Introduction to Lasers (520.482)
Solution to Homework 5

Go back to the HW4 and now model the Q-switched pulse. Consider this to be a Nd:YAG laser with rod that is 5 mm long and 1mm in diameter. The total cavity length is 4cm. The material parameters are given in Lecture 5. Assume the intrinsic absorption/scattering losses of the order $\alpha \sim 0.1 cm^{-1}$. The laser is pumped at 880nm and emits at 1060nm. Pumping efficiency (percent of the power actually absorbed by the Nd atoms is η_{pump} ~50%.)

Choose the mirror reflectivity at will. Then find the cavity lifetime. Your pump pulse is as before super-gaussian and you shall try different pulse lengths, pump pulse energies, and also try different times of Q-switch opening relative to the pump pulse. Assume some residual absorption for the Q-switch in the open state.

Do not forget to reduce the step of your integration routine once the lasing starts.

With all that show how the Q-switch pulse varies as you change all the above parameters.

Numbers for Nd:YAG

$$N \sim 1.4\times10^{20} cm^{-3};\;\; \sigma_{21} \sim 3\times10^{-19} cm^2;\;\; \tau_2 \sim 300\mu s;$$
$$\lambda_{pump} \sim 880nm;\;\; \eta_{pump} \sim 0.5$$

Refractive index of the rod: $n_r = 1.82$

Residual absorption of the rod: $\alpha_r = 0.1cm^{-1}$

Refractive index of the shutter: $n_s = 2.7$

Absorption of the shutter when close: $\alpha_s = 5cm^{-1}$

Choose the mirror reflectivity: $R_1 = 1, R_2 = 0.95$

Use Mathematica to solve the following equations:

Q-close state (IC: population inversion = photon density = 0 at T = 0)

Assume: $\tau_{pc} = \dfrac{2(nL)}{c(\ln\dfrac{1}{R_1R_2} + 2\alpha L)} = 1.83x10^{-11}\text{s}$

$$\frac{dn_2}{dt} = \frac{1}{\tau_2}(p - n_2 - n_2 p)$$

$$\frac{dn_p}{dt} = \frac{n_p}{\tau_{pc}}(n_2 - 1) + \beta_{sp}\frac{n_2}{\tau_2}$$

Q-open state

$$\tau_{po} = \frac{2nL}{c(\ln\dfrac{1}{R_1R_2} + 2\alpha L)} = 4.2x10^{-9}\text{s}$$

$$\frac{d\Delta n_{21}}{dt} = -2\tau_2^{-1}\Delta n_{21} n_p$$

$$\frac{dn_p}{dt} = \frac{n_p}{\tau_{po}}\left(\Delta n_{21} - 1\right)$$

Normalized unit:

Threshold population inversion: $N_t = \left(\sigma_{21} v_g \tau_p\right)^{-1}$; $\Delta n_{21} = \Delta N_{21} / N_t$

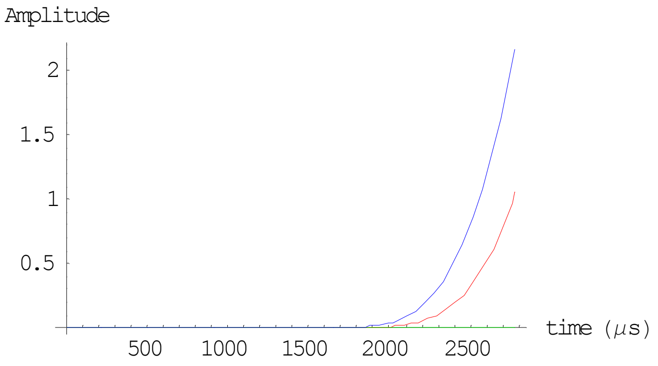
Saturation density of photons: $N_{p,sat} = \left(\sigma_{21} v_g \tau_2\right)^{-1}$; $n_p = N_p / N_{p,sat}$

Conclusions from the graphs:
(Blue: Pump function, Red: Population Inversion, Green: Photon density)

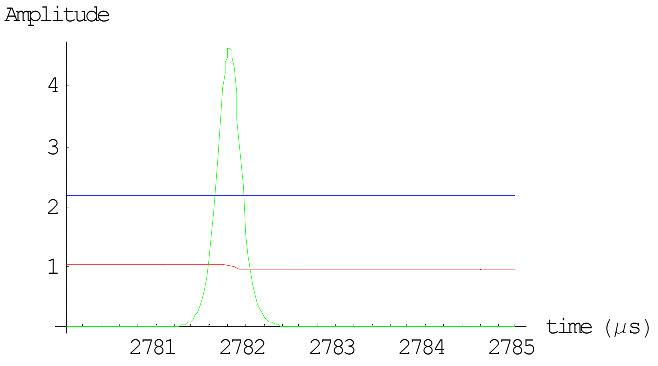
Graph 0: We see the lasing after the Q-switch opens because the population inversion is sufficiently high when the gate opens.

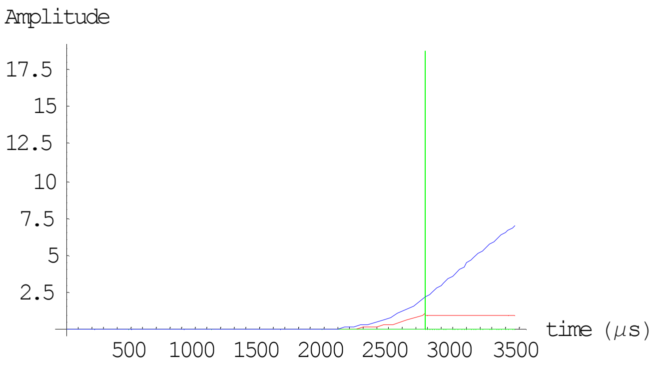
0) P0=10, Pulse length=3000, t_{open}=2780

Before Q-switch



After Q-switch



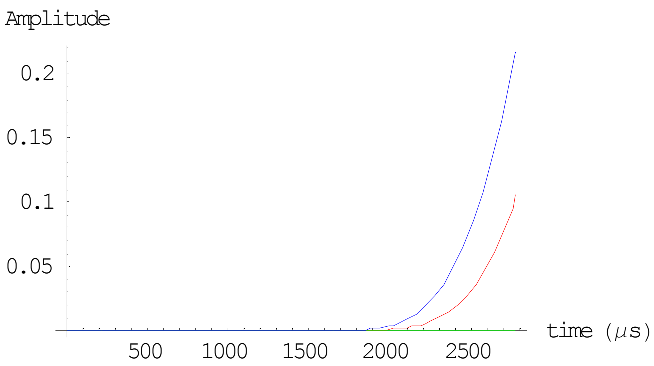


Overall

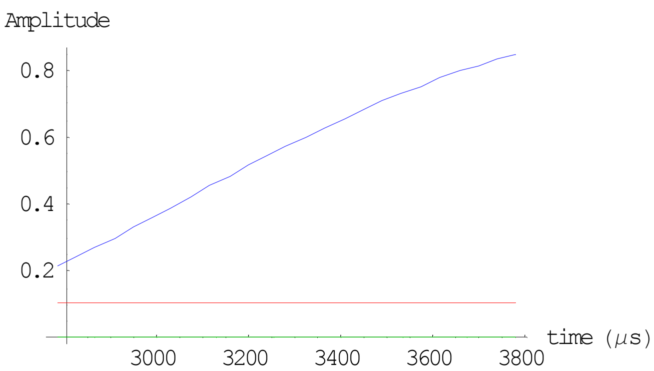
Graph 1-3: The Q-switch photon density can be seen as we increase the peak power.

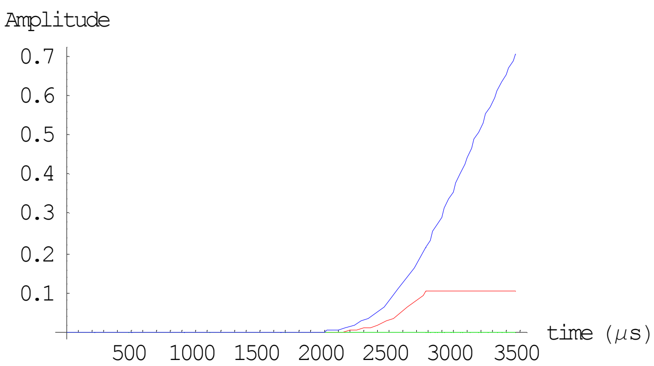
1) P0=1, Pulse length=3000, t_{open}=2780

Before Q-switch



After Q-switch

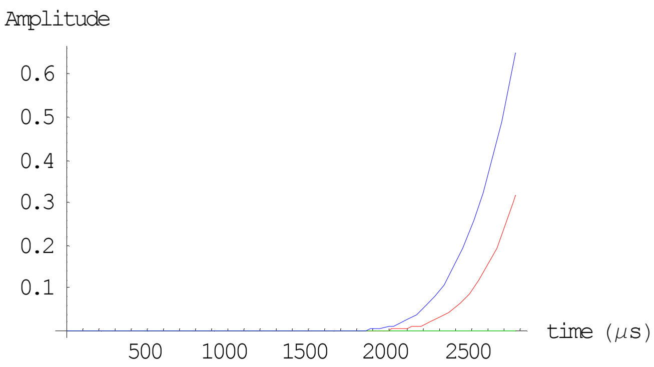




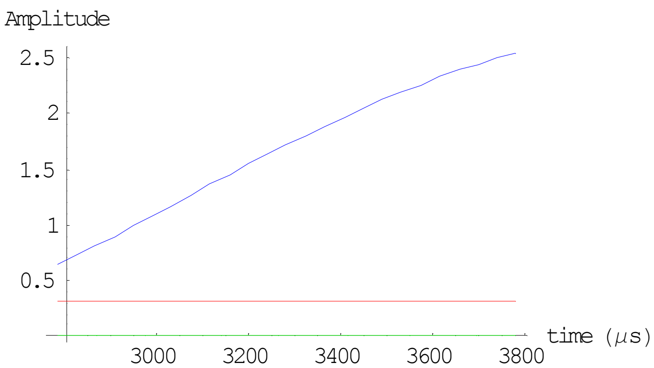
Overall

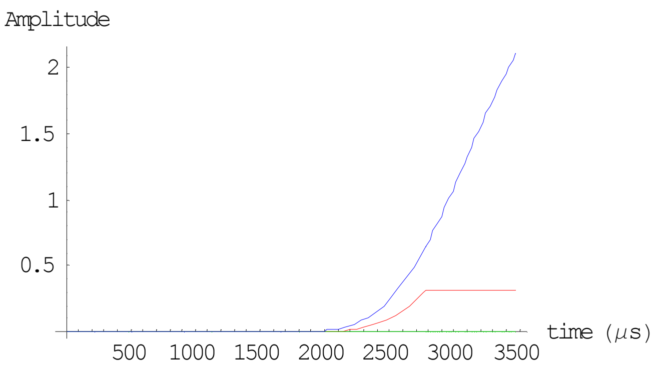
2) P0=3, Pulse length=3000, t_{open}=2780

Before Q-switch



After Q-switch

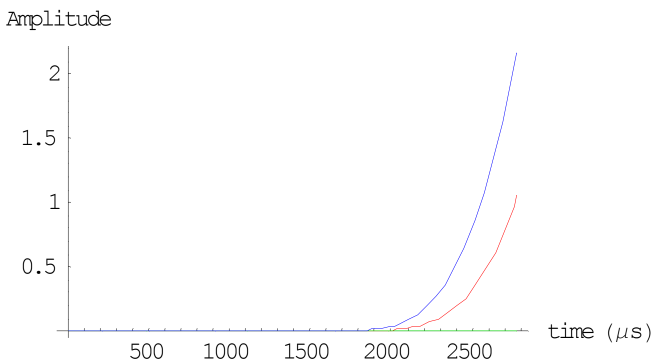




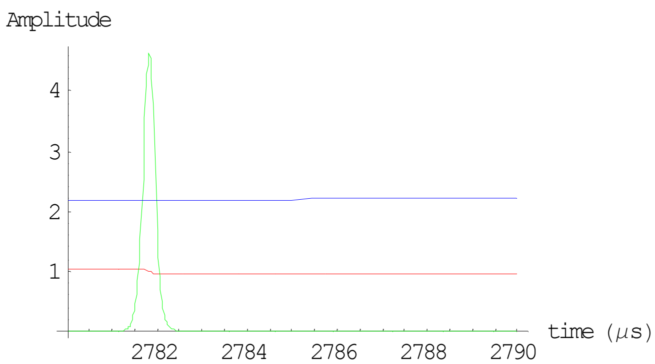
Overall

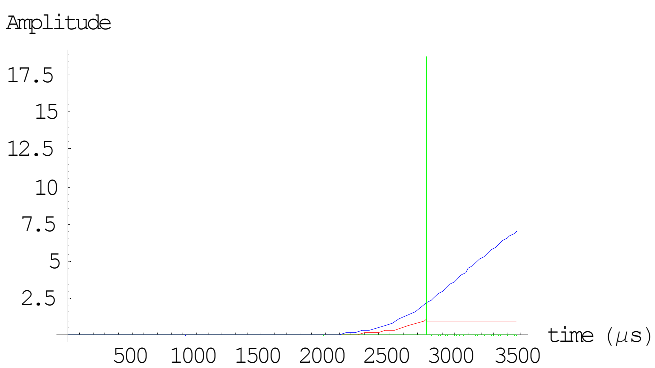
3) P0=10, Pulse length=3000, t_{open}=2780

Before Q-switch



After Q-switch



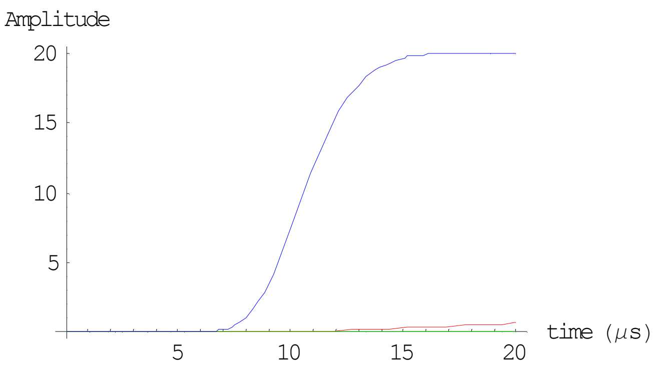


Overall

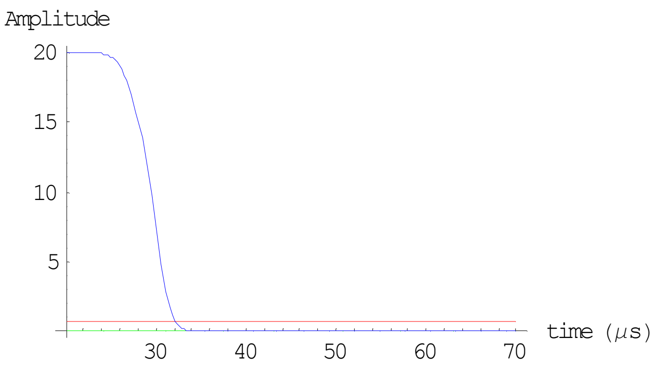
Graph 4-5: If we use a very short pulse, it provides very low energy to achieve sufficient population inversion. If we use very high pump power and open the switch very late, the lasing will occur before we open the switch. i.e. Q-switch won't work.

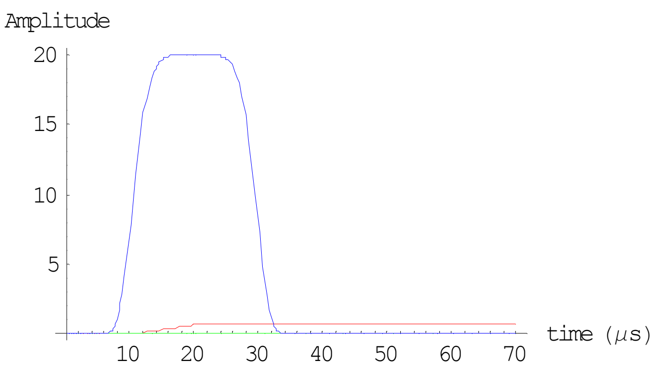
4) P0=20, Pulse length=10, t_{open}=20

Before Q-switch



After Q-switch

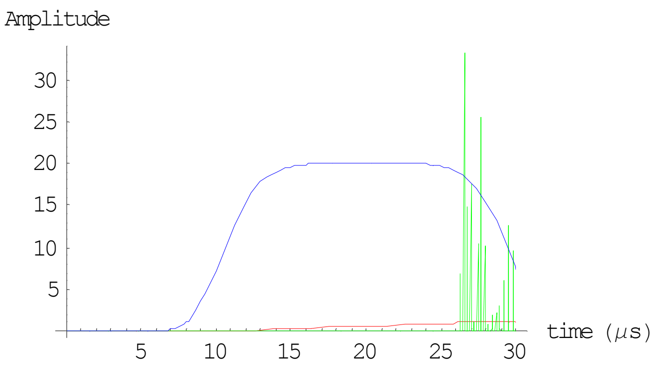




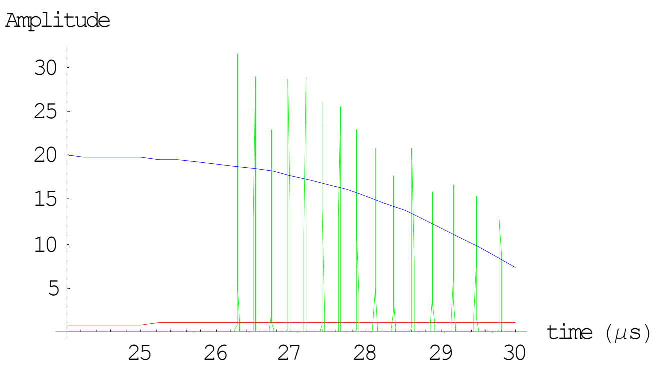
Overall

5) P0=20, Pulse length=10, t_{open}=30

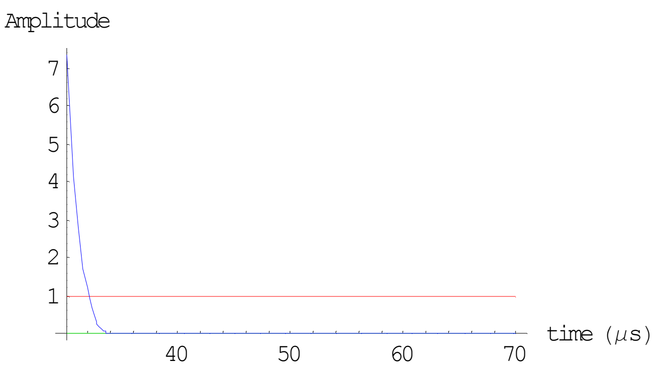
Before Q-switch

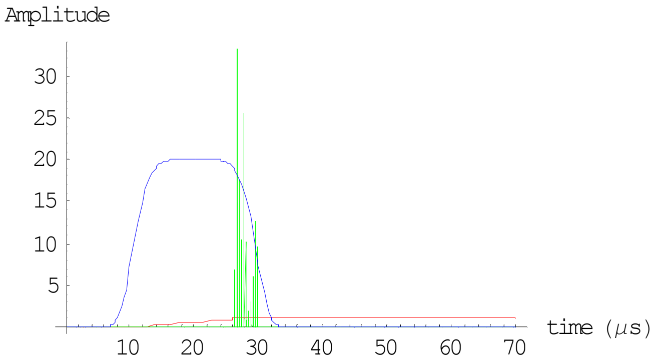


Zoom-in



After Q-switch



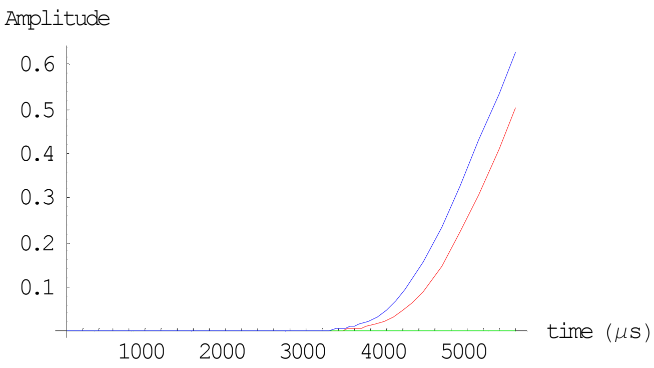


Overall

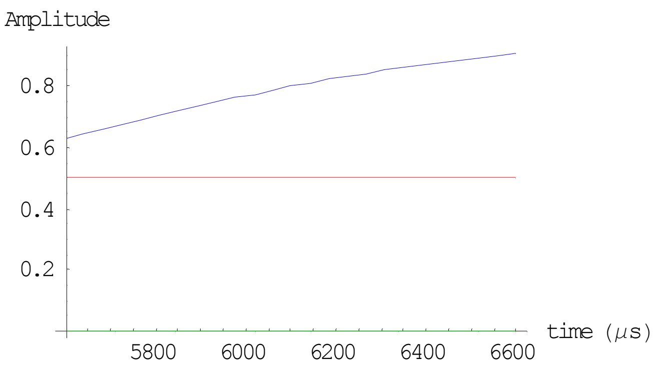
Graph 6-7 : If we use a long duration pulse, sufficient population inversion is achieved even at lower pump power. And the lasing would occur before the Q-switch opens.

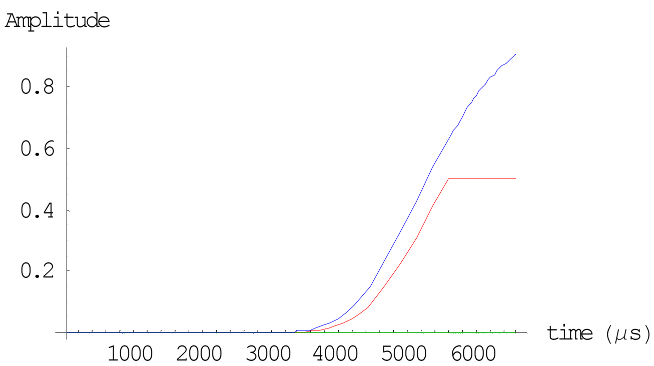
6) P0=1, Pulse length=5000, t_{open}=5600

Before Q-switch



After Q-switch

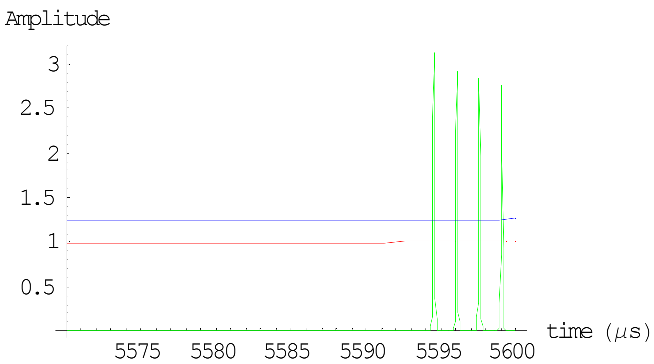




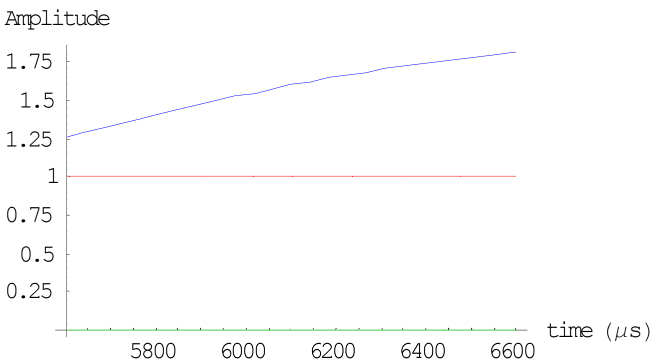
Overall

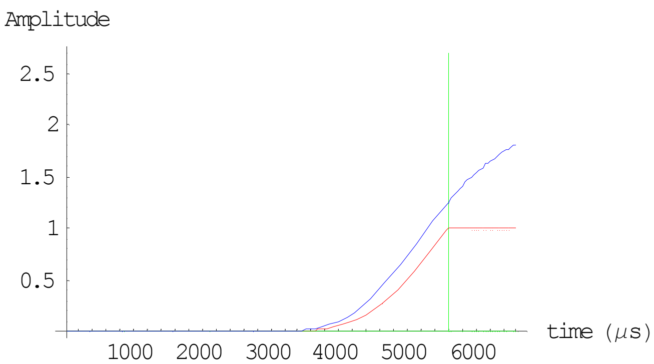
7) P0=2, Pulse length=5000, t_{open}=5600

Before Q-switch



After Q-switch





Overall

Conclusions:

In order to get the Q-switch lasing, pumping length should be long enough. If the pump duration is too short, we cannot achieve population inversion after open the gate. If the pump duration is too long, population inversion is easily achieved (even for Q-closed state), so we need to open the gate early to prevent lasing before Q-switch opens. For better Q-switch lasing, the time to open the gate must be at the maximum of population inversion. When we increase the pump power, the photon output would also be increased.