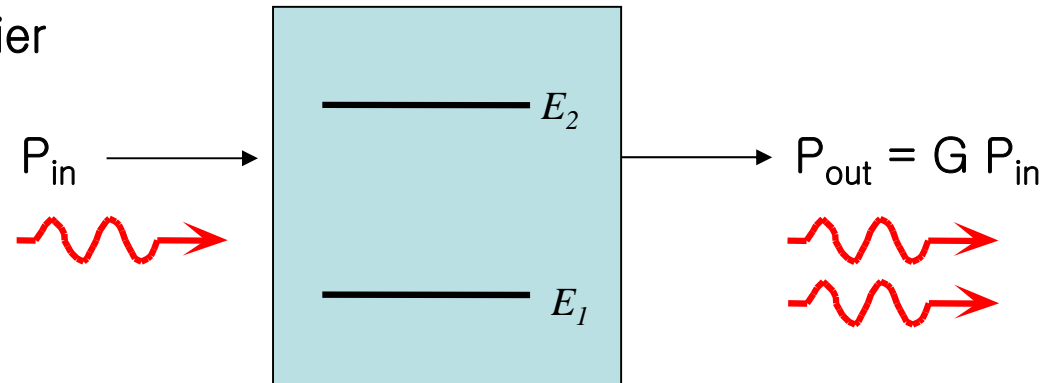


# Lect. 21: Optical Pumping and Optical Amplifiers

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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

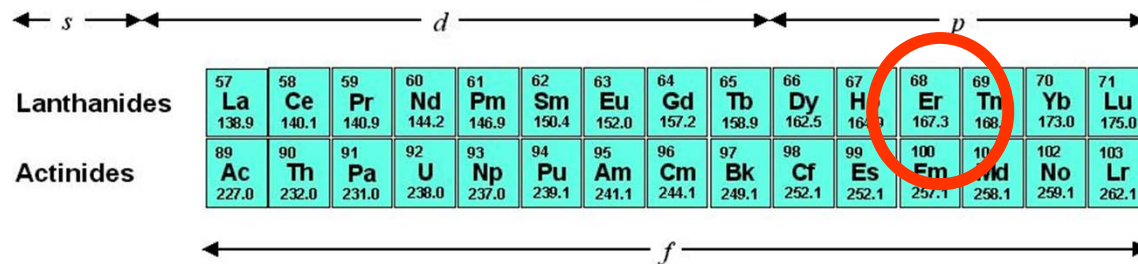
Materials having desired energy level separation are needed

# Lect. 21: Optical Pumping and Optical Amplifiers

Optical Pumping for  $\lambda = 1.55\mu\text{m}$

**Periodic Table**  
1998 Dr. Michael Blaber

1 1 H 1.008																	2 2 He 4.003
3 3 Li 6.941	4 4 Be 9.012											5 5 B 10.81	6 6 C 12.01	7 7 N 14.01	8 8 O 16.00	9 9 F 19.00	10 10 Ne 20.18
11 11 Na 22.99	12 12 Mg 24.30	← VIII →						13 13 Al 26.98	14 14 Si 28.09	15 15 P 30.97	16 16 S 32.07	17 17 Cl 35.05	18 18 Ar 39.95				
19 19 K 39.10	20 20 Ca 40.08	21 21 Sc 44.96	22 22 Ti 47.87	23 23 V 50.94	24 24 Cr 52.00	25 25 Mn 54.94	26 26 Fe 55.85	27 27 Co 58.93	28 28 Ni 58.69	29 29 Cu 63.55	30 30 Zn 65.39	31 31 Ga 69.72	32 32 Ge 72.61	33 33 As 74.92	34 34 Se 78.96	35 35 Br 79.90	36 36 Kr 83.80
37 37 Rb 85.47	38 38 Sr 87.62	39 39 Y 88.91	40 40 Zr 91.22	41 41 Nb 92.91	42 42 Mo 95.94	43 43 Tc 98.91	44 44 Ru 101.1	45 45 Rh 102.9	46 46 Pd 106.4	47 47 Ag 107.9	48 48 Cd 112.4	49 49 In 114.8	50 50 Sn 118.7	51 51 Sb 121.8	52 52 Te 127.6	53 53 I 126.9	54 54 Xe 131.3
55 55 Cs 132.9	56 56 Ba 137.3	La-Lu	72 72 Hf 178.5	73 73 Ta 180.9	74 74 W 183.8	75 75 Re 186.2	76 76 Os 190.2	77 77 Ir 192.2	78 78 Pt 195.1	79 79 Au 197.0	80 80 Hg 200.6	81 81 Tl 204.4	82 82 Pb 207.2	83 83 Bi 209.0	84 84 Po 210.0	85 85 At 210.0	86 86 Rn 222.0
87 87 Fr 223.0	88 88 Ra 226.0	Ac-Lr	104 104 Db	105 105 JI	106 106 Rf	107 107 Bh	108 108 Hn	109 109 Mt	110 110 Uun	111 111 Uuu							

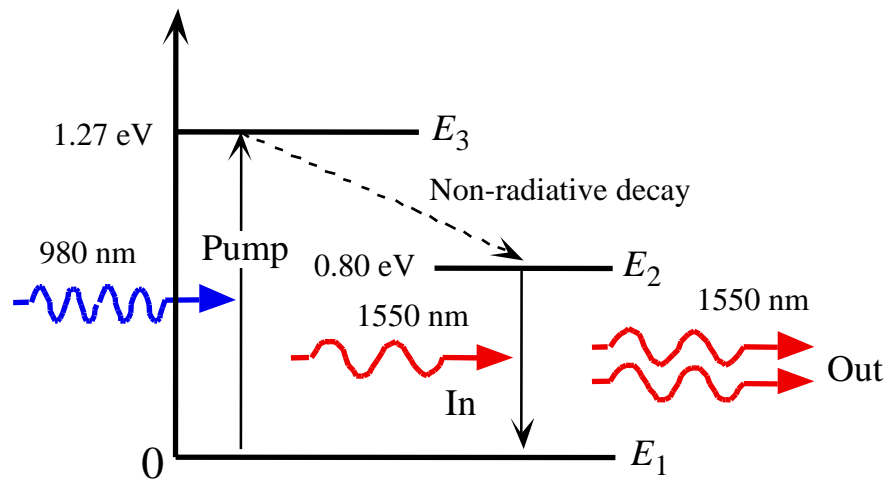


Erbium Rare earth metal



# Lect. 21: Optical Pumping and Optical Amplifiers

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

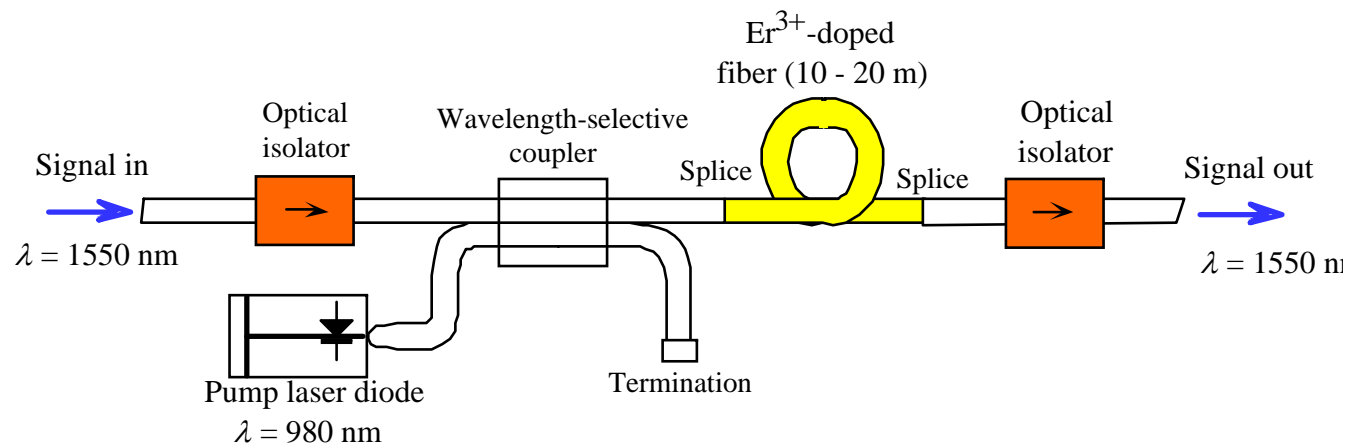
Pumping source (980nm) is easily available

Er can be easily added to core of Silica fiber

→ EDF (Er-Doped Fiber)

# Lect. 21: Optical Pumping and Optical Amplifiers

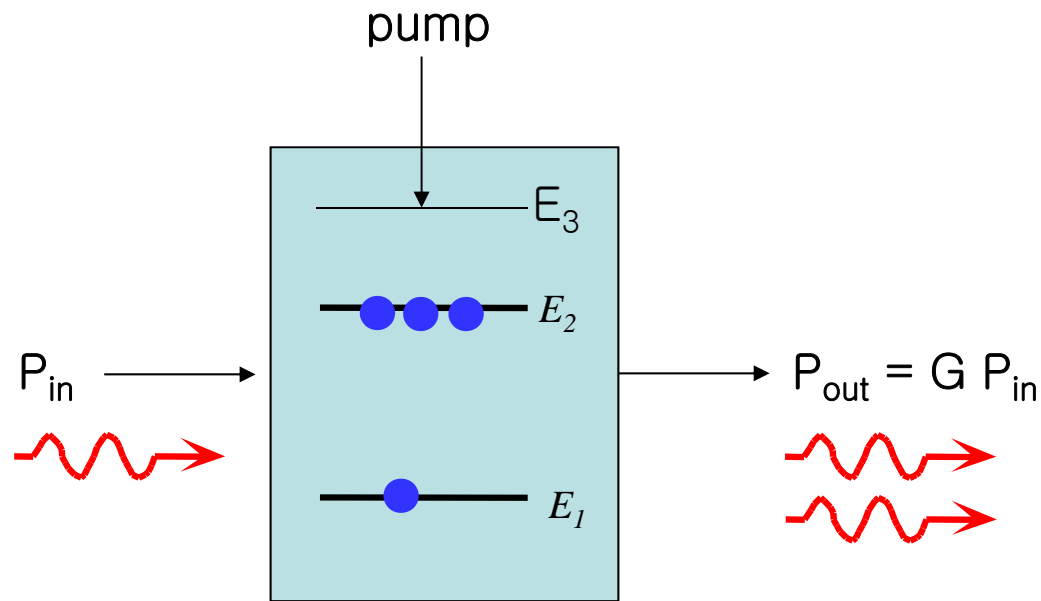
## EDFA: Er-Doped Fiber Amplifier



EDFA compensates fiber loss for long distance optical fiber communication

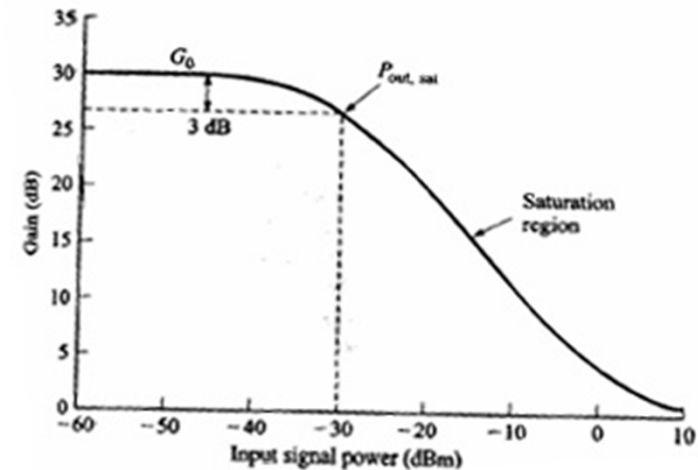
➔ One of the key components that make long distance optical fiber communication possible

# Lect. 21: Optical Pumping and Optical Amplifiers



$$G = \exp(gL)$$

G in a typical EDFA



G becomes smaller with larger  $P_{in}$

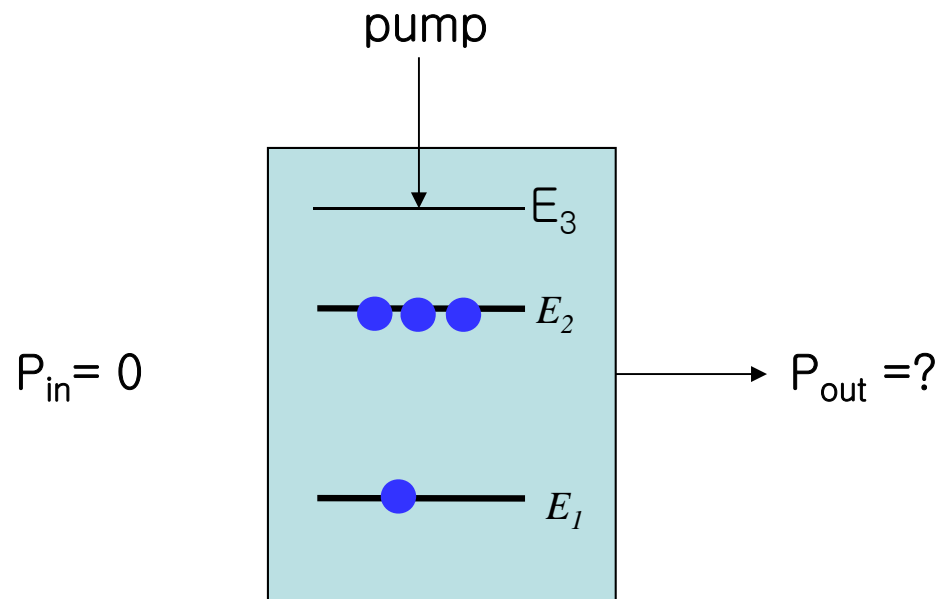
Gain saturation

Due to limited carriers at  $E_2$

# Lect. 21: Optical Pumping and Optical Amplifiers

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What about spontaneous emission?



Noise in EDFA

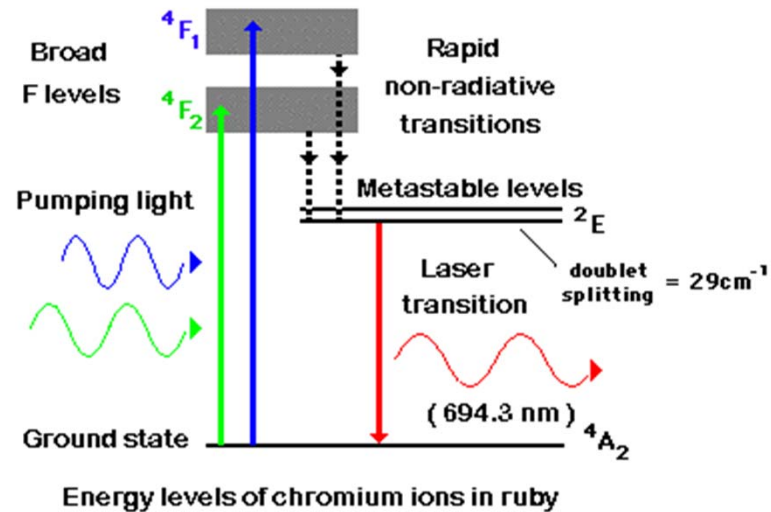
Amplified Spontaneous Emission (ASE)

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

# Lect. 21: Optical Pumping and Optical Amplifiers

Other optical gain materials

- Crystals doped with impurities: Ruby doped with Cr ( $\text{Al}_2\text{O}_3:\text{Cr}^{3+}$ )



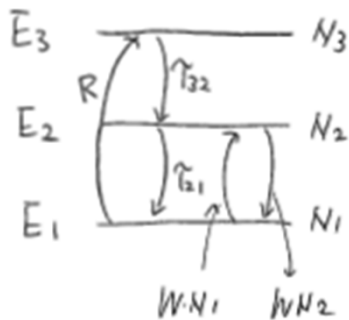
- Gases, Semiconductors, ...

These materials can be used for lasers

# Lect. 21: Optical Pumping and Optical Amplifiers

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Rate Equations for 3-level systems



Assume  $\tau_{32}$  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 ( $N_2 = N_1$ )