# PHY4311 ASSIGNMENT 11

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MARCH 23 2015

**Problem 1.** A short pulse amplifier has a gain of 20%/cm and a gain length of 10cm.

**(a)** Assuming an input fluence of $F_{in} = 1\text{mJ/cm}^2$ and a saturation fluence of $F_{sat} = 1\text{J/cm}^2$, determine the total output fluence of the amplifier.

The gain is $g_0 = 0.2\text{cm}^{-1}$ and the gain length is $z = 10\text{cm}$. The output fluence is given by

$$\begin{aligned} F_{out} &= F_{sat} \ln(1 + e^{g_0 z}[e^{F_{in}/F_{sat}} - 1]) \\ &= (1) \ln(1 + e^{(0.2*10)}[e^{1\times10^{-3}/1} - 1]) \\ &= 7\text{mJ/cm}^2 \end{aligned}$$

**(b)** If the input fluence was $F_{in} = 1\ \text{J/cm}^2$ what is the output fluence? $F_{in} = F_{sat}$.

$$\begin{aligned} F_{out} &= F_{sat} \ln(1 + e^{g_0 z}[e^{F_{in}/F_{sat}} - 1]) \\ &= (1) \ln(1 + e^{2}[e - 1]) \\ &= 2.6\text{J/cm}^2 \end{aligned}$$

**(c)** In Europe a 10 PetaWatt laser is being built with these values. If the pulse duration of the amplified pulse is 10 femtoseconds about how large an area will they need for an amplifier?

I assume that the output power is $P_{out} = 10\times10^{15}\text{W}$, $F_{out} = 2.6\text{J/cm}^2$, $F_{in} = 1\text{J/cm}^2$, and $F_{sat} = 1\text{J/cm}^2$. The amplified pulse duration is $\tau = 10 \times 10^{-15}\text{s}$.

The output intensity is related to the output fluence by

$$F_{out} = \int_{-\infty}^{\infty} I(t)dt = I_{out}\tau$$

Let $A$ denote the area the pulse covers after it emerges from the amplifier.

$$\begin{aligned} I_{out} &= \frac{P_{out}}{A} \\ A &= \frac{P_{out}}{I_{out}} = \frac{P_{out}\tau}{F_{out}} \\ &= \frac{(10 \times 10^{15})(10 \times 10^{-15})}{2.6} \\ &= 38.5\text{cm}^2 \end{aligned}$$

So I guess this means that since the output pulse will cover an area of $38.5\text{cm}^2$ after it leaves the amplifier, the amplifier should at least have a cross-sectional area of that much to be able to hold the pulse, otherwise the pulse will hit the edges of the amplifier and leave. Is that what was mean by the question how large an area will be needed? The gain length required for this pulse is already known.

**Problem 2.** The noise equivalent input is the effective input power due to spontaneous emission. For a Ti:Sapphire laser operating at 800nm, with a linewidth of 150nm and with a solid angle of 0.01str, what is the noise equivalent input?

The noise equivalent input is

$$\begin{aligned} I_{noise} &= \frac{hc^2\pi\Omega}{\lambda^5}\Delta\lambda \\ &= \frac{6.63\times10^{-34}(3\times10^8)^2\pi(0.01)}{(800\times10^{-9})^5}(150\times10^{-9}) \\ &= 8.6\times10^5\mathrm{W/m^2} = 86\mathrm{W/cm^2} \end{aligned}$$

**Problem 3.** Excimer lasers are important for lithography. The most important of these operates at 248nm.

**(a)** Assuming a bandwith of 1nm, what is the noise equivalent input? I'm gonna assume the solid angle is 0.01str again.

$$\begin{aligned} I_{noise} &= \frac{hc^2\pi\Omega}{\lambda^5}\Delta\lambda \\ &= \frac{6.63\times10^{-34}(3\times10^8)^2\pi(0.01)}{(248\times10^{-9})^5}(1\times10^{-9}) \\ &= 2.0\times10^6\mathrm{W/m^2} = 2.0\times10^2\mathrm{W/cm^2} \end{aligned}$$

**(b)** An X-ray laser operates at 10nm and has a bandwidth of 0.1nm. With the same solid angle what is the noise equivalent input?

$$\begin{aligned} I_{noise} &= \frac{hc^2\pi\Omega}{\lambda^5}\Delta\lambda \\ &= \frac{6.63\times10^{-34}(3\times10^8)^2\pi(0.01)}{(10\times10^{-9})^5}(0.1\times10^{-9}) \\ &= 1.87\times10^{12}\mathrm{W/m^2} = 1.87\times10^8\mathrm{W/cm^2} \end{aligned}$$