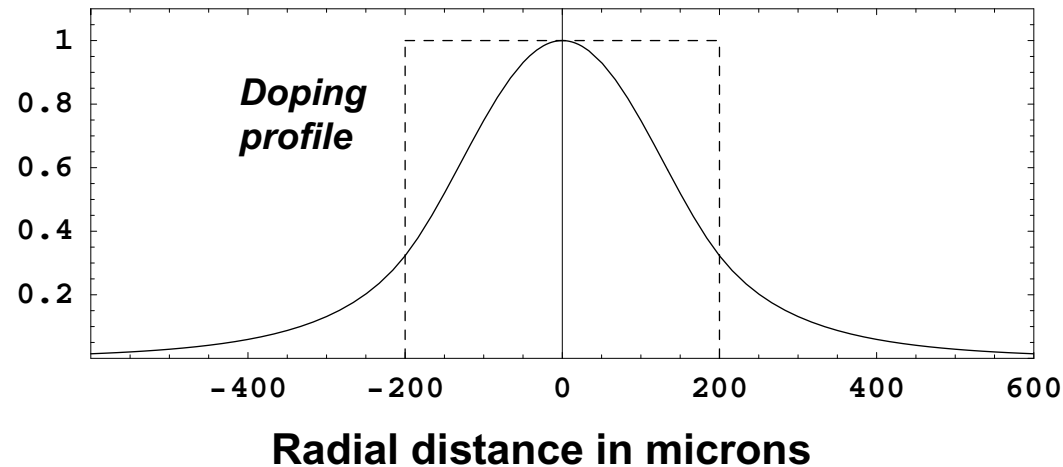
Step gain-guided example

Doping diameter = 400 microns

On-axis gain = 0.1/cm

TEM00 mode gain = 0.48/cm

Percent power in core = 48%



Summary

High-power gain-guided fiber lasers:

- *Large diameter cores (150+ microns)*
- *Heavily doped, heavily pumped, high gain*
- *Must have very small index step ($\pm 10^{-5}$)*
- *Very weak guiding = poor bending tolerance*
- *But fibers can be short (order of 10 cm)*
- *Gain saturation effects not yet evaluated (but potentially deleterious)*
- *Thermal effects not yet evaluated (but may produce unwanted thermal trapping)*

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