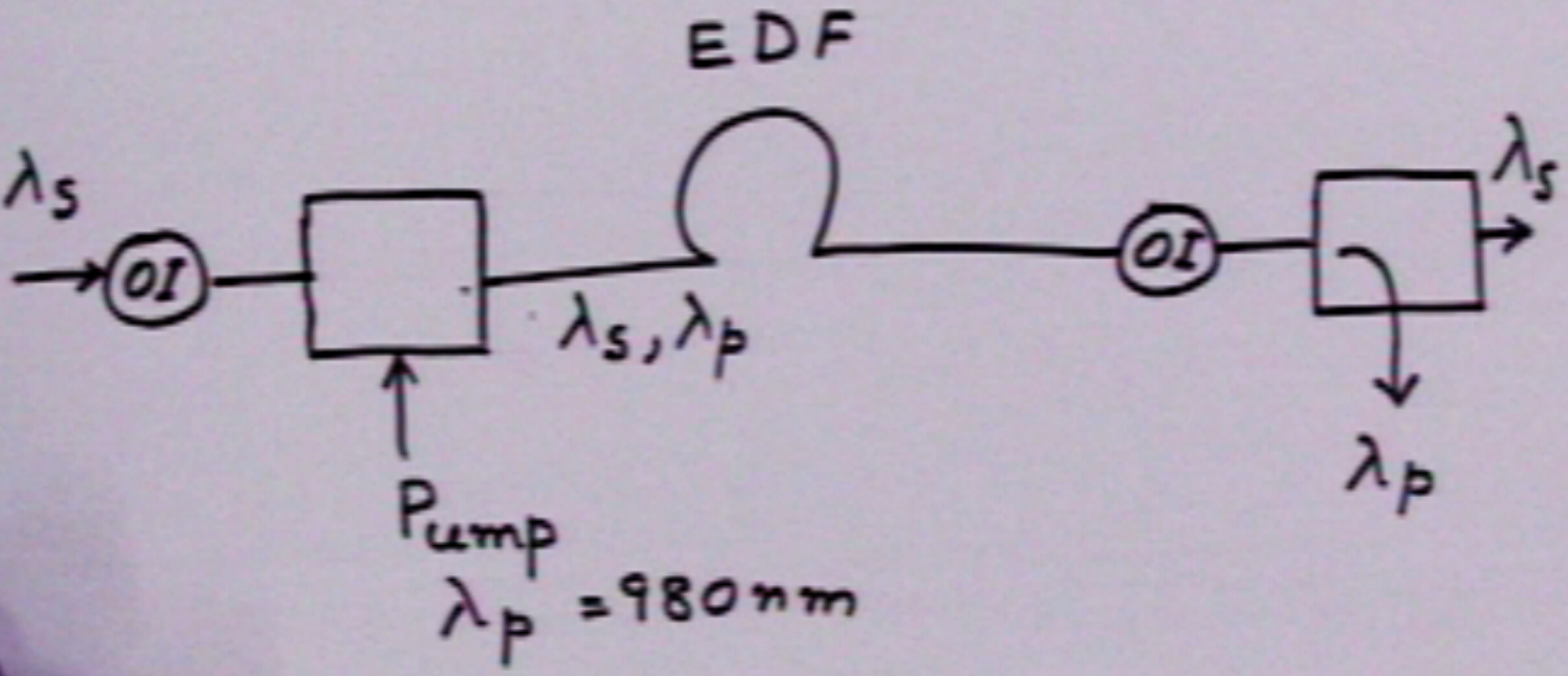
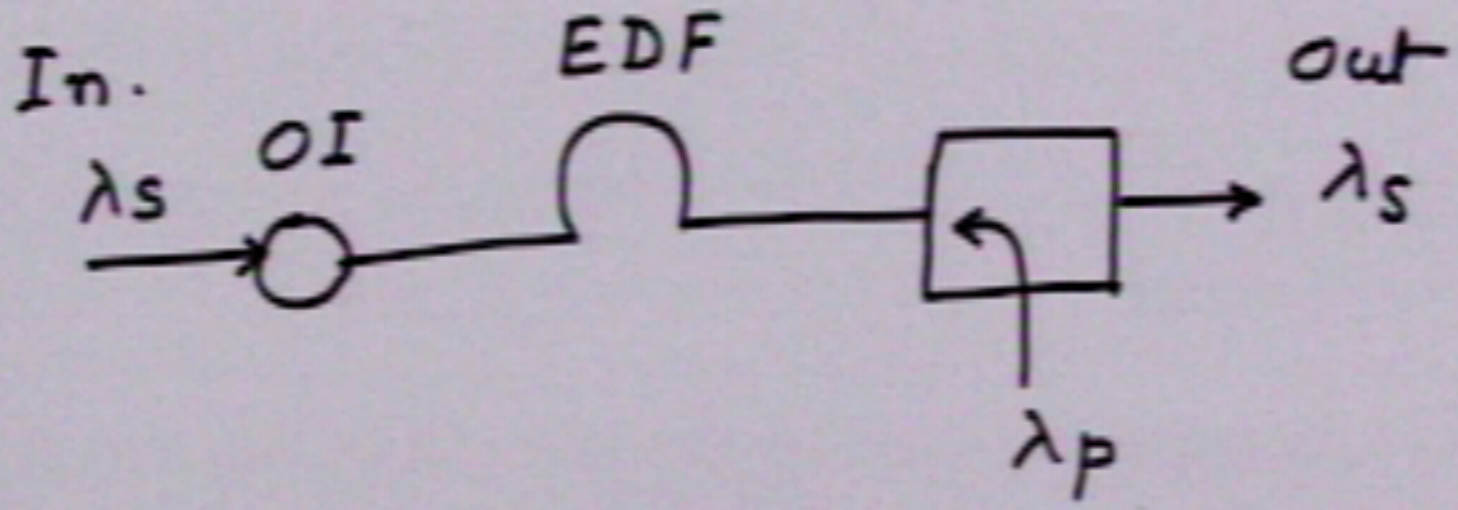
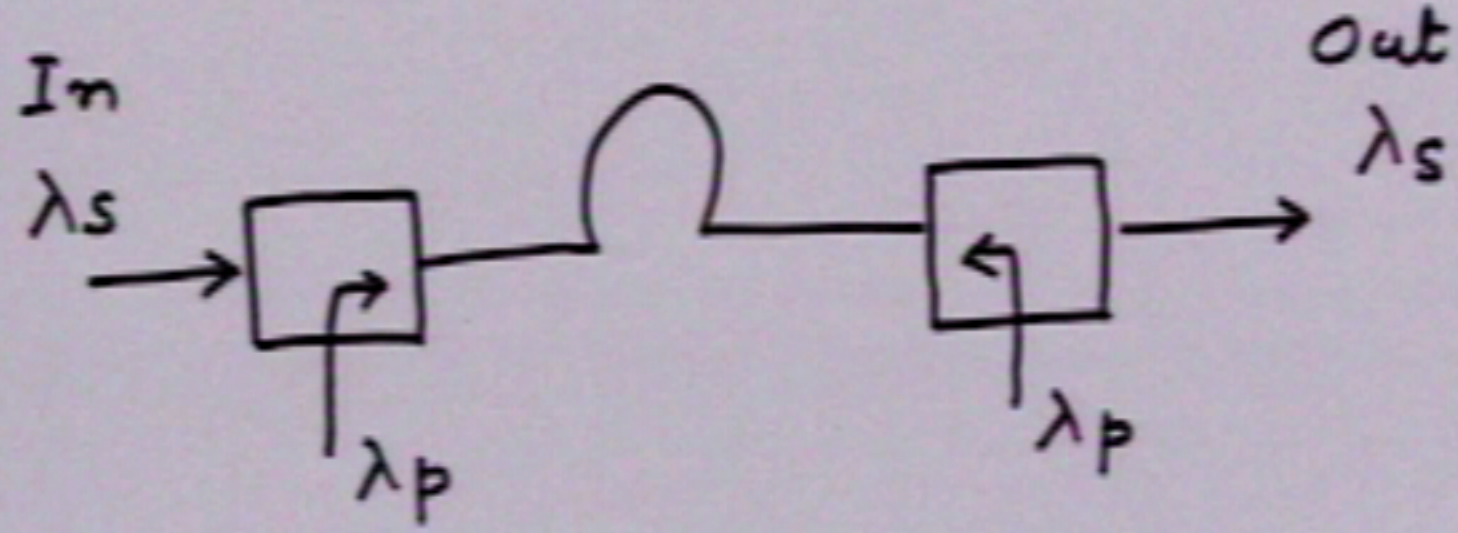


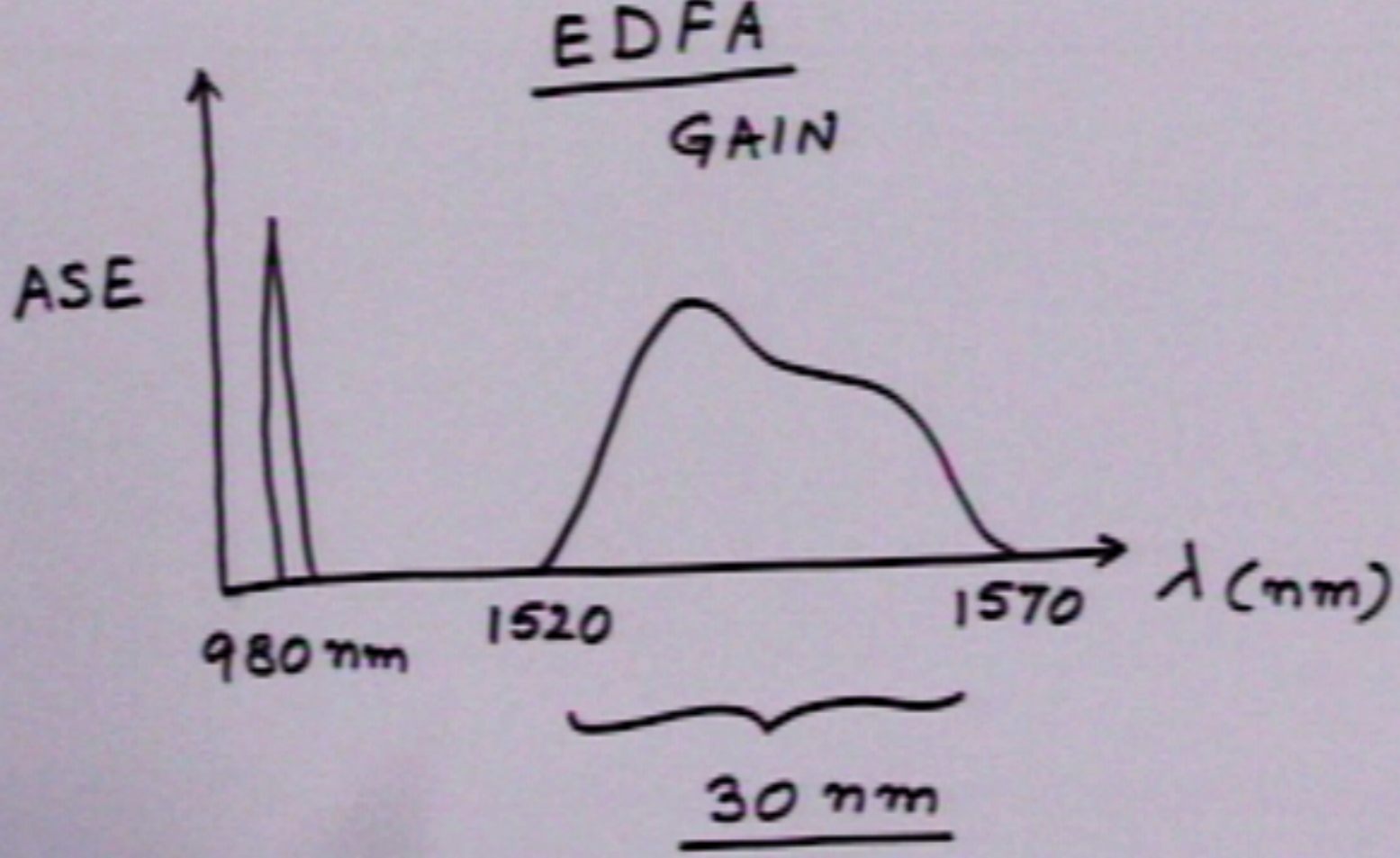
Co-directional

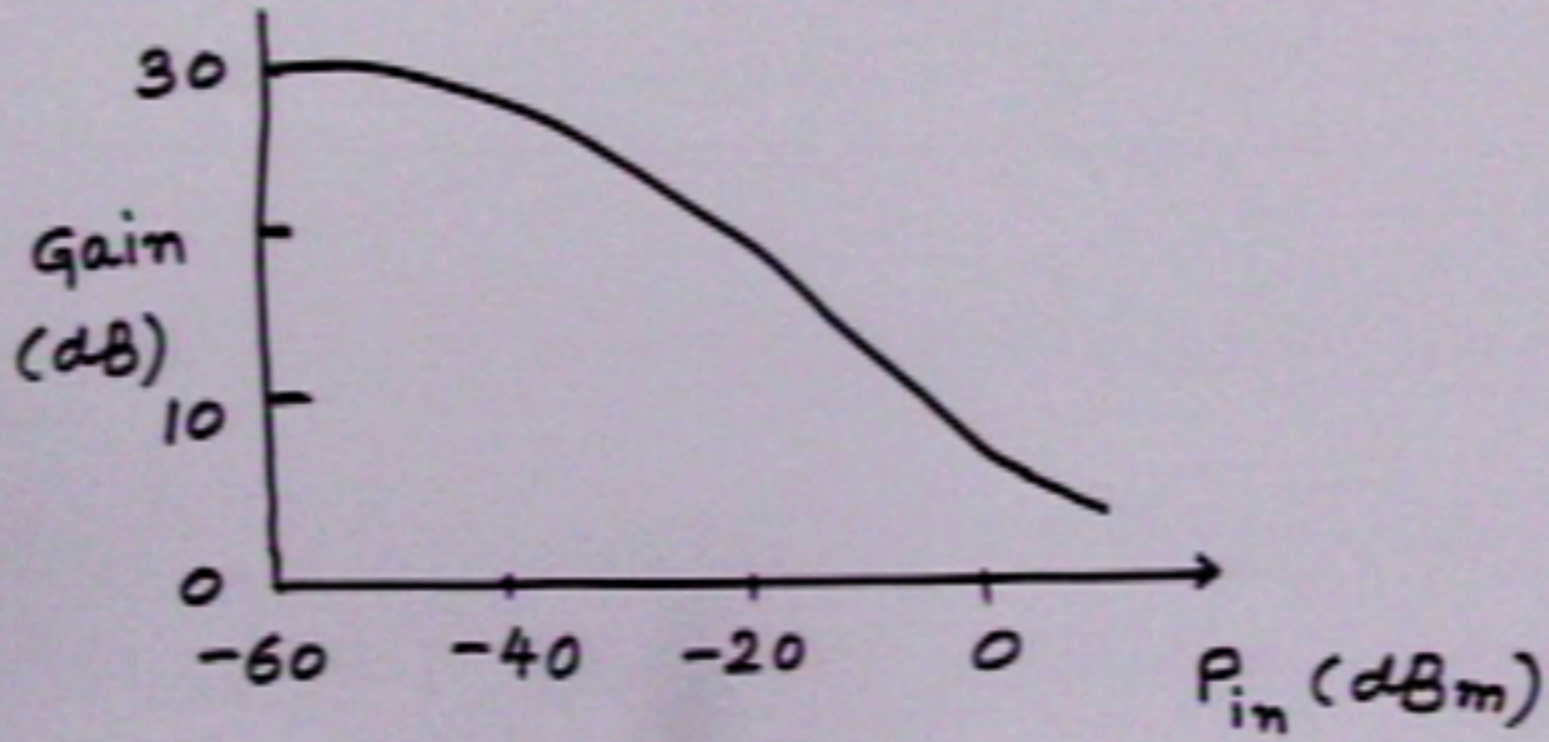
Better Noise performance



Counter Directional scheme


In
λs
λp
λp
out
λs


EDFA
GAIN
ASE
λ (nm)
980 nm
1520
1570
30 nm


30
Gain
(dB)
10
0
-60
-40
-20
0
P_{in} (dBm)

$$P_{S\,out} \leq P_{S\,in} + \frac{\lambda_P}{\lambda_S} P_{P\,in}$$

Power Conversion efficiency

$$PCE = \frac{P_{S\,out} - P_{S\,in}}{P_{P\,in}} = \frac{\lambda_P}{\lambda_S} \leq 1$$

Quantum conversion efficiency

$$QCE = \frac{\lambda_S}{\lambda_P} PCE \leq 1$$

Gain

$$G = \frac{P_{sout}}{P_{sin}} \leq 1 + \frac{\lambda_p}{\lambda_s}\frac{P_{pin}}{P_{sin}}$$

$$G \approx \frac{\lambda_p}{\lambda_s}\frac{P_{pin}}{P_{sin}} \quad \text{for } P_{sin} << P_{pin}$$

$$\approx 1 \quad \text{for } P_{sin} > \frac{\lambda_p}{\lambda_s} P_{pin}$$

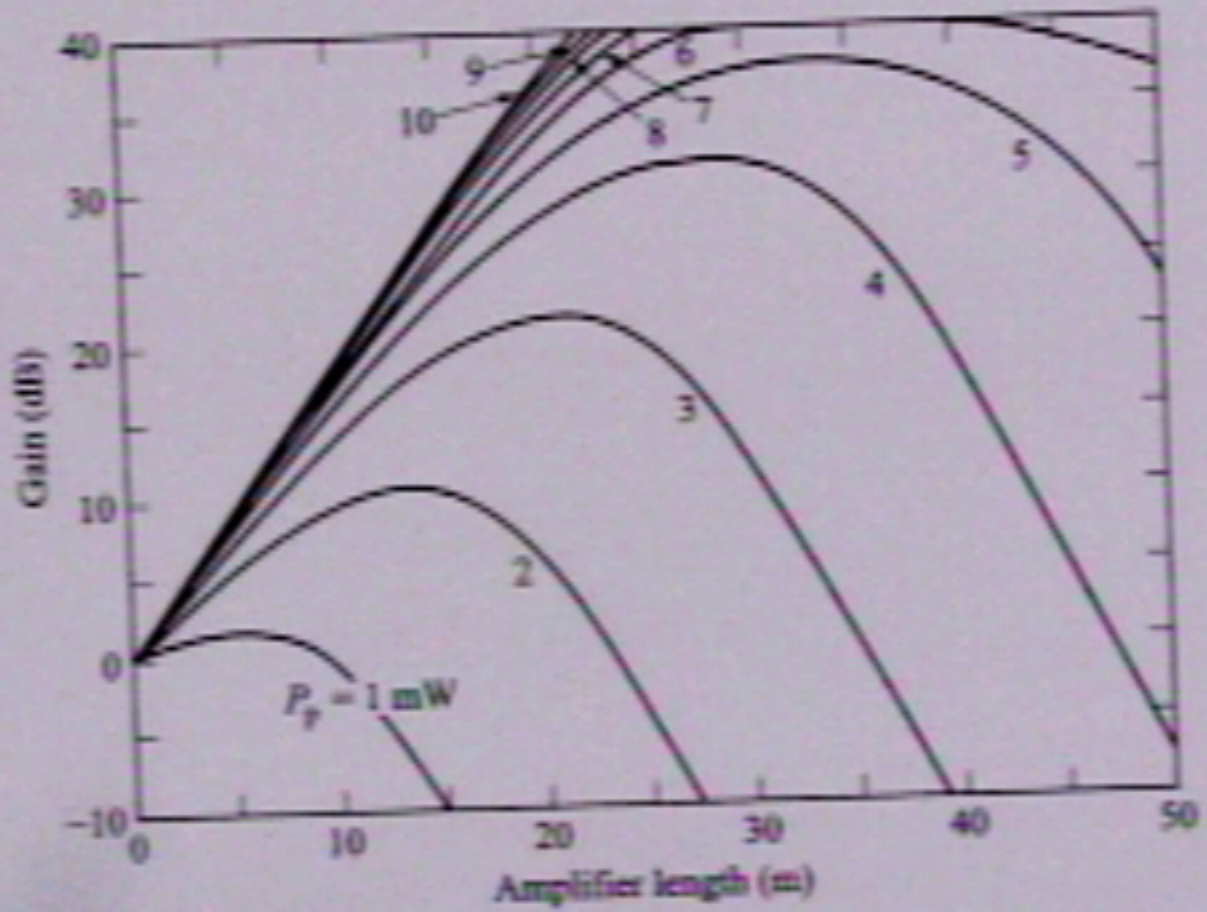
$$(P_{sin})_{max} = \frac{(\lambda_p/\lambda_s)\, P_{pin}}{G-1}$$

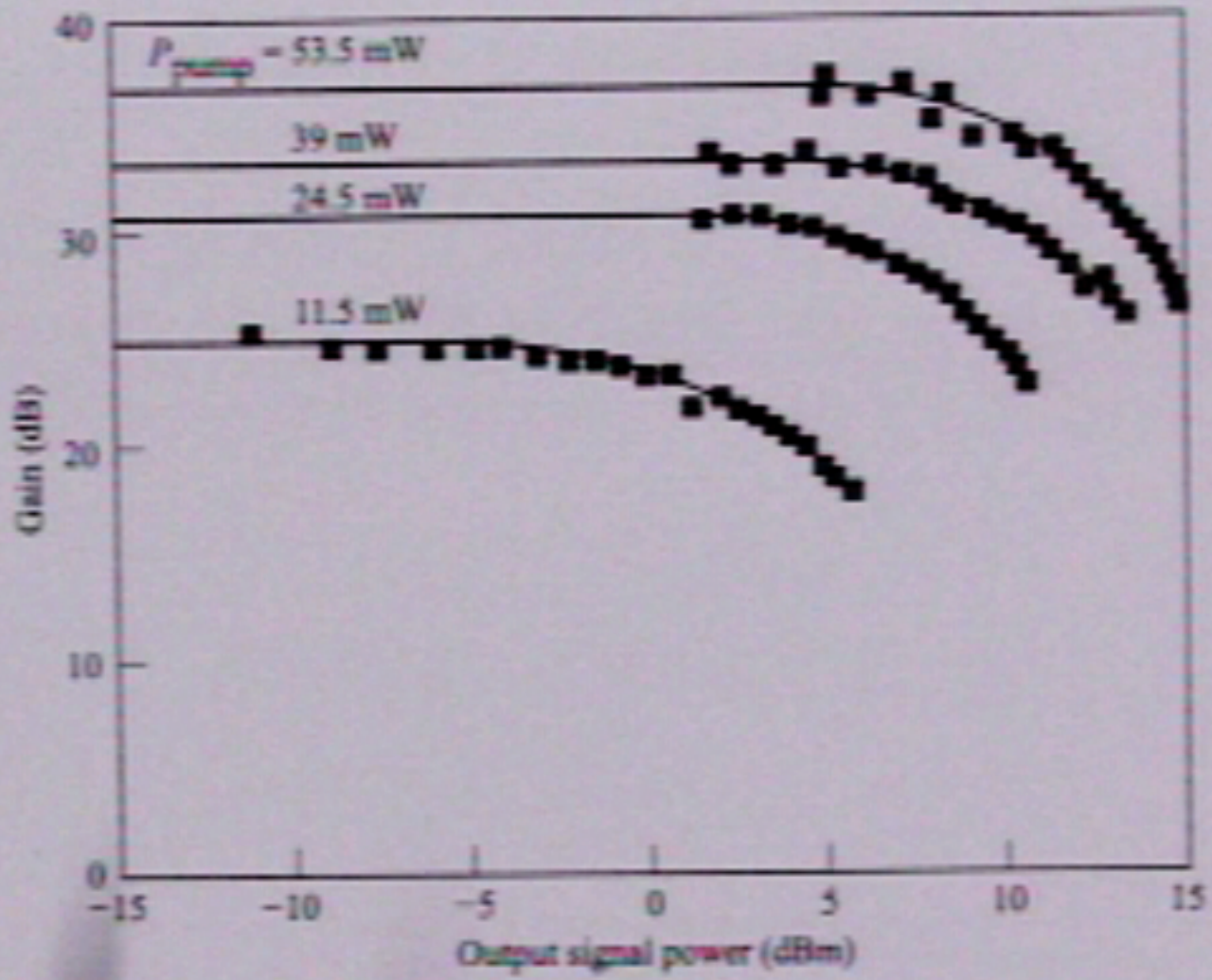
σ_e = Signal Emission cross-section

ρ = Er doping concentration

$$G_{max} = e^{\rho \sigma_e L}$$

$$G \leq \min \left\{ e^{\rho \sigma_e L}, \; 1 + \frac{\lambda_p}{\lambda_s} \frac{P_{pin}}{P_{sin}} \right\}$$


40
30
20
10
0
−10
0
10
20
30
40
50
Gain (dB)
Amplifier length (m)
P_p = 1 mW
2
3
4
5
6
7
8
9
10


40
30
20
10
0
P_{pump} = 53.5 mW
39 mW
24.5 mW
11.5 mW
Gain (dB)
−15
−10
−5
0
5
10
15
Output signal power (dBm)

Amplified Spontaneous Emission

ASE - Noise

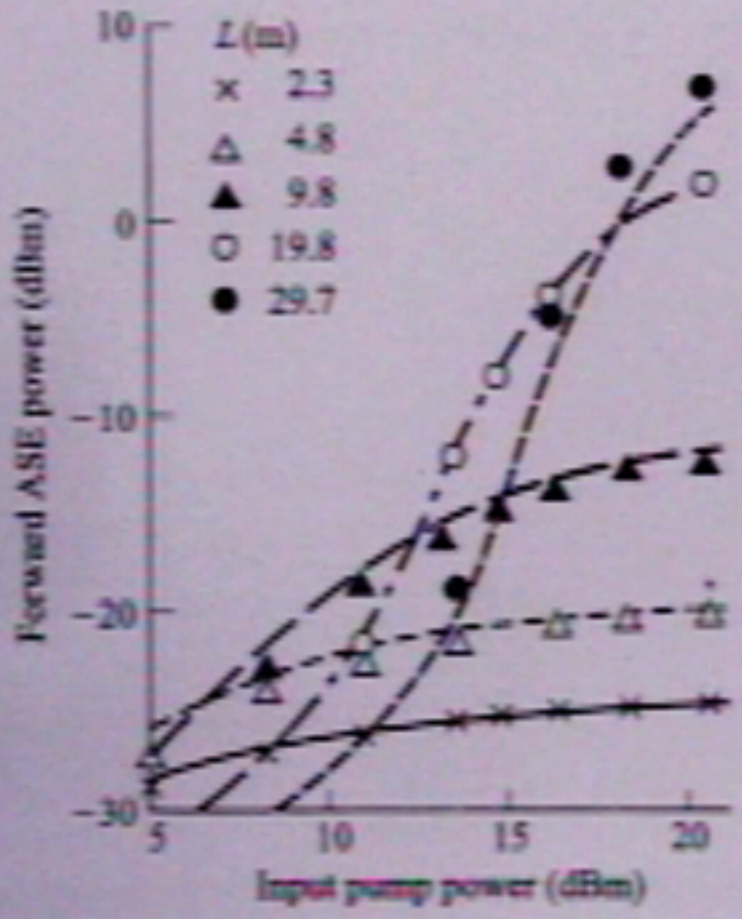
$$BW = B_{opt} \approx 30 - 40\ nm$$

Spectral density

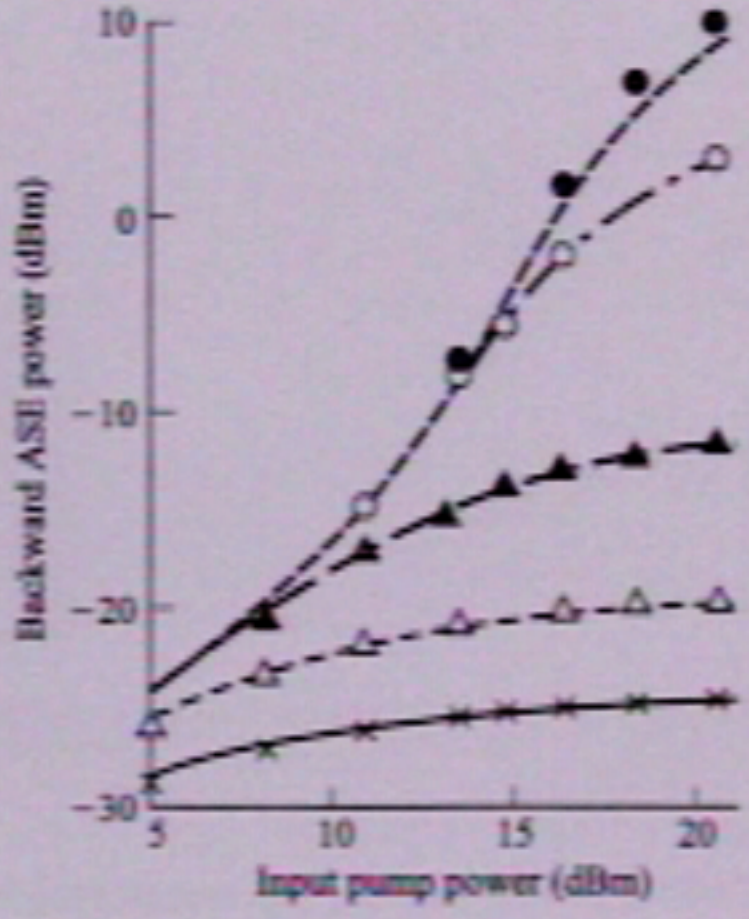
$$S_{ASE}(f) = hf\, n_{sp}\,(G(f) - 1)$$

↑ Population inversion factor

$$n_{sp} \rightarrow 1.4 \text{ to } 4$$


L(m)
2.3
4.8
9.8
19.8
29.7
Forward ASE power (dBm)
10
0
−10
−20
−30
5
10
15
20
Input pump power (dBm)

(a)


Backward ASE power (dBm)
10
0
−10
−20
−30
5
10
15
20
Input pump power (dBm)

(b)

Photo current

$$i_p \propto (E_s + E_n)^2$$

$$\propto E_s^2 + E_n^2 + 2 E_s \cdot E_n$$

E_s^2: Signal power

E_n^2: Noise power

$2 E_s \cdot E_n$: Beat signal (Mixing term)

$$(S/N)_{out} = \frac{R P_{sin}}{2qB} \frac{G}{1 + 2\eta n_{sp}(G-1)}$$

η: quantum eff

Noise Figure

$$F = \frac{(S/N)_{in}}{(S/N)_{out}} = \frac{1 + 2\eta n_{sp}(G-1)}{G}$$

$$\approx 2\eta n_{sp} \quad \text{for } G >> 1$$

Typical EDFA $n_{sp} \approx 2$

$F = 4$ (6 dB).