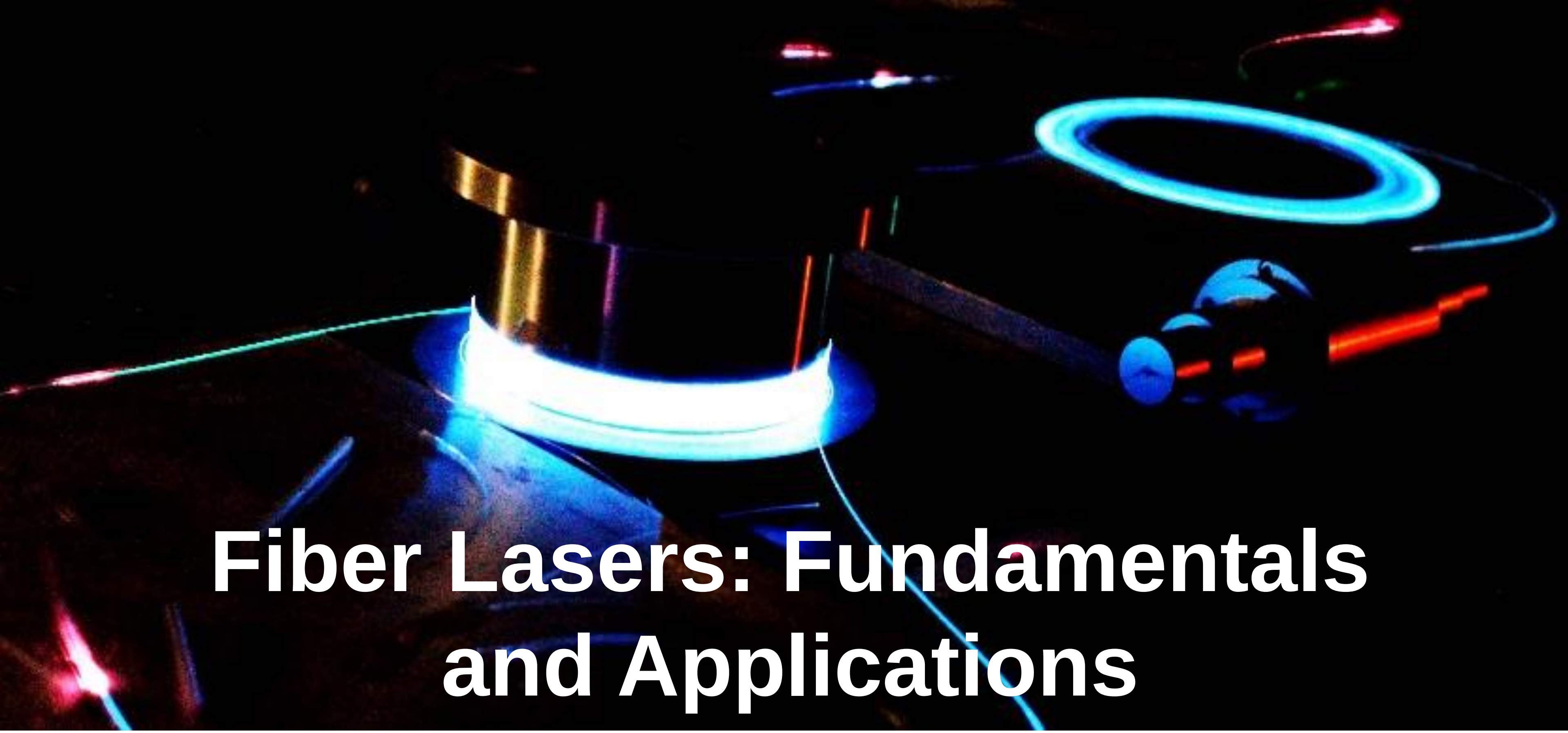

Fiber Lasers: Fundamentals and Applications

Lecture 4

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Source Material

New review paper: V R Supradeepa, Yan Feng, Jeffrey W. Nicholson, "Raman Fiber Lasers," IOP Journal of Optics (2017). Please refer to the paper for exact references to material shown in this lecture

Raman fiber lasers

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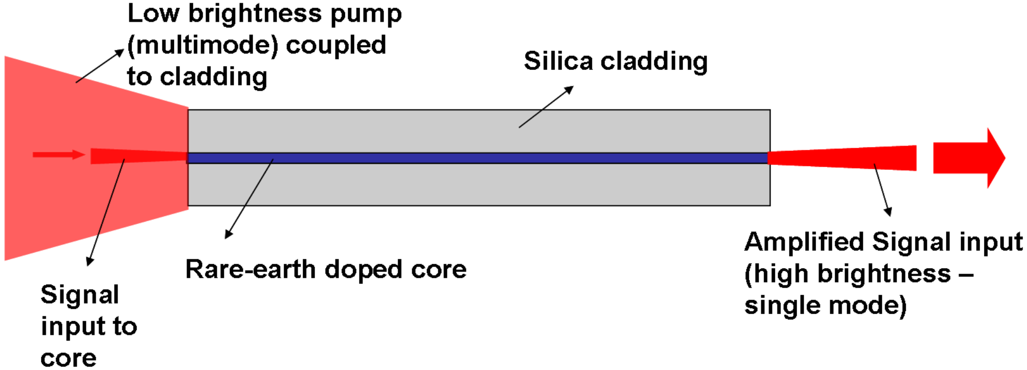
Abstract

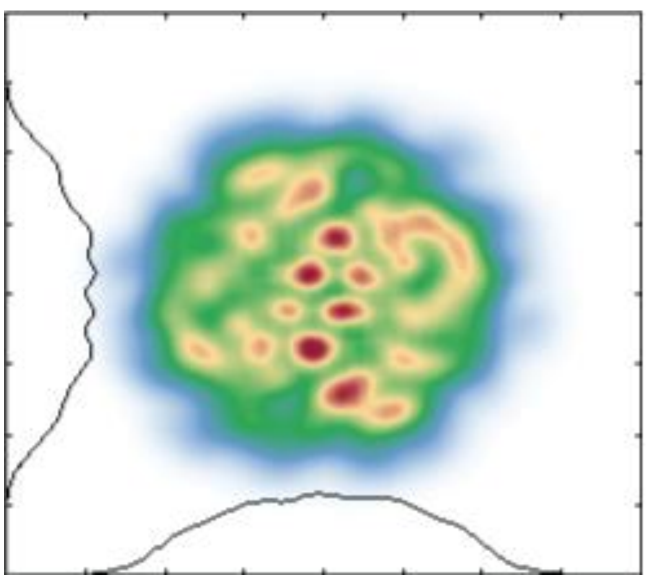
High-power fiber lasers have seen tremendous development in the last decade, with output powers exceeding multiple kilowatts from a single fiber. Ytterbium has been at the forefront as the primary rare-earth-doped gain medium owing to its inherent material advantages. However, for this reason, the lasers are largely confined to the narrow emission wavelength region of ytterbium. Power scaling at other wavelength regions has lagged significantly, and a large number of applications rely upon the diversity of emission wavelengths. Currently, Raman fiber lasers are the only known wavelength agile, scalable, high-power fiber laser technology that can span the wavelength spectrum. In this review, we address the technology of Raman fiber lasers, specifically focused on the most recent developments. We will also discuss several applications of Raman fiber lasers in laser pumping, frequency conversion, optical communications and biology.

Technology

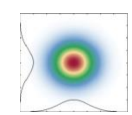


The rare-earth doped core absorbs and reemits the pump light into a high brightness beam (multimode to single mode conversion)

Highly multimode pump light

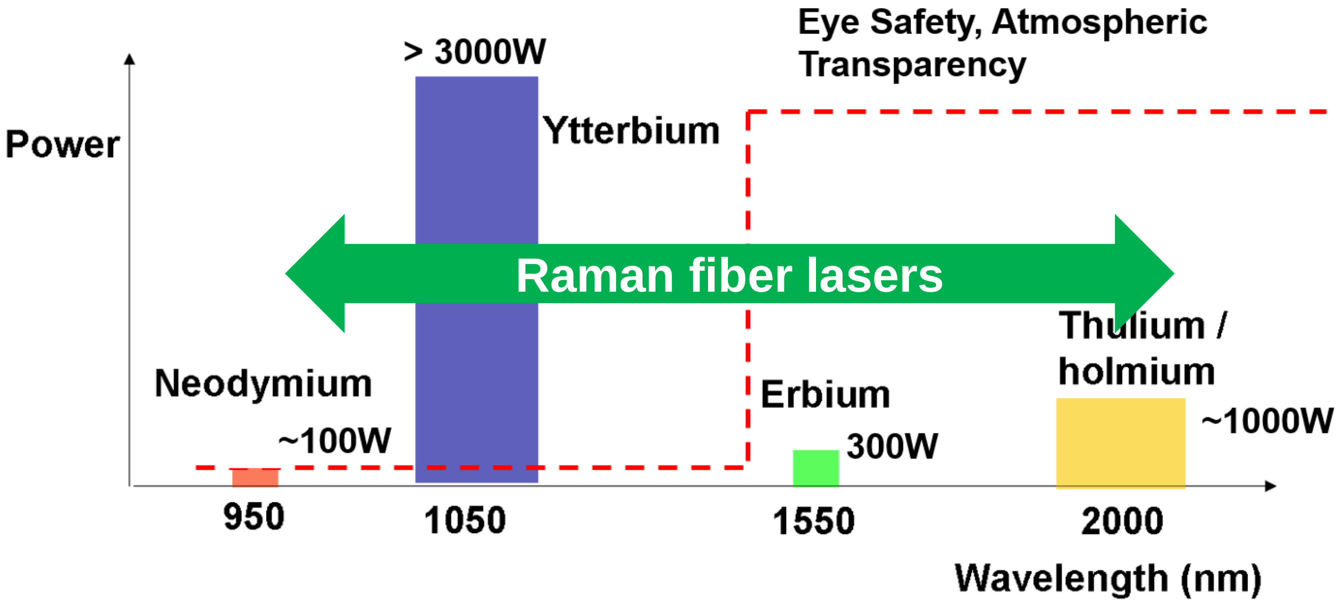


Single mode laser light



From encyclopedia of laser physics and technology

Current Technology of High Power Fiber Lasers

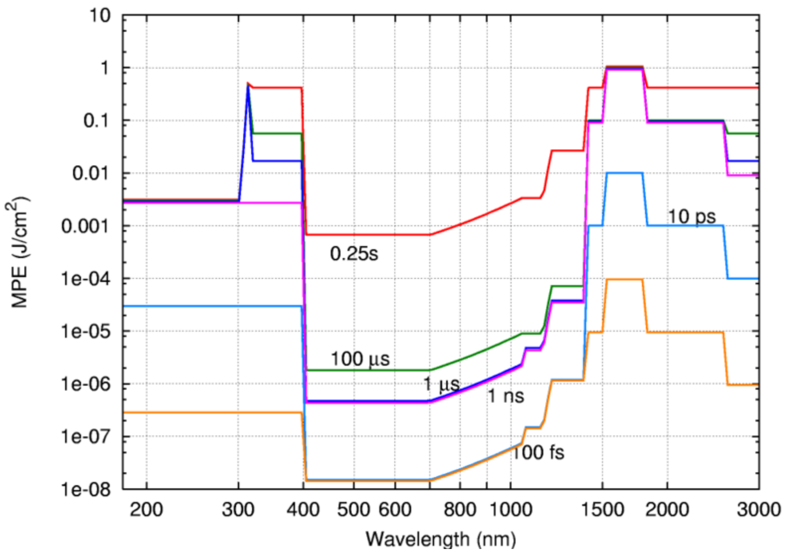


- **Power availability**: Limited primarily to Ytterbium doped lasers
- **Wide white-spaces**: No laser technology available
- **Wide variety of technologies**: Every wavelength needs a different laser

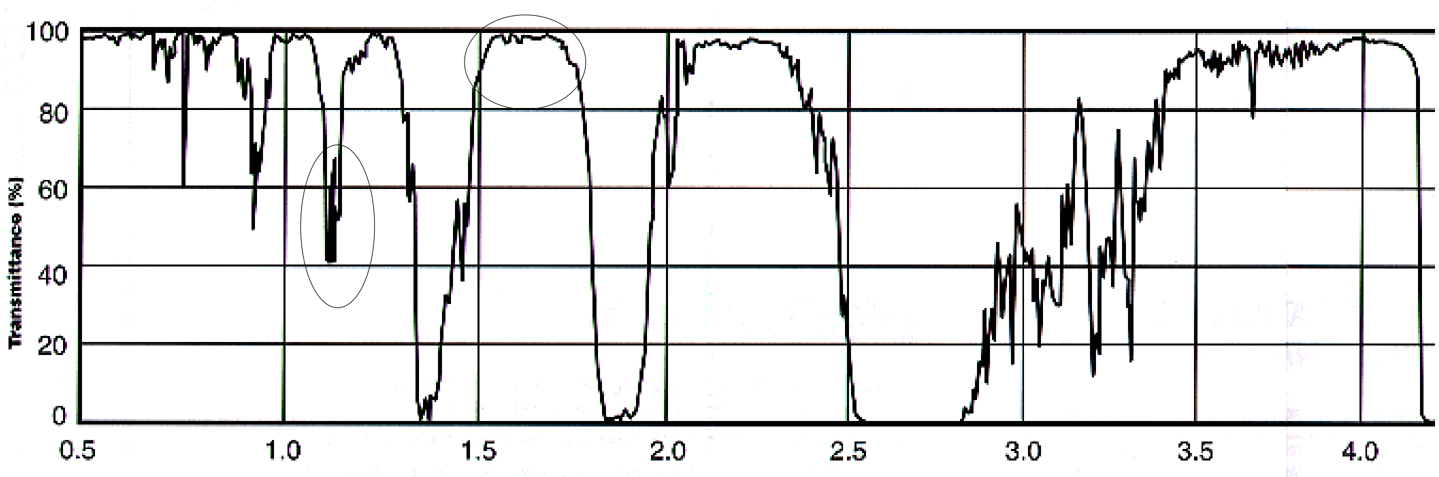
Raman laser – only scalable technology

1.5micron band lasers

Eye Safety



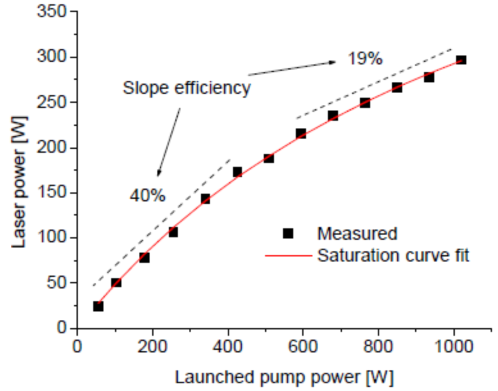
Atmospheric Transparency

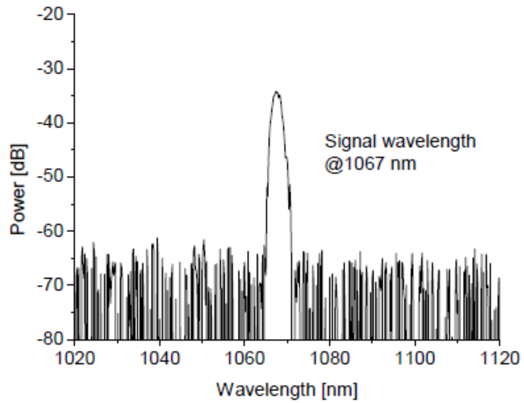


From wikipedia

High power 1.5micron lasers

- **Cladding pumped Er:Yb doped fiber lasers**
  - Pumped using 975nm diodes
  - Spurious lasing by Yb ions
  - Low efficiency < 25%



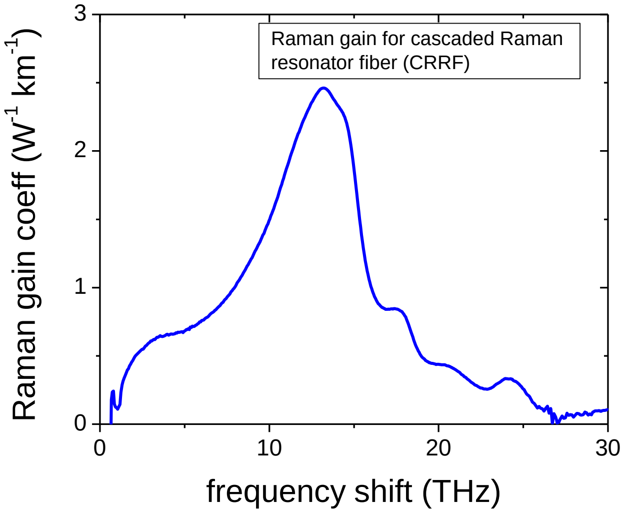


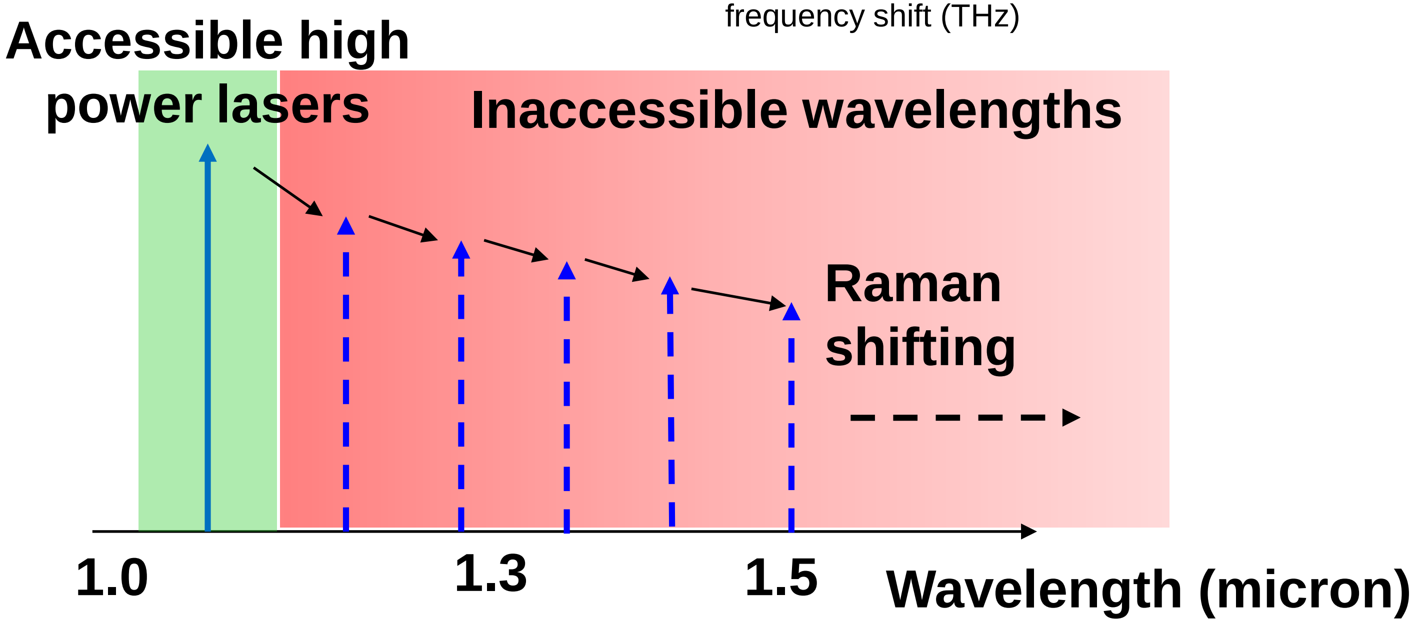
- **Resonantly Cladding pumped Yb free Er doped fiber using 15xx pump diodes**
  - Expensive
  - Long wavelength operation
  - Reduced Beam quality

- **Raman lasers offer a more efficient, cost-effective and scalable solution.**

Technology of (Cascaded) Raman Fiber Lasers

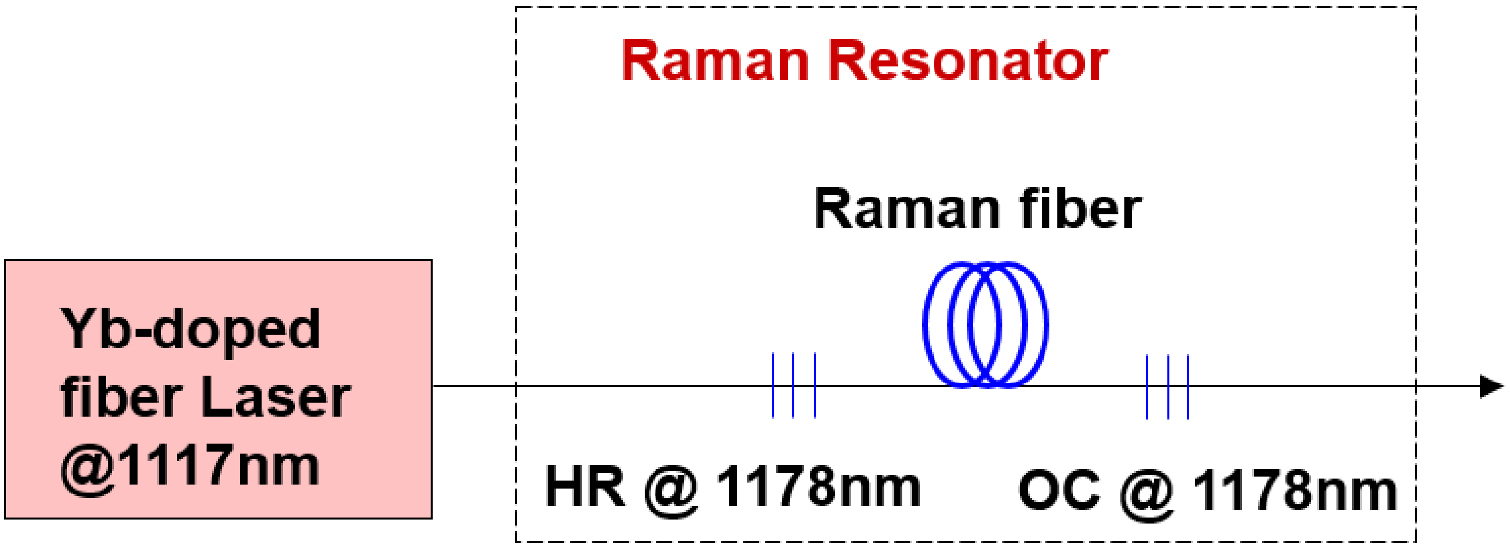
Principle of Raman Lasers



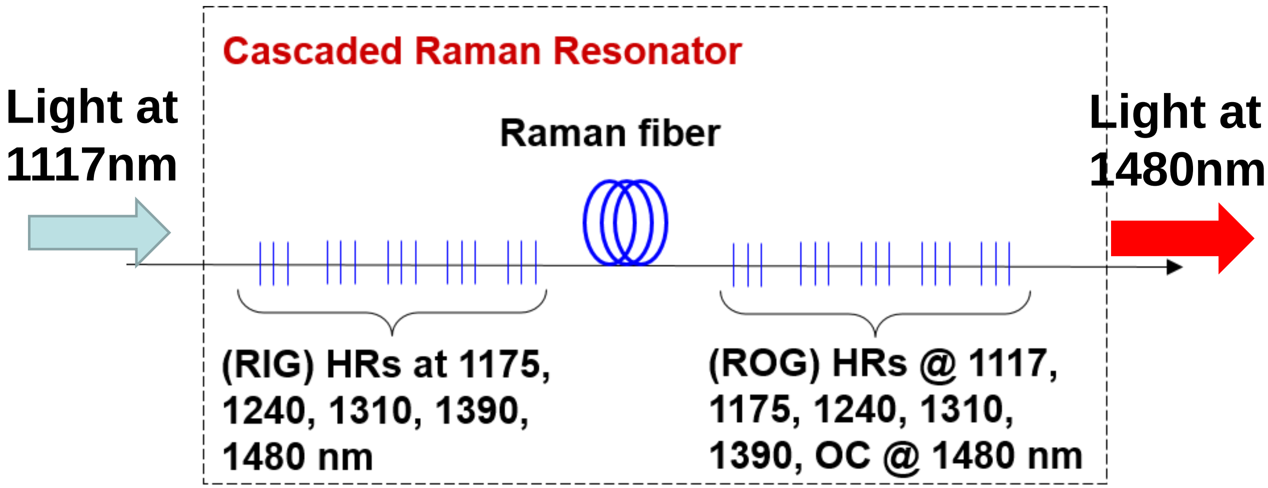


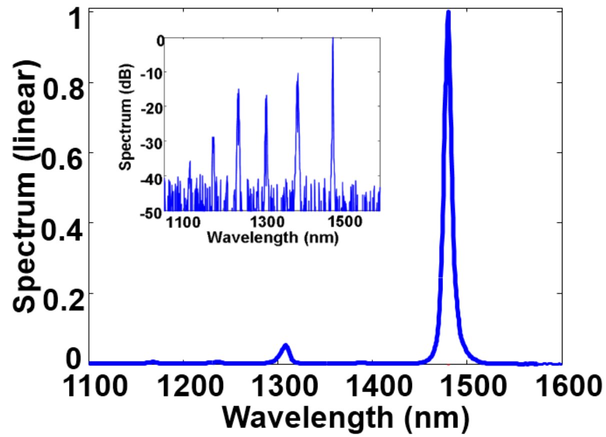
Conventional implementation of Cascaded Raman Fiber Lasers

Raman Laser with one wavelength shift



Cascaded Raman laser (more than one wavelength shift)

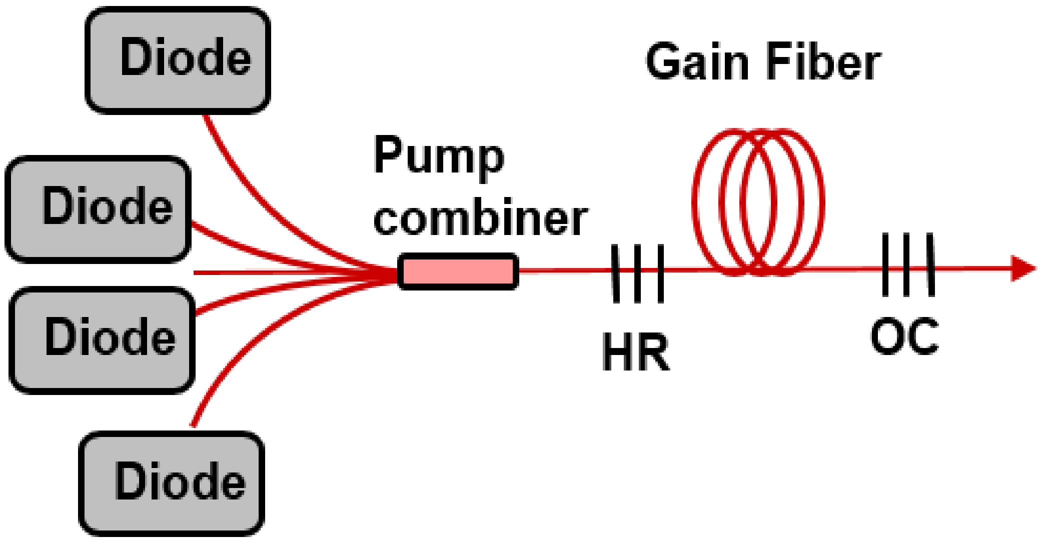




- **Raman conversion achieved with nested cavities spaced at the Stokes shifts**
- **Salient Points –**
  - **First Proposed in 1993 (1 W level), scaled to 40W in 2007**
  - **Efficiency (best efficiencies achieved for a 5th order cascaded system - ~30% (1117 to 1480, Quantum limited efficiency – ~75%)**
  - **Further Scattering of Signal – Unstable at higher powers**

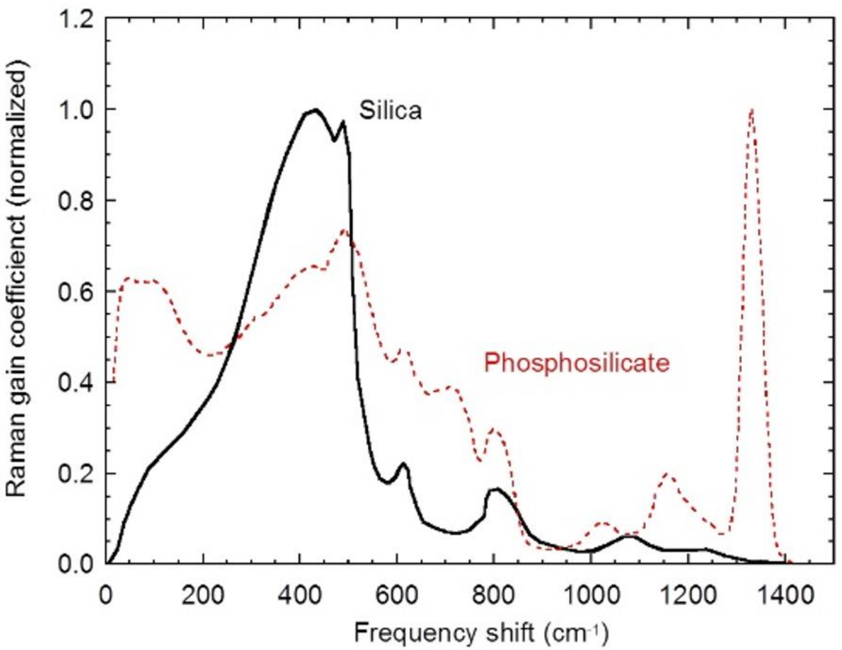
Systems and components of Raman Lasers

High Power Rare-earth doped fiber laser



Raman Wavelength conversion

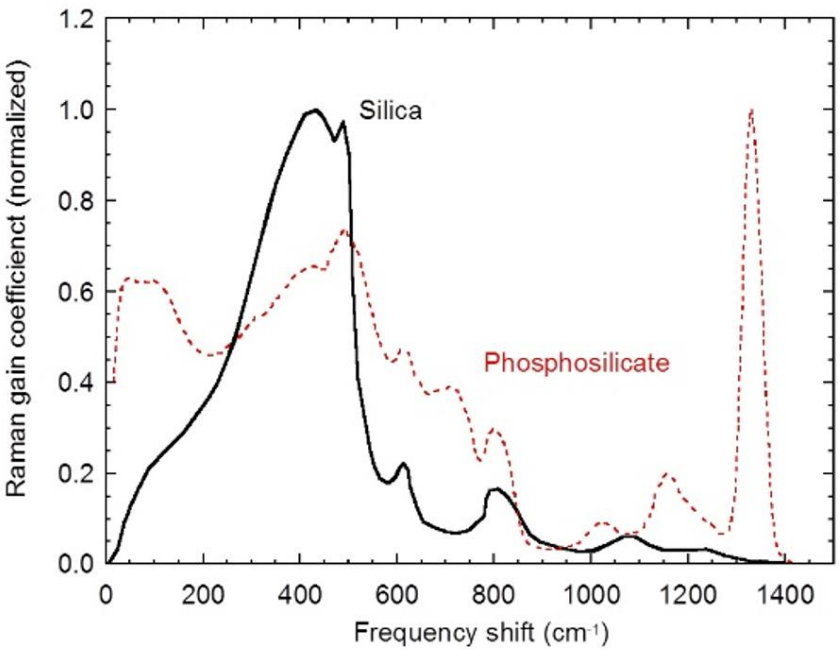
Fibers for Raman Wavelength conversion



Fiber Bragg gratings for wavelength conversion

Raman Wavelength conversion

Fibers for Raman Wavelength conversion



Fiber Bragg gratings for wavelength conversion

Components for isolation of Raman cavity from rare-earth doped fiber laser –

- Long period gratings
- Tilted fiber Bragg gratings
- Wavelength division multiplexers

Design of Raman Fiber Lasers

Numerical Modeling of Raman Fiber Lasers

$$\frac{dP_k^{b,f}}{dz} = \pm\alpha_k P_k^{b,f} \mp \sum_{j<k} \frac{g_R(j,k)}{A_{eff}^j}\left(P_j^f + P_j^b\right) P_k^{b,f} \pm \sum_{j>k} \frac{\upsilon_k g_R(k,j)}{\upsilon_j A_{eff}^j}\left(P_j^f + P_j^b\right) P_k^{b,f}$$

$$\mp \sum_{j<k} \frac{g_R(j,k)}{A_{eff}^j} h\upsilon_k \Delta\upsilon(\mathrm{j}) \left(P_j^f + P_j^b\right) \pm \sum_{j>k} \frac{\upsilon_k g_R(k,j)}{\upsilon_j A_{eff}^j} h\upsilon_j \Delta\upsilon(\mathrm{j}) P_j^{b,f}$$

$$P_k^f(0) = R_k^f P_k^b(0), P_k^b(L) = R_k^b P_k^f(L) \qquad R_1^f = 0, \qquad R_n^b = R_{oc}$$

$$P_{out} = (1 - R_{oc}) P_n^f(L)$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{(1 - R_{oc}) P_n^f(L)}{P_1^f(0)}$$

Optimization of Resonator Components

- Fiber Length
- Grating reflectivities
- Grating Bandwidths
- Splice losses between various fibers