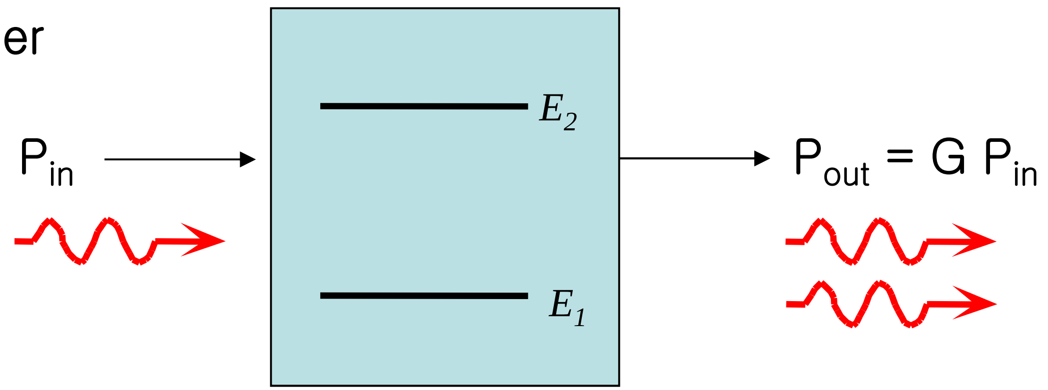
Lect. 21: Optical Pumping and Optical Amplifiers

Optical Amplifier



Which process is useful for optical amplifier?

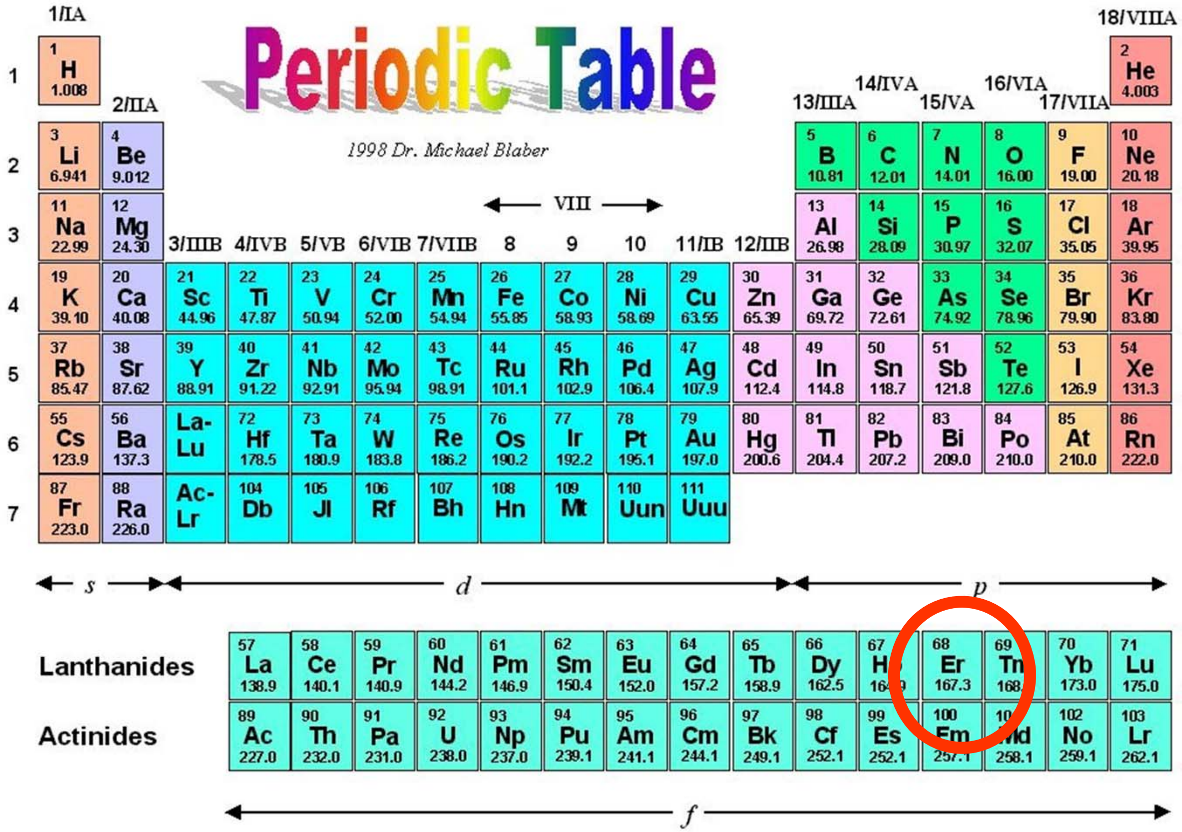
How can we make stimulated emission dominant over absorption?

Pump carriers into N_2 so that $N_2 > N_1$ ➔ Population Inversion

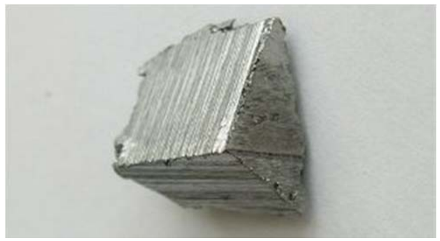
Optical pumping and electrical pumping are possible

Materials having desired energy level separation are needed

Optical Pumping for λ = 1.55μm



Erbium   Rare earth metal



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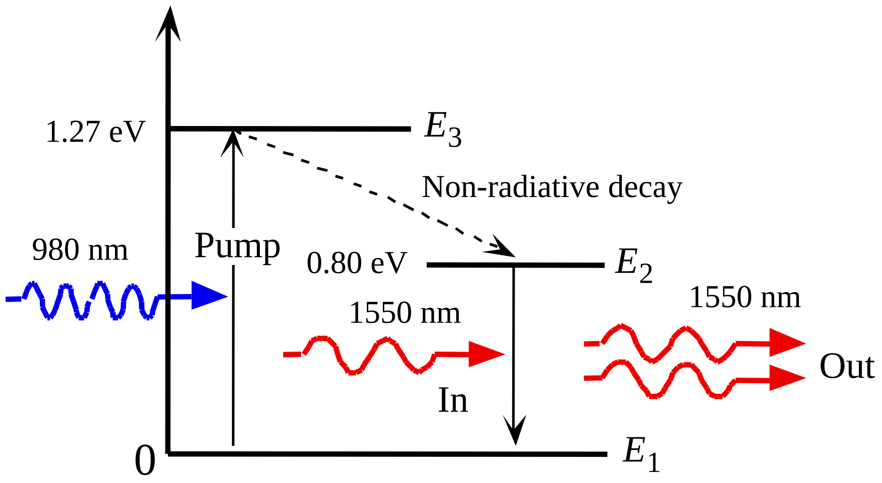
Energy levels in Er



–Pump light is absorbed at E_3 generating carriers

– Carriers at E_3 rapidly transfer to E_2
➔ N_2 builds up

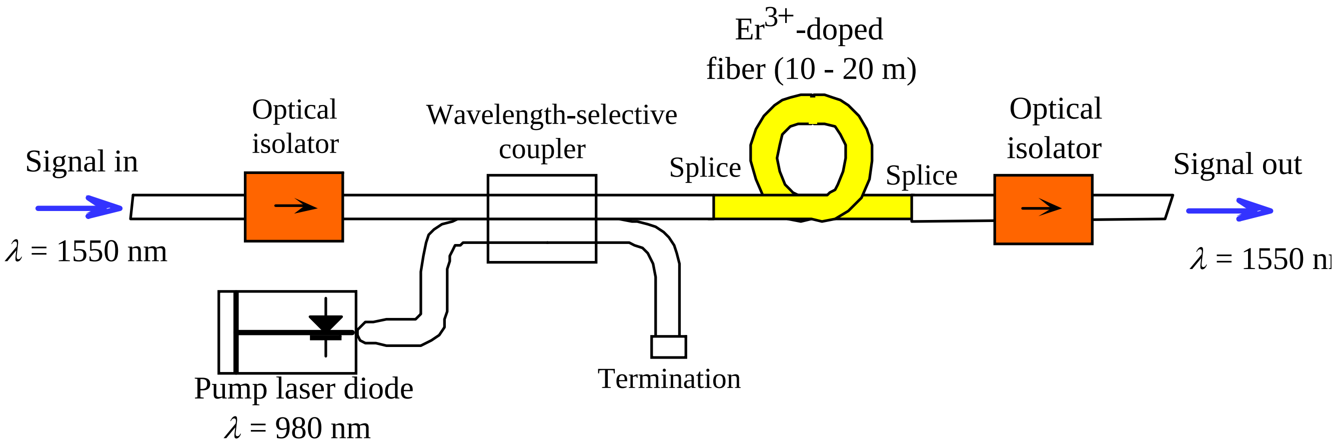
– When $N_2 > N_1$ (population inversion), stimulated emission > absorption for 1550nm light

Pumping source (980nm) is easily available

Er can be easily added to core of Silica fiber

➔ EDF (Er-Doped Fiber)

EDFA: Er-Doped Fiber Amplifier



EDFA compensates fiber loss for long distance optical fiber communication

➔ One of the key components
that make long distance optical fiber communication possible

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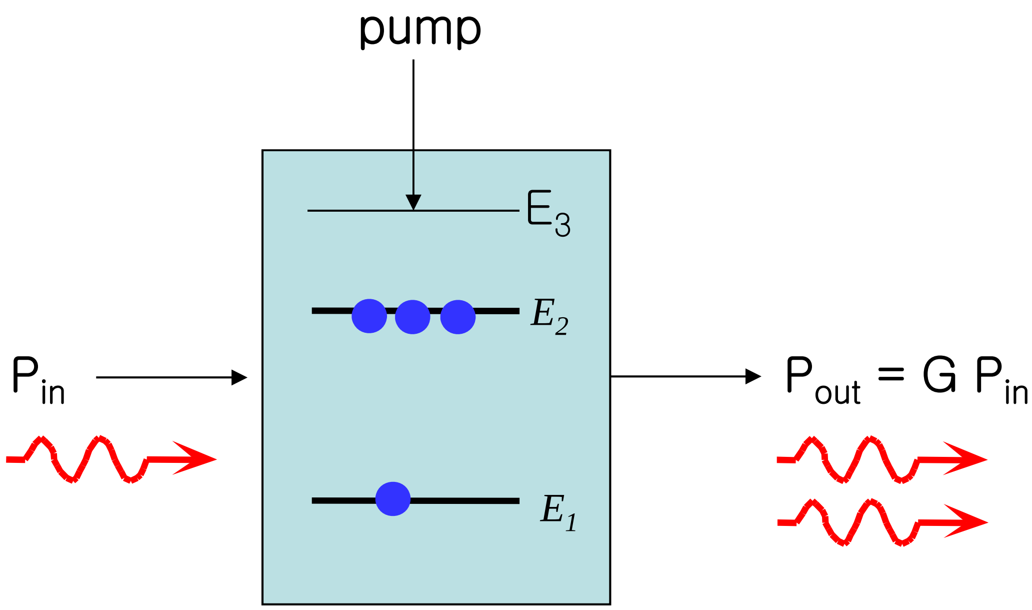
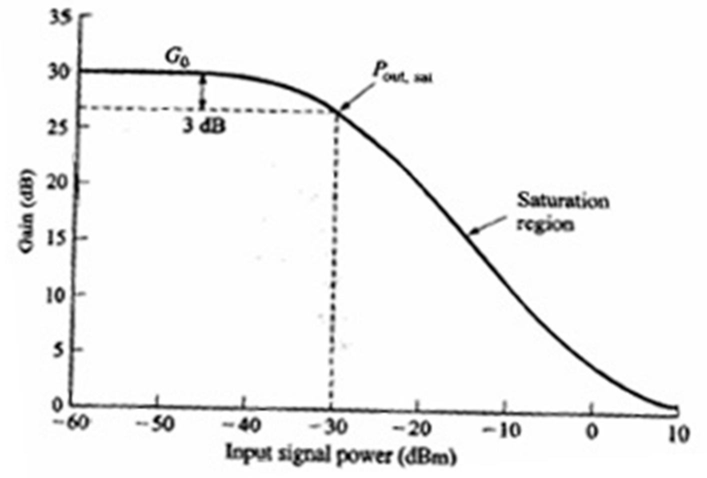


G in a typical EDFA



$G = \exp(gL)$

G becomes smaller with larger P_{in}

Gain saturation

Due to limited carriers at E_2

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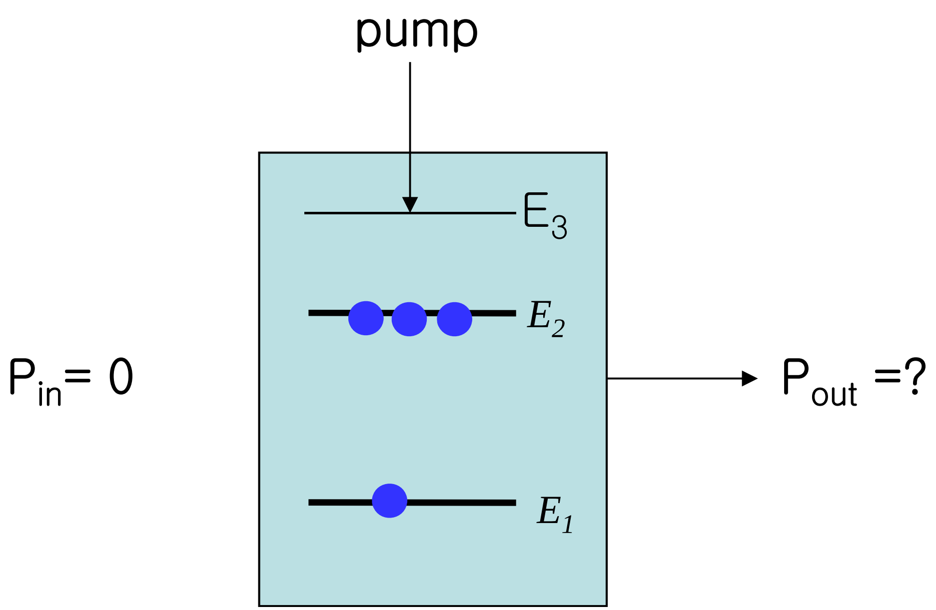
What about spontaneous emission?



Noise in EDFA

Amplified Spontaneous Emission (ASE)

Output SNR (Signal-to-Noise Ratio) is always smaller than input SNR

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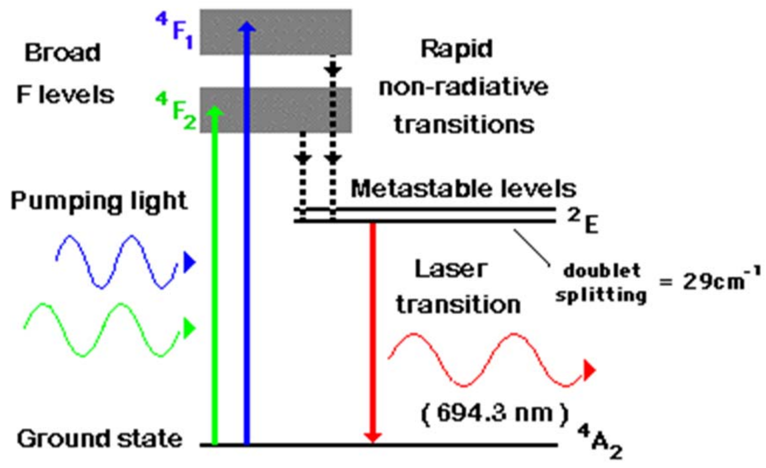
Other optical gain materials

- Crystals doped with impurities: Ruby doped with Cr ($Al_2O_3:Cr^{3+}$)



Energy levels of chromium ions in ruby

- Gases, Semiconductors, …

These materials can be used for lasers

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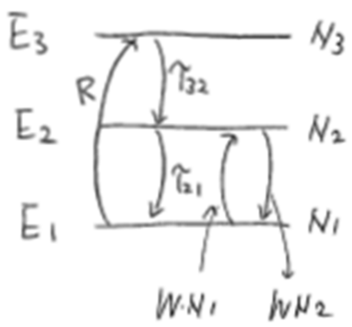
Rate Equations for 3-level systems



Assume τ_{32} is very small so that $N_3 = 0$ $\tau_{21} = \tau$

$N_1 + N_2 = N$

$$\frac{dN_2}{dt} = R - \frac{N_2}{\tau} - WN_2 + WN_1$$

$$\frac{dN_1}{dt} = -R + \frac{N_2}{\tau} + WN_2 - WN_1$$

Homework:

- Determine the expression for $N_2 - N_1$ at the steady-state

- Determine R required for transparency ($N_2 = N_1$)