DFC-PowerChip高出力極限固体レーザの開発

Design calculations for 2J system

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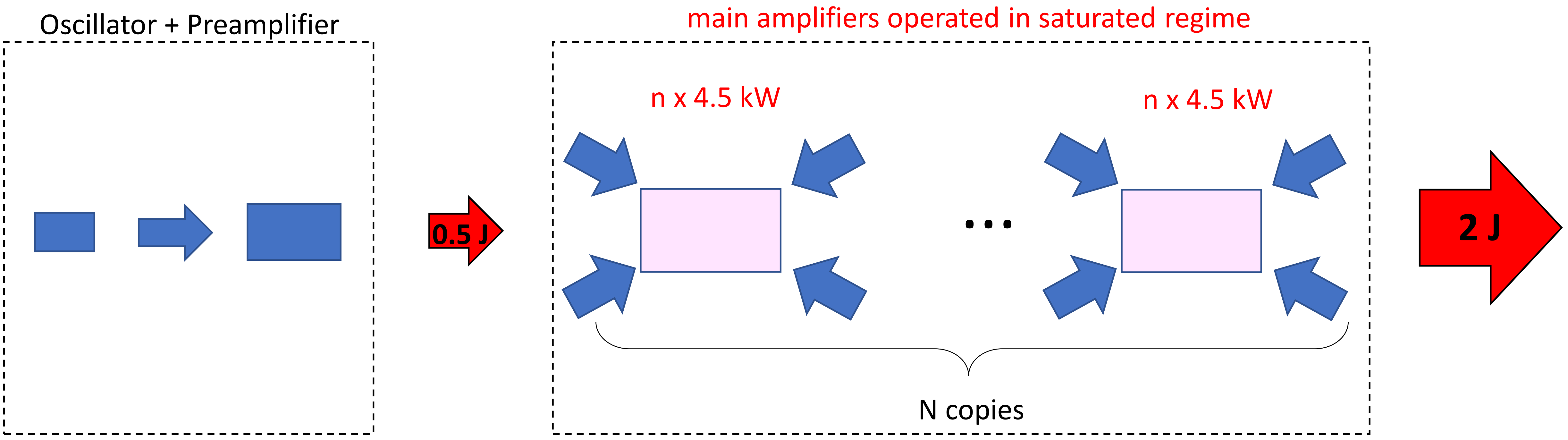
1. Introduction

In todays presentation, I will focus on the amplifier part of the 2J-MOPA laser and pump power scaling :



The model reduces the N identical amplifiers to 1 single amplifier with variable input energy (corresponding to the output of the preceding stages).

2. Reminder about the calculation model

Input beam	Pump beam	Crystal
Input energy range : E_{in} = E_{min} to E_{max}	Pump power for 1 module P_p	Gain medium length l_c
	Pulse duration t_p	Doping concentration C
	Wavelength λ_p : 808nm or 885nm	Temperature T
Beam half width : w_b Beam shape : ➢ top hat square ➢ top hat round ➢ Gaussian	Beam half width : w_p Beam shape : ➢ top hat square ➢ top hat round ➢ Gaussian	Fixed values (Nd:YAG) Absorption cross section $\sigma_{abs}(\lambda)$ Emission cross section $\sigma_{em}(T)$ Concentration quenching parameter C_0 Fluorescence time t_0 for C=0 Absorption saturation factor B
Fixed value Wavelength λ_b fixed at 1064nm	Pump geometry : ➢ number of modules ➢ position : front or back	

Input beam fluence distribution

absorption

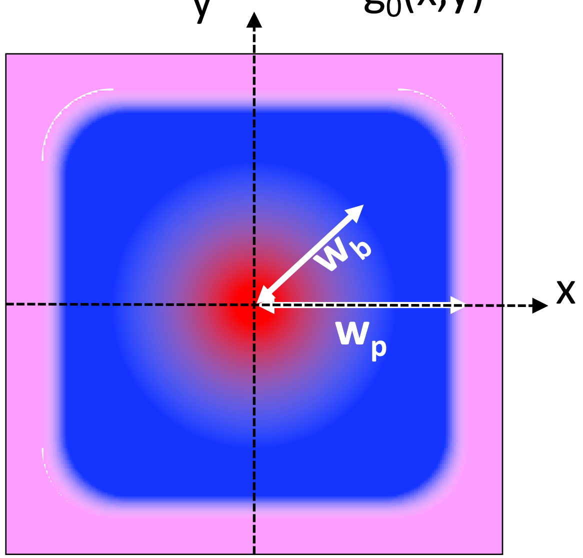
gain

2. Reminder about the calculation model

Gain distribution calculation

- calculation of absorbed intensity at each position x,y,z (including pump saturation effects)
- small signal gain is calculated for each position x,y,z from absorbed intensity
- small signal gain is integrated over crystal length to get $g_0(x,y)$

$F_{in}(x,y)$
$g_0(x,y)$



Frantz-Nodvik (x,y)

$$F_{out}(x,y) = F_S ln \left\{ 1 + \frac{\left[e^{F_{in}(x,y)/F_S} - 1 \right] e^{F_{in}(x,y)/F_S} e^{2g_0 l}}{1 + \left[e^{F_{in}(x,y)/F_S} - 1 \right] e^{g_0 l}} \right\}$$

output profile $F_{out}(x,y)$

$$E_{out} = \iint_S F_{out}(x,y)dxdy$$

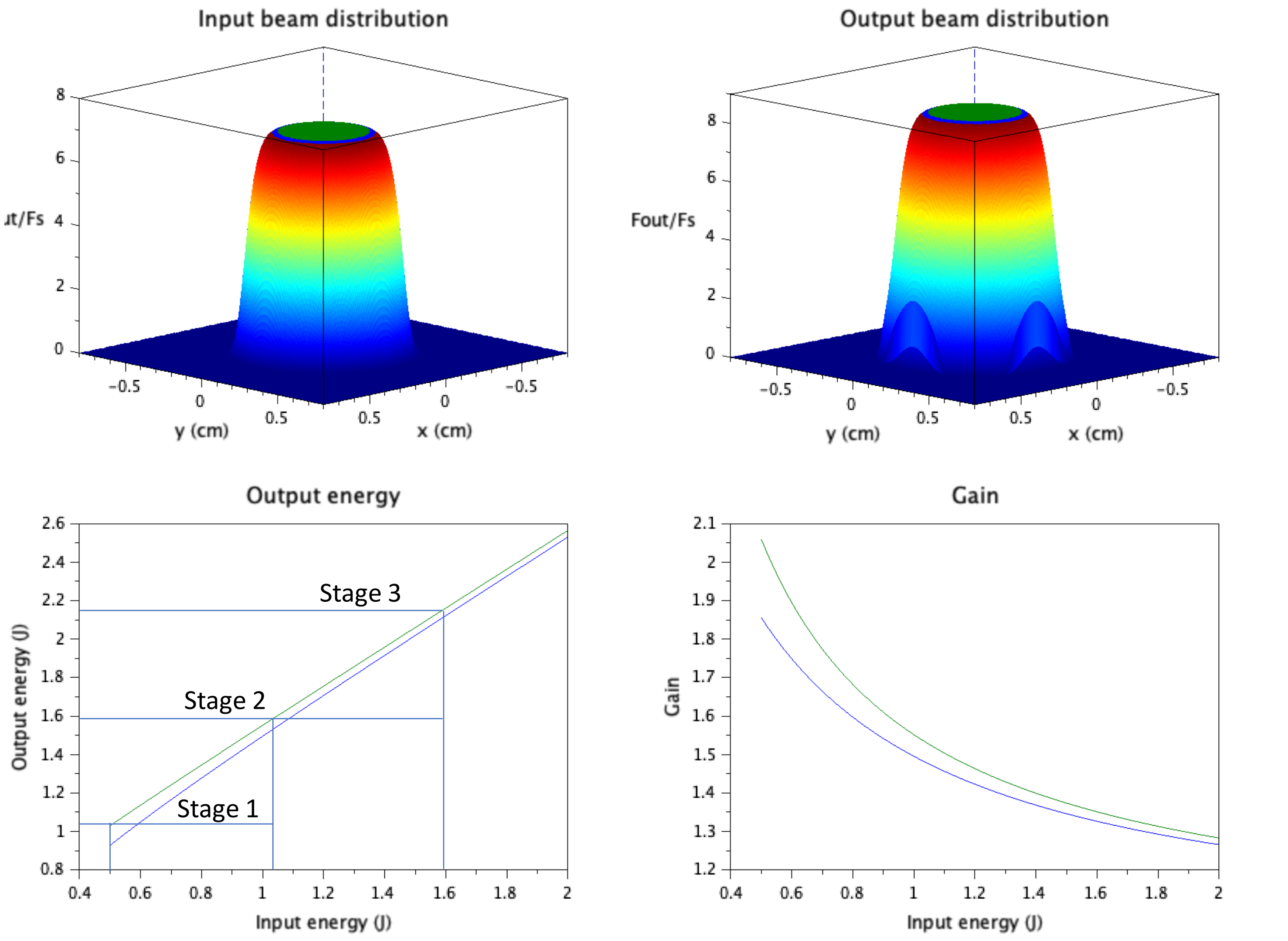
2. Reminder about the calculation model

One example of the model output with :

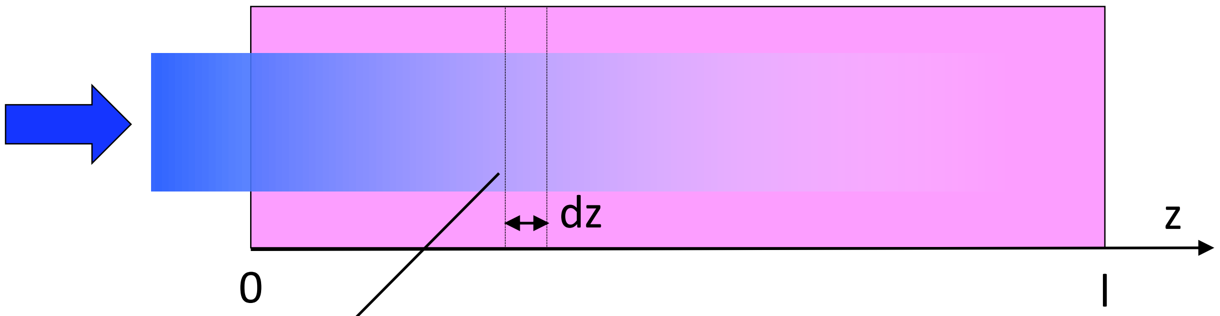
0.5J supergaussian input beam
2 modules of 4.5kW/stage

2J output requires 3 amplification stages for these pumping condition.

However, the efficiency is overestimated : KEK experiment show that absorption is lower than in calculations.



3. Pump absorption and limits of the current model



- simple treatment

$$dI_{abs}\left(r,z\right)=\alpha_0 I_p(r,z)dz$$

- for high power pump : absorption saturation

$$\alpha=\frac{\alpha_0}{1+\eta_q\frac{I_p}{I_p^S}} \qquad I_p^S=\frac{h\nu_p}{\sigma_{abs}\tau_f}$$

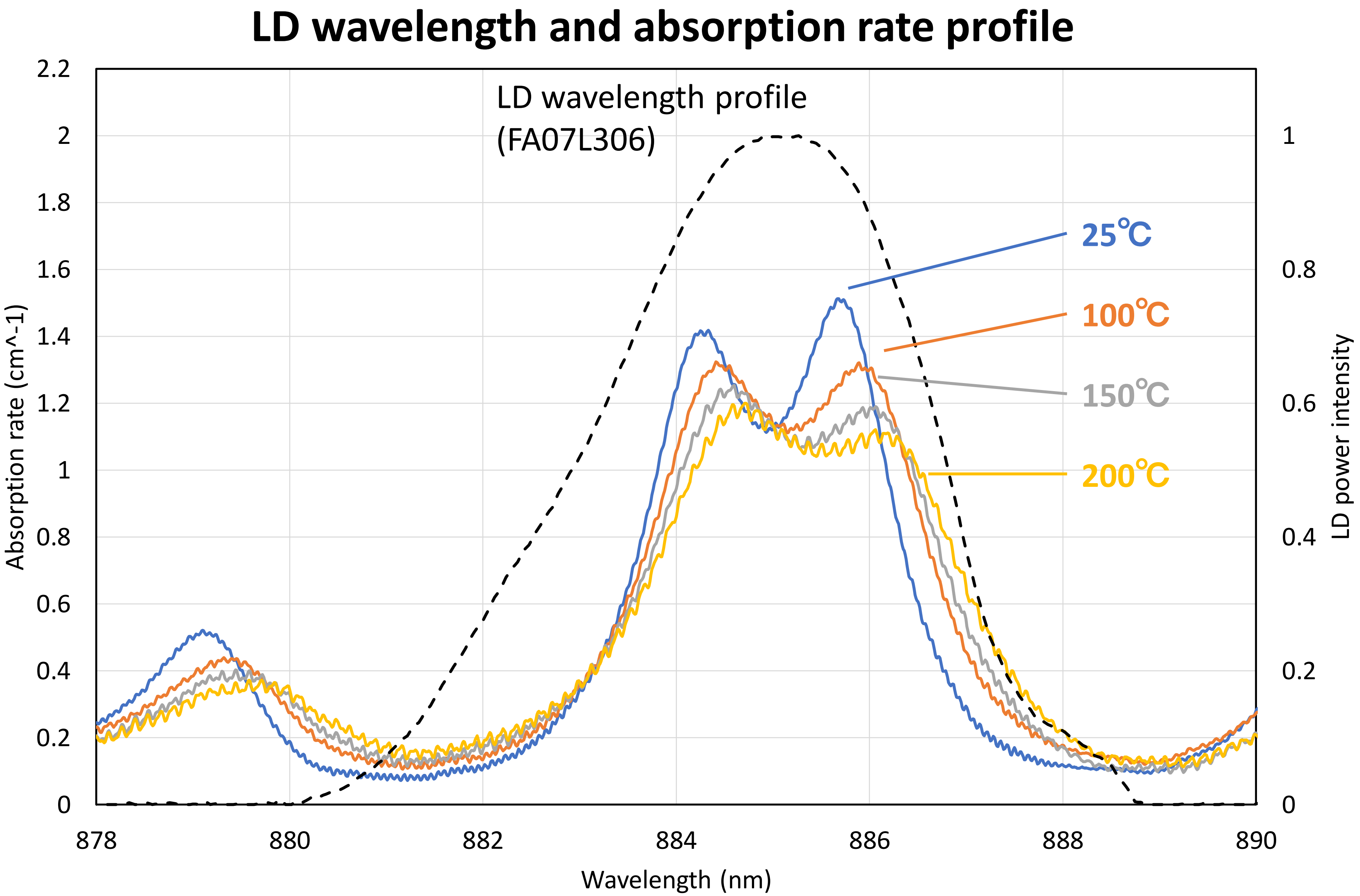
Y. Sato and T. Taira, "Saturation Factors of Pump Absorption in Solid-State Lasers", IEEE J. Quantum Electron **40**, 3 (2004)

$$\overline{dI_{abs}}(r,z)=\alpha_0\frac{\overline{I}(r,z)}{1+\eta_q\overline{I}(r,z)}dz$$

$$\overline{I_p}(r,z)=\overline{I_p}(r,0)-\alpha_0\int_0^z\frac{\overline{I_p}(r,z')}{1+\eta_q\overline{I_p}(r,z')}dz'$$

Problem :

Does not take into account the wavelength dependence of the absorption coefficient
Does not take into account the spectral width of the pump

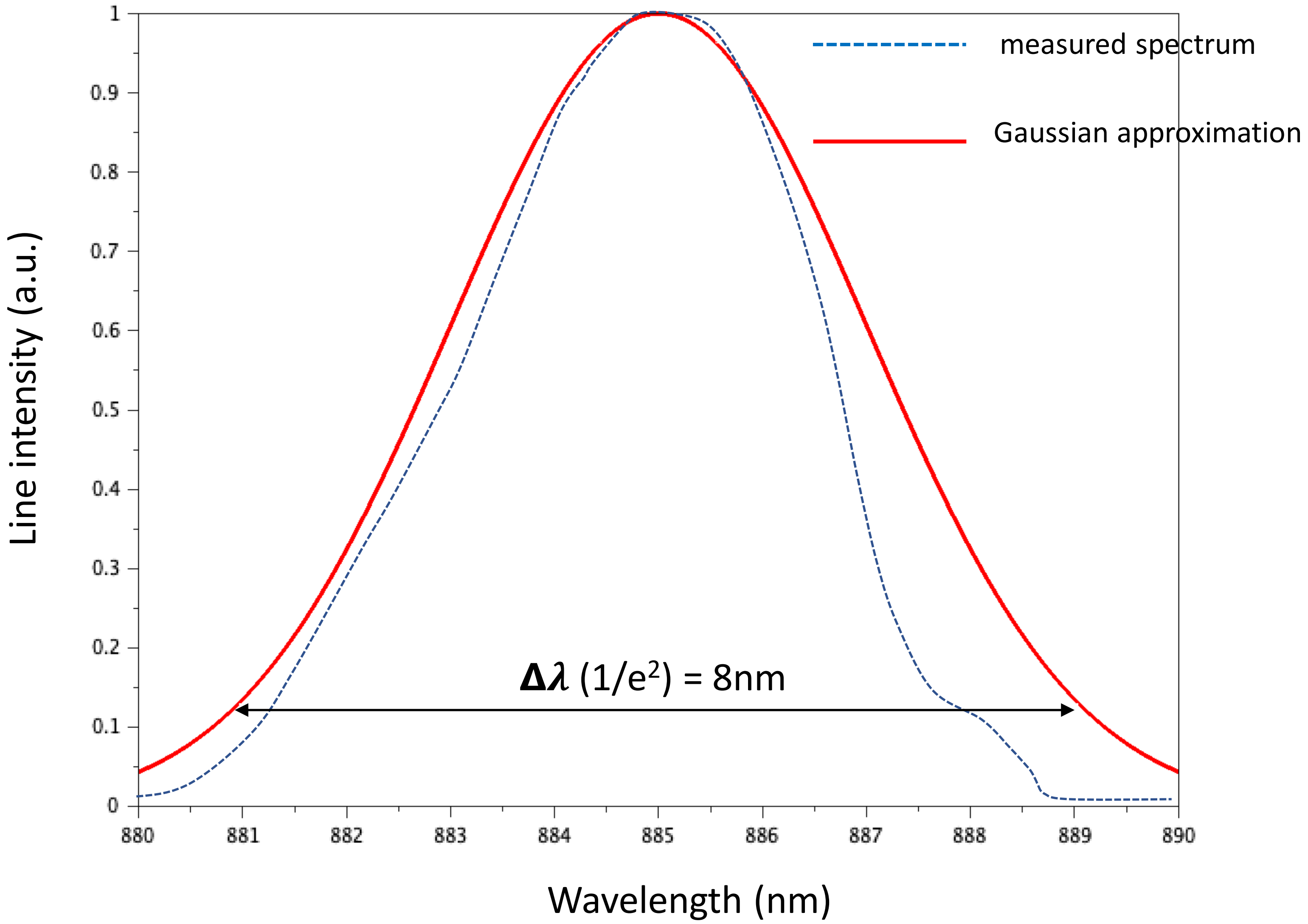


※Absorption rate data are measured by Sato.

5. Evaluation of the effect of LD spectrum on absorption

For first evaluation, a Gaussian profile is used for the pump spectrum.

$$I^{\lambda_0,\Delta\lambda}_{spectral}(\lambda) = exp\left[-2\left(\frac{\lambda-\lambda_0}{\Delta\lambda/2}\right)^2\right]$$



In future, the real shape will be used.

5. Evaluation of the effect of LD spectrum on absorption

Absorption spectrum uses the data of bellow article :

V. Lupei et al., Laser emission under resonant pump in the emitting level of concentrated Nd:YAG ceramics, Appl. Phys. Lett. ***79****, 590 (2001)*

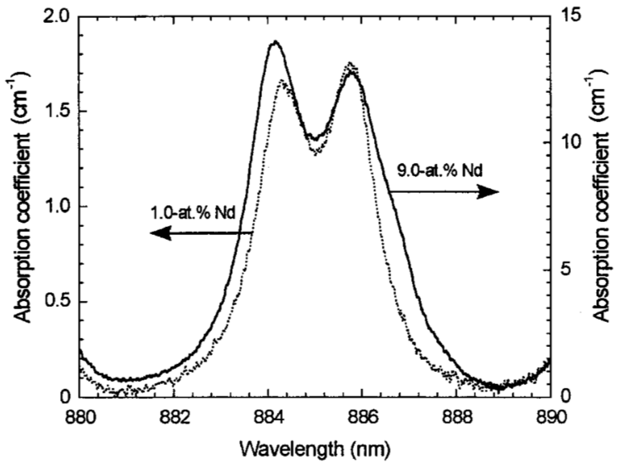
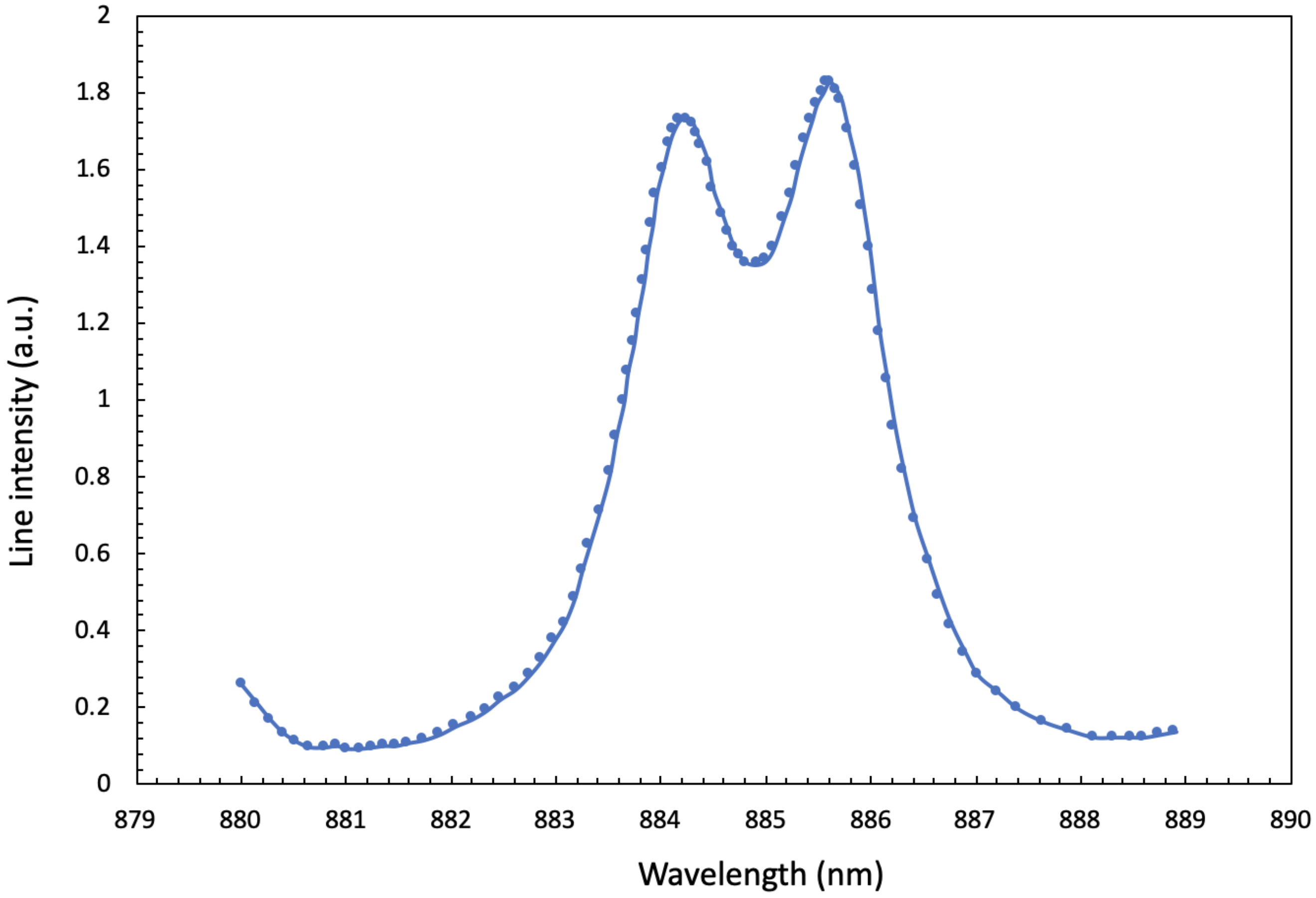


FIG. 1. The absorption profile of Nd:YAG ceramics (1.0 and 9.0 at.% doping) at room temperature around 885 nm is shown.

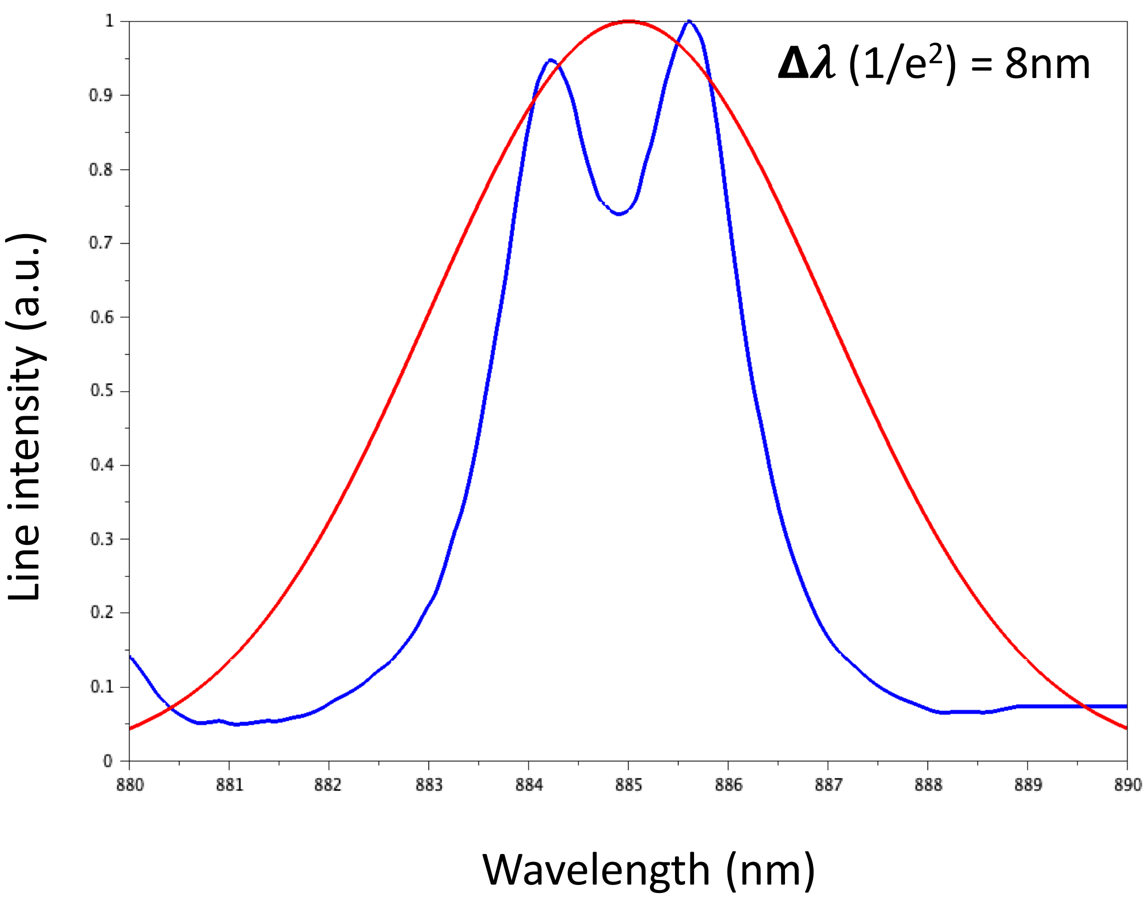


In future, I will use the new data with temperature dependence.

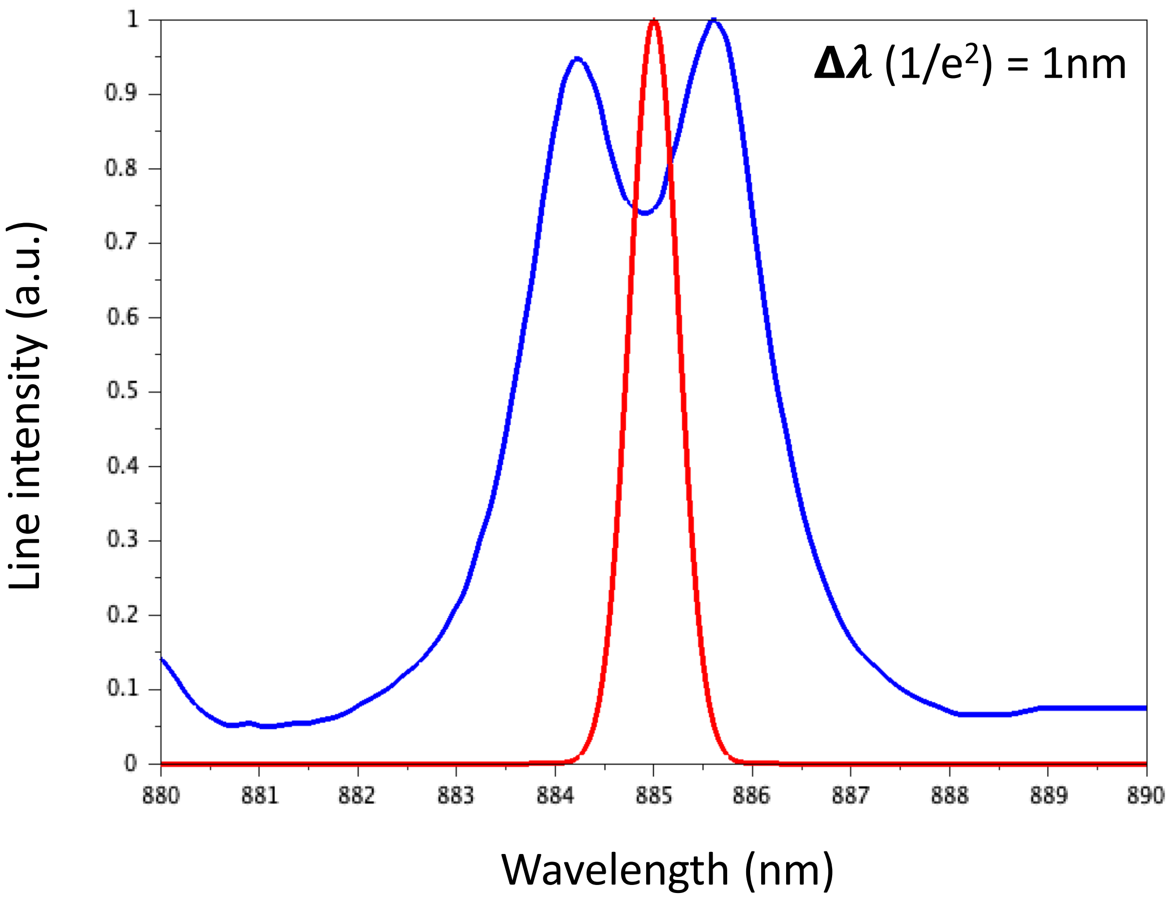
5. Evaluation of the effect of LD spectrum on absorption

To assess the effect of the spectrum, I evaluated the following cases :

Near real case



Near ideal case



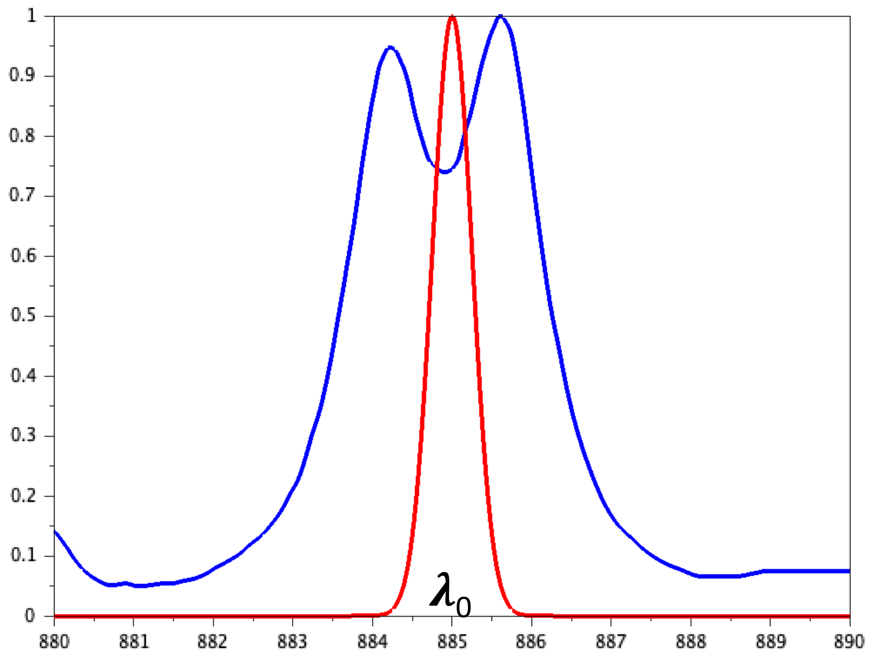
5. Evaluation of the effect of LD spectrum on absorption

LD spectral intensity at λ

absorption efficiency at λ

$$\eta_{abs}(\lambda_0) = \frac{\int_{\lambda_{min}}^{\lambda_{max}} I_{spectral}^{\lambda_0,\Delta\lambda}(\lambda)\{1 - exp[-\alpha(\lambda)\, l_c]\}\, d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} I_{spectral}^{\lambda_0,\Delta\lambda}(\lambda)\, d\lambda}$$

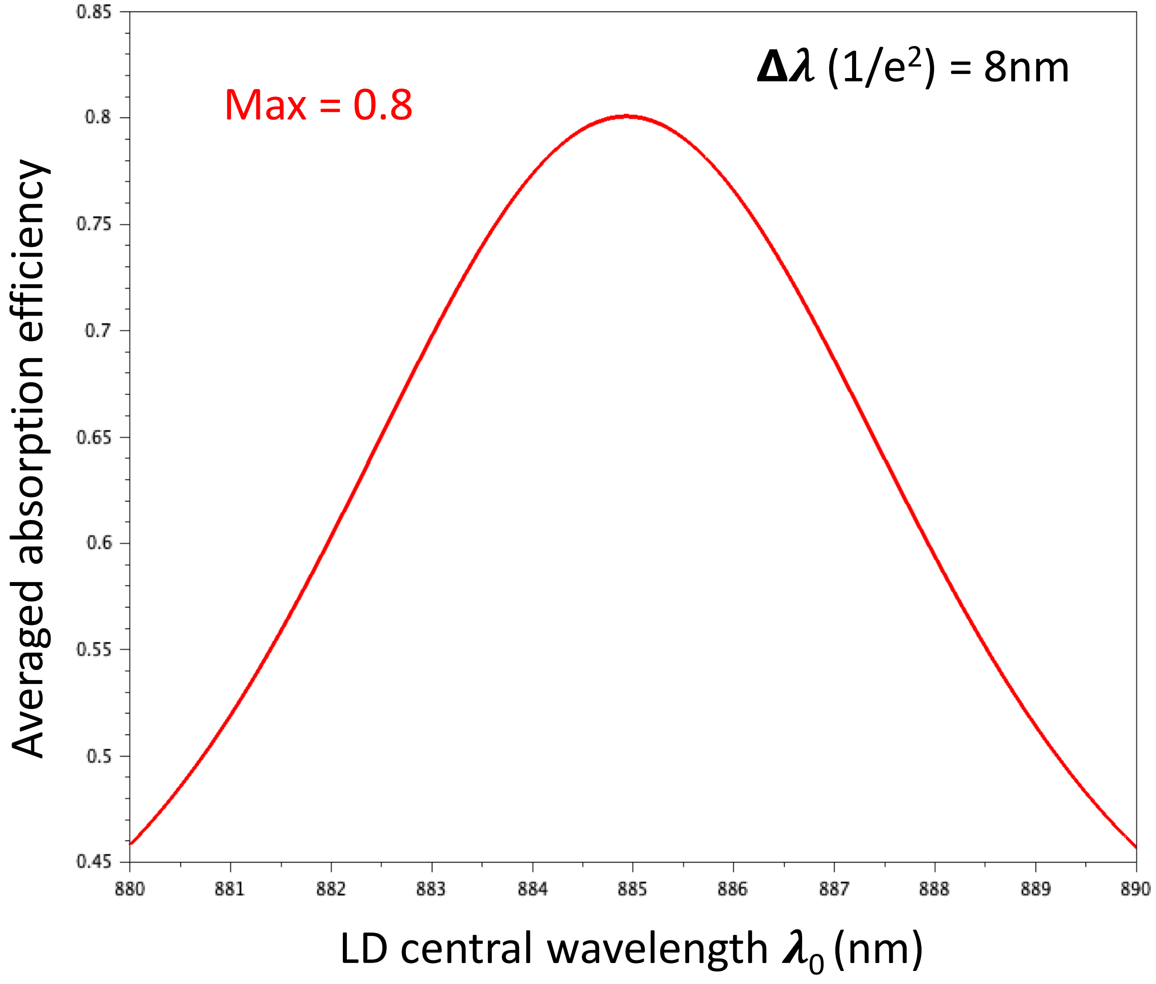
Absorption efficiency averaged over wavelength with LD spectrum centered on λ_0

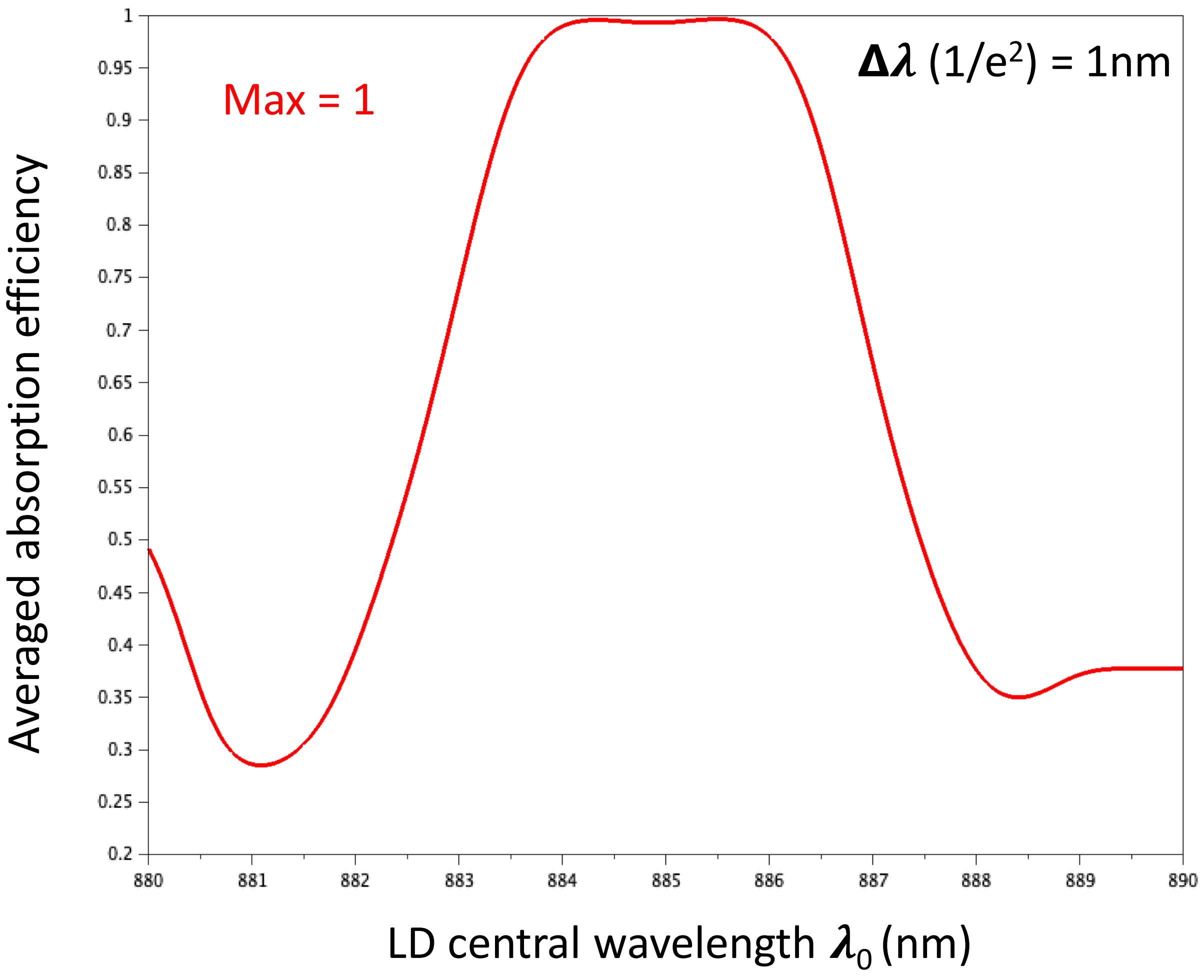


5. Evaluation of the effect of LD spectrum on absorption

$$\eta_{abs}\left(\lambda_0\right)=\frac{\int_{\lambda_{min}}^{\lambda_{max}} I_{spectral}^{\lambda_0,\Delta\lambda}\left(\lambda\right)\left\{1-exp\left[-\alpha\left(\lambda\right)l_c\right]\right\}d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} I_{spectral}^{\lambda_0,\Delta\lambda}\left(\lambda\right)d\lambda}$$

In this case, gain length is 35mm

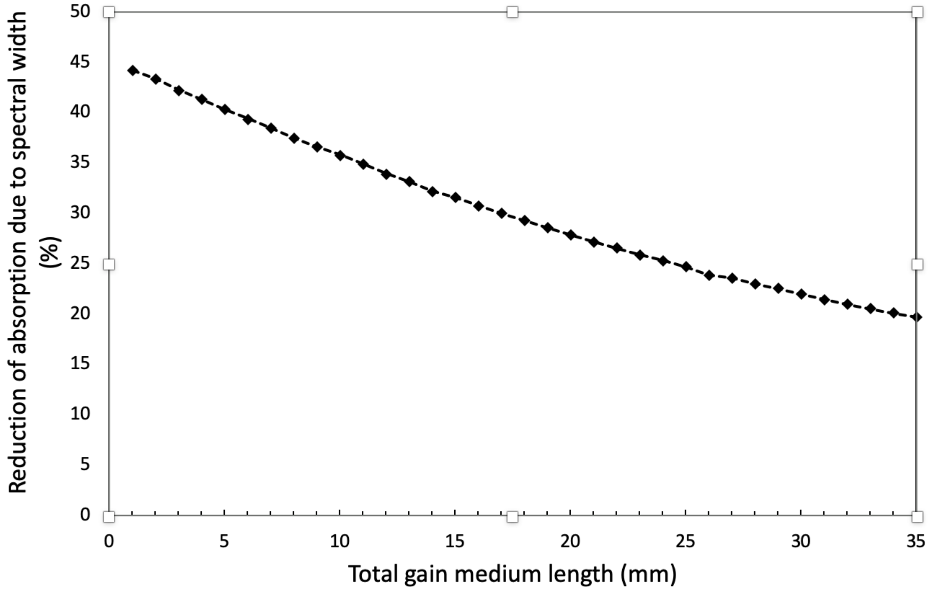


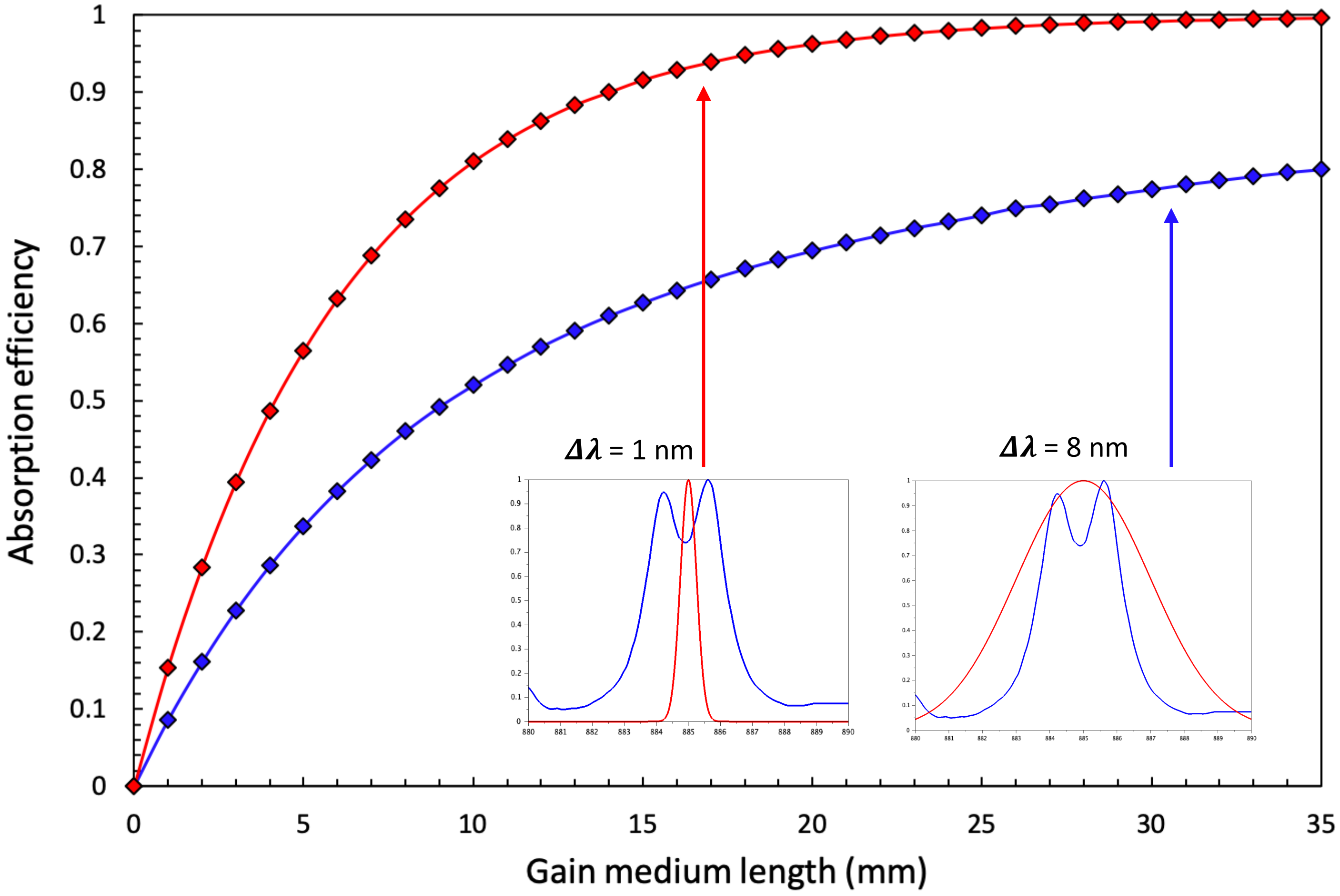


5. Evaluation of the effect of LD spectrum on absorption

Effect of gain medium length on total absorption for narrow and wide LD spectrum :

The reduction effect is substantial especially for shorter gain length : -35% for 1cm crystal !





6. Modified amplification calculations

Input beam	Pump beam	Crystal
Input energy range : E_{in} = E_{min} to E_{max}	Pump power for 1 module P_p	Gain medium length l_c
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Fixed value Wavelength λ_b fixed at 1064nm	Pump geometry : ➢ number of modules ➢ position : front or back	

Input beam fluence distribution

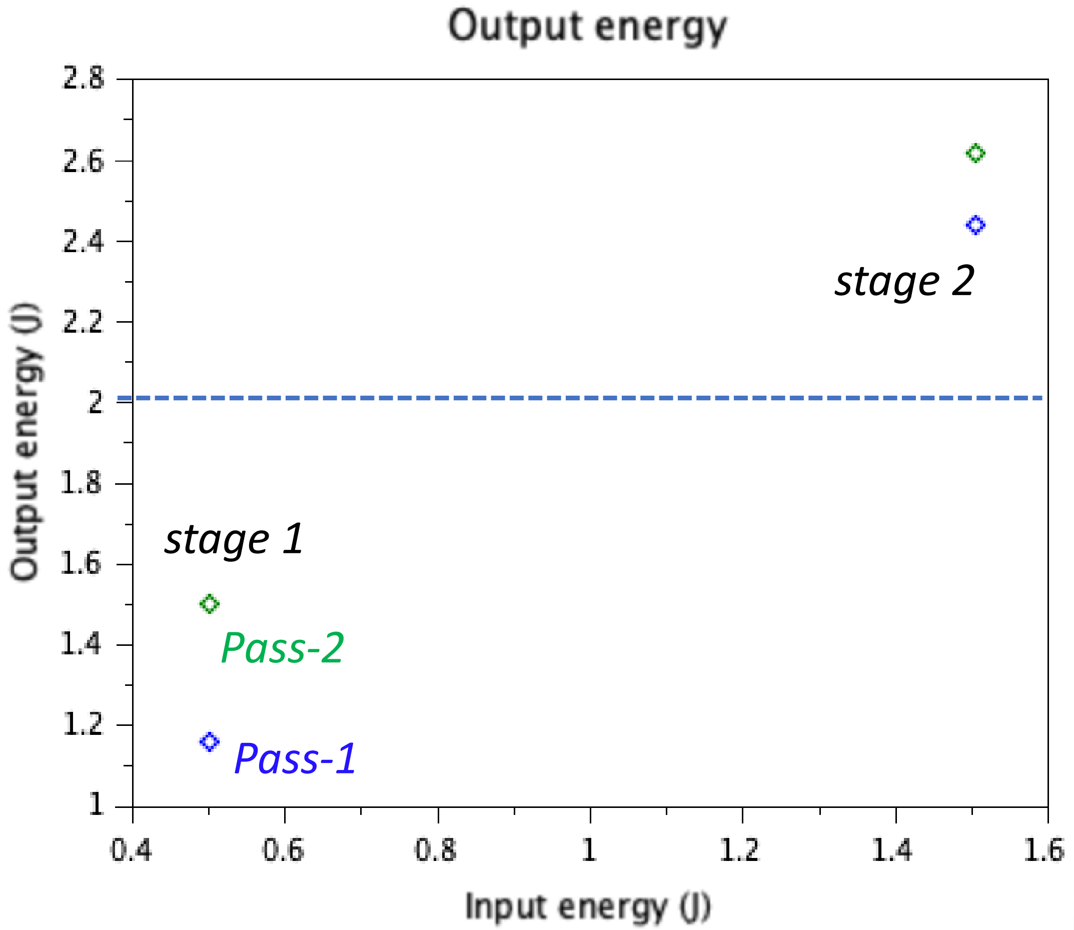
absorption

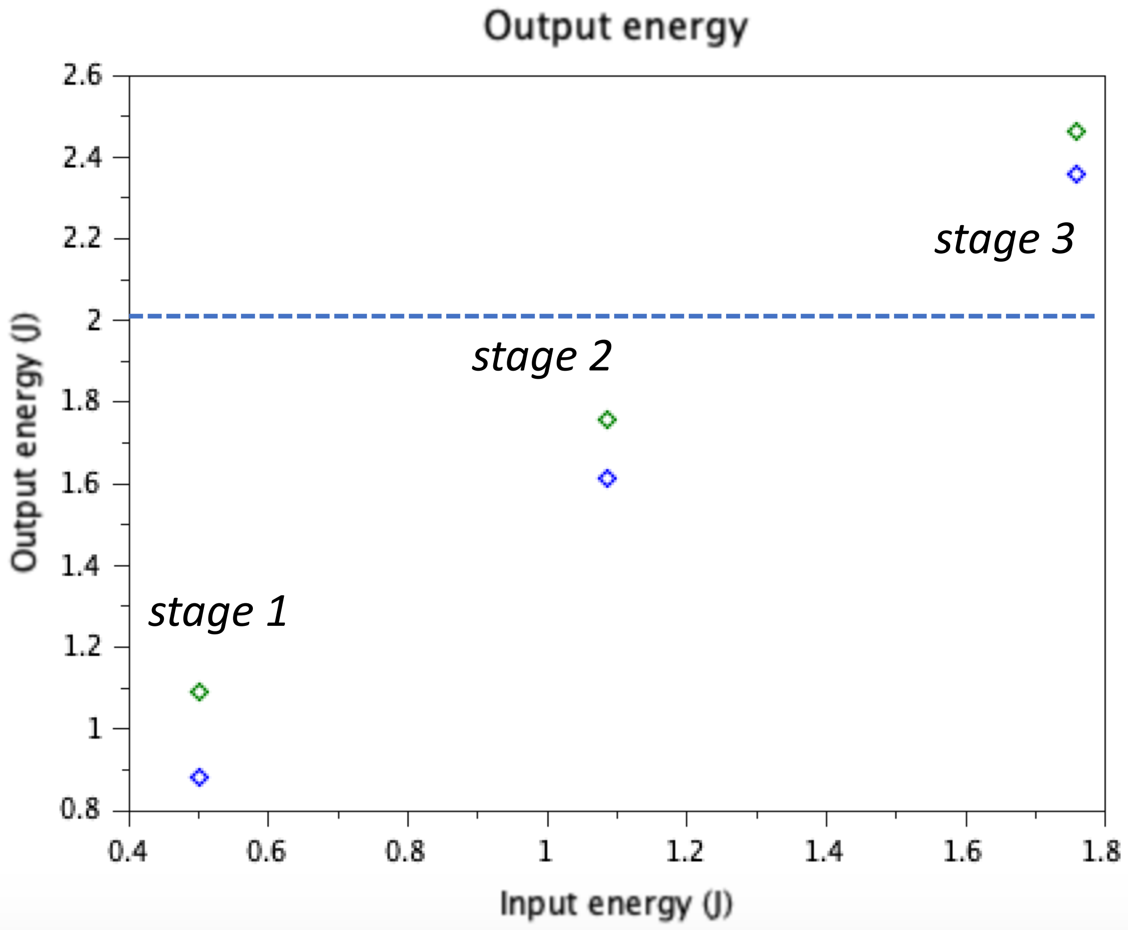
gain

Short cut
With “effective absorption”

6. Modified amplification calculations

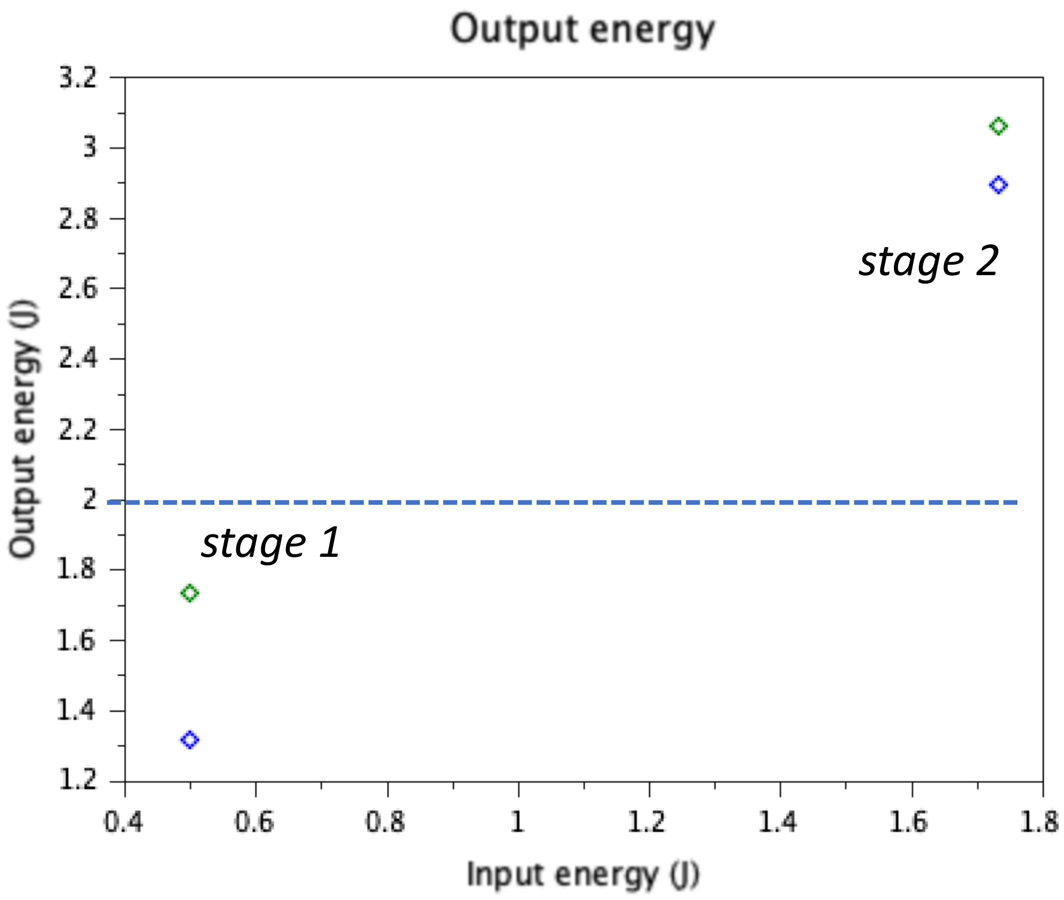
LD power	4 x 4.5kW	4 x 4.5kW
Gain length	10mm	10mm
Spectral width	1nm	8nm

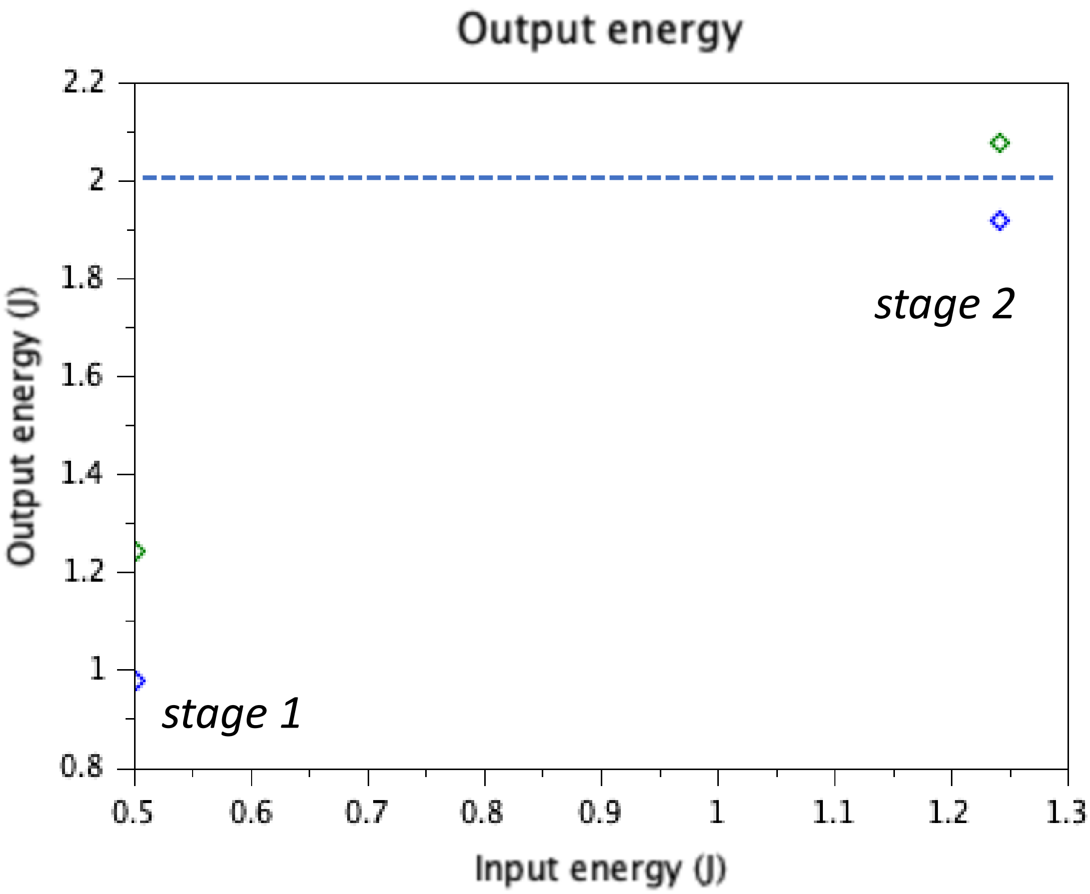




6. Modified amplification calculations

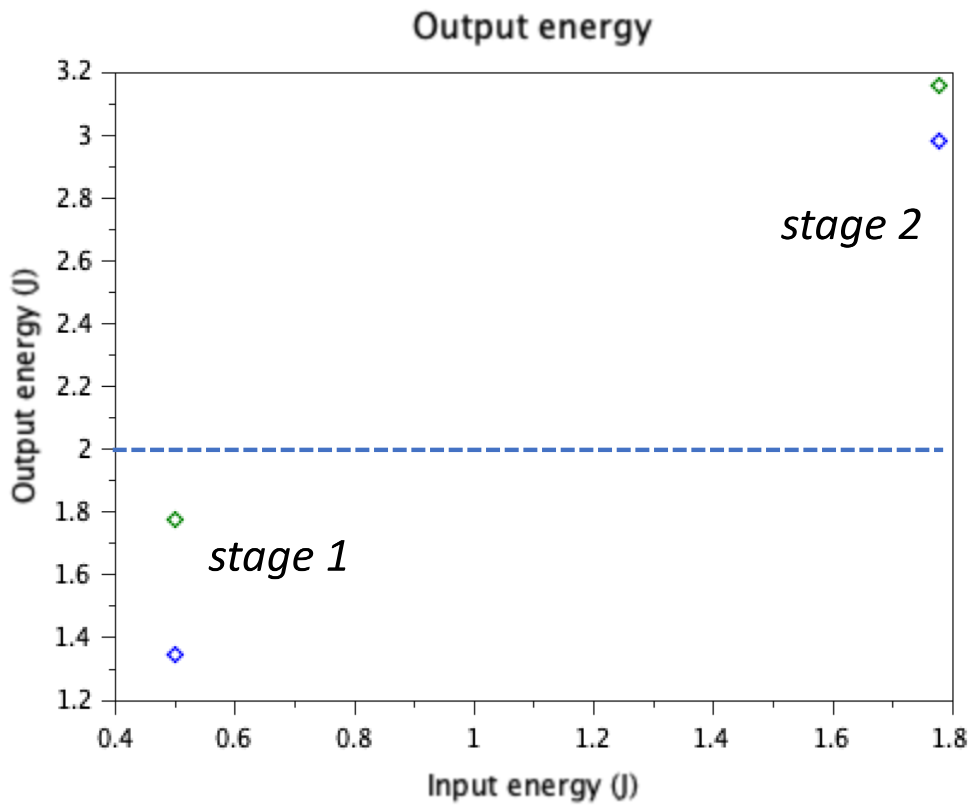
LD power	4 x 4.5kW	4 x 4.5kW
Gain length	20mm	20mm
Spectral width	1nm	8nm

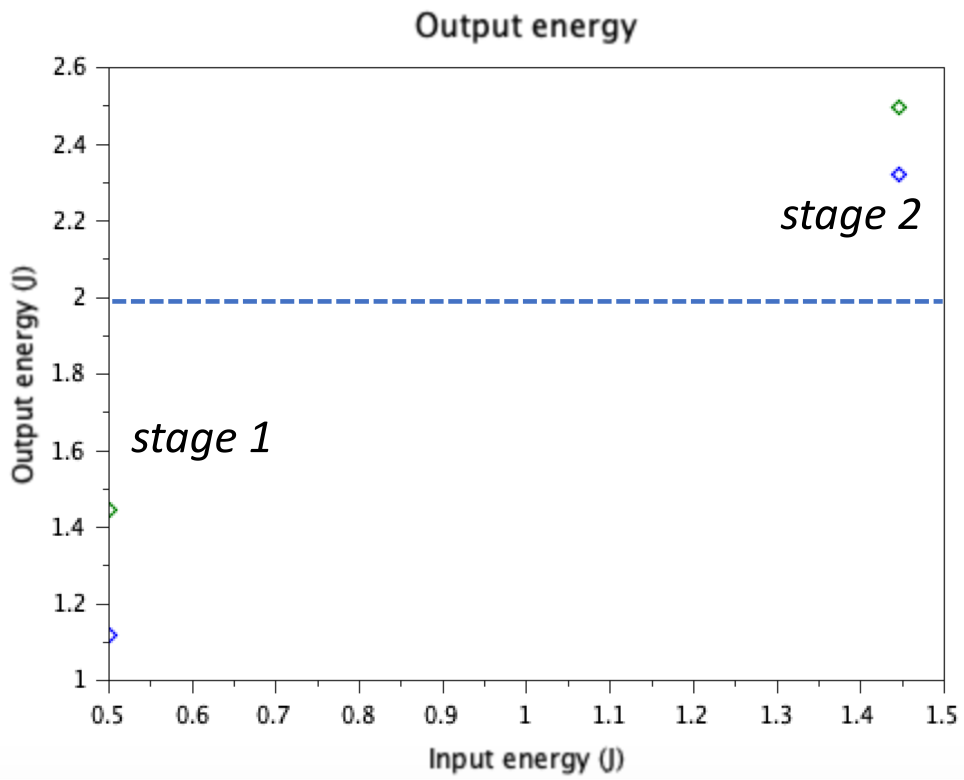




6. Modified amplification calculations

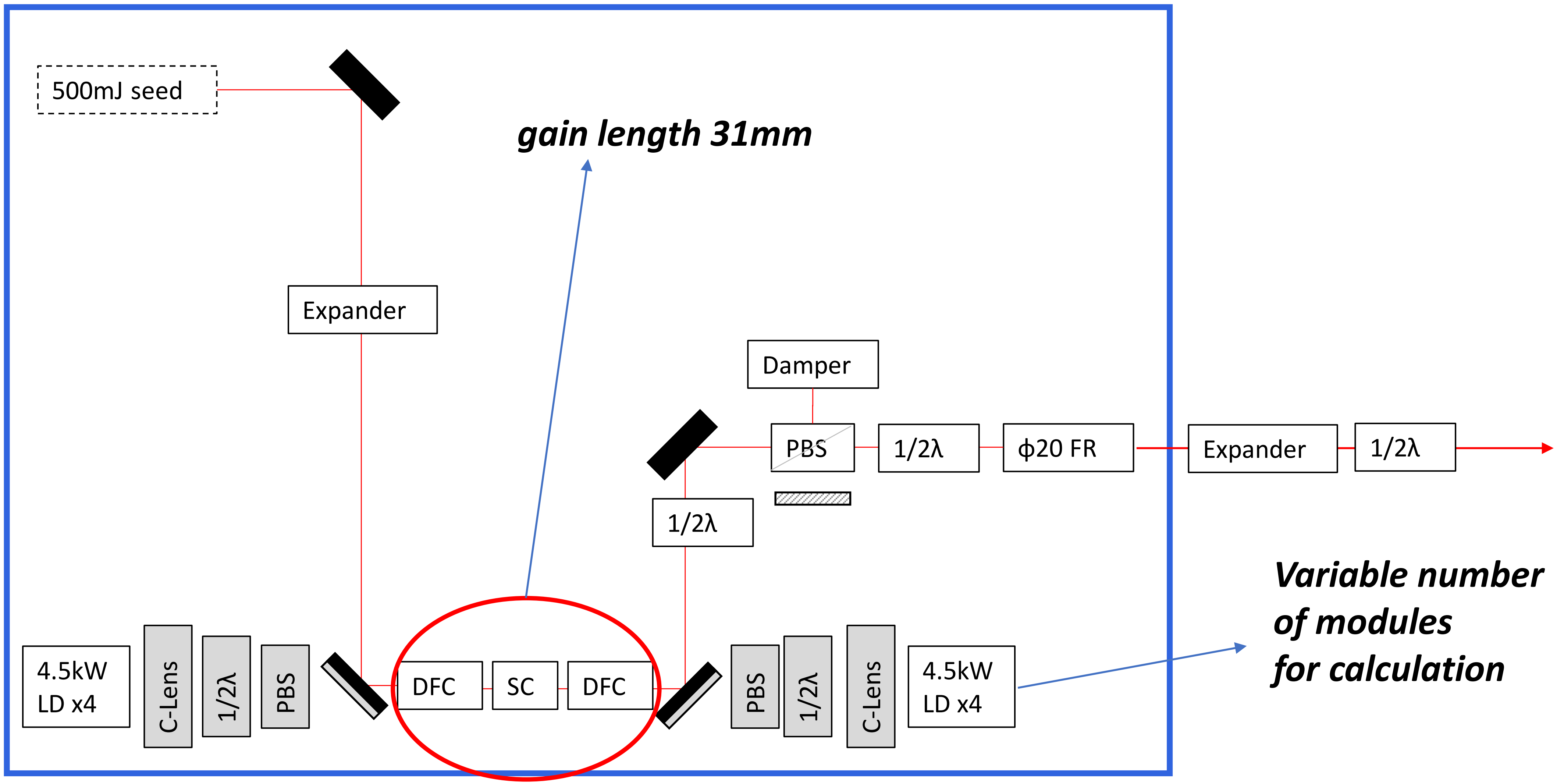
LD power	4 x 4.5kW	4 x 4.5kW
Gain length	30mm	30mm
Spectral width	1nm	8nm



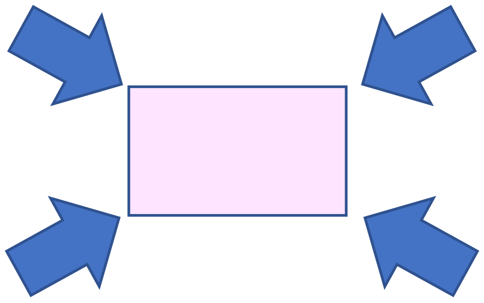


System composition @2J amp

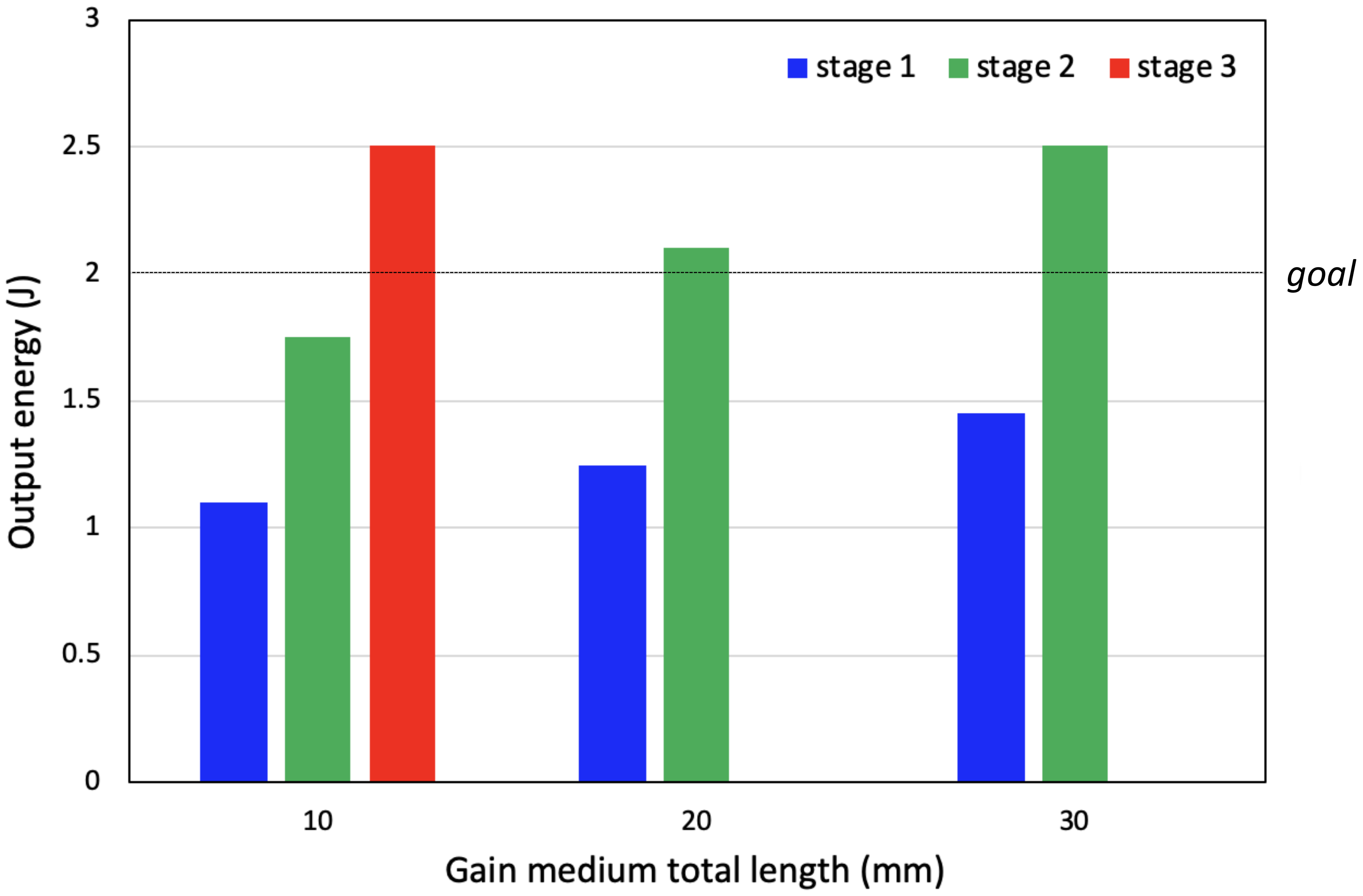
450mm x 750mm x 17.5mmt



7. Estimation of number of modules and stages for our system



2 X 2 LD



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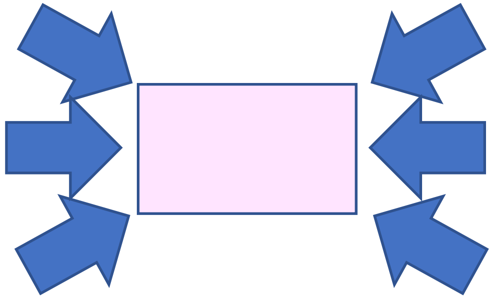
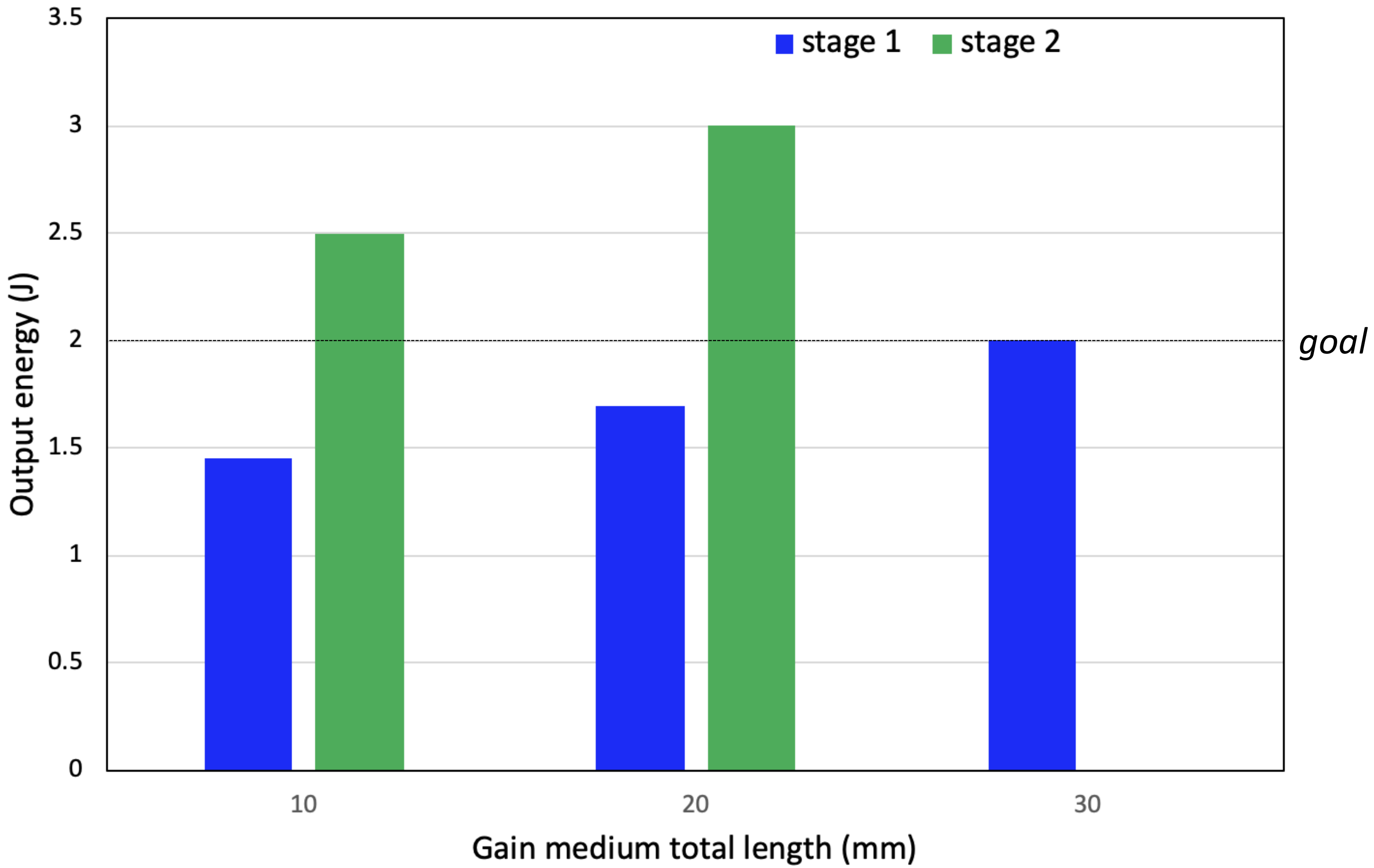


2 X 3 LD



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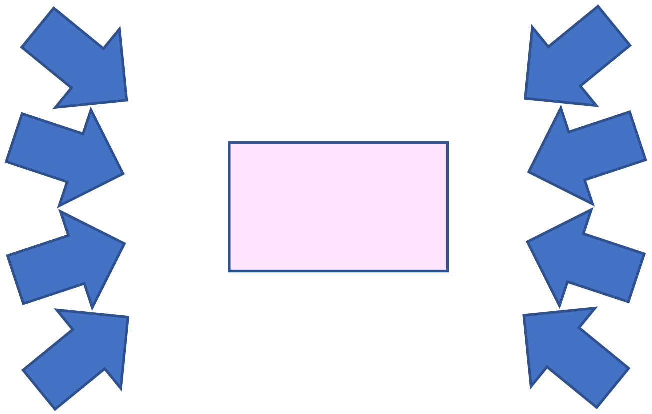
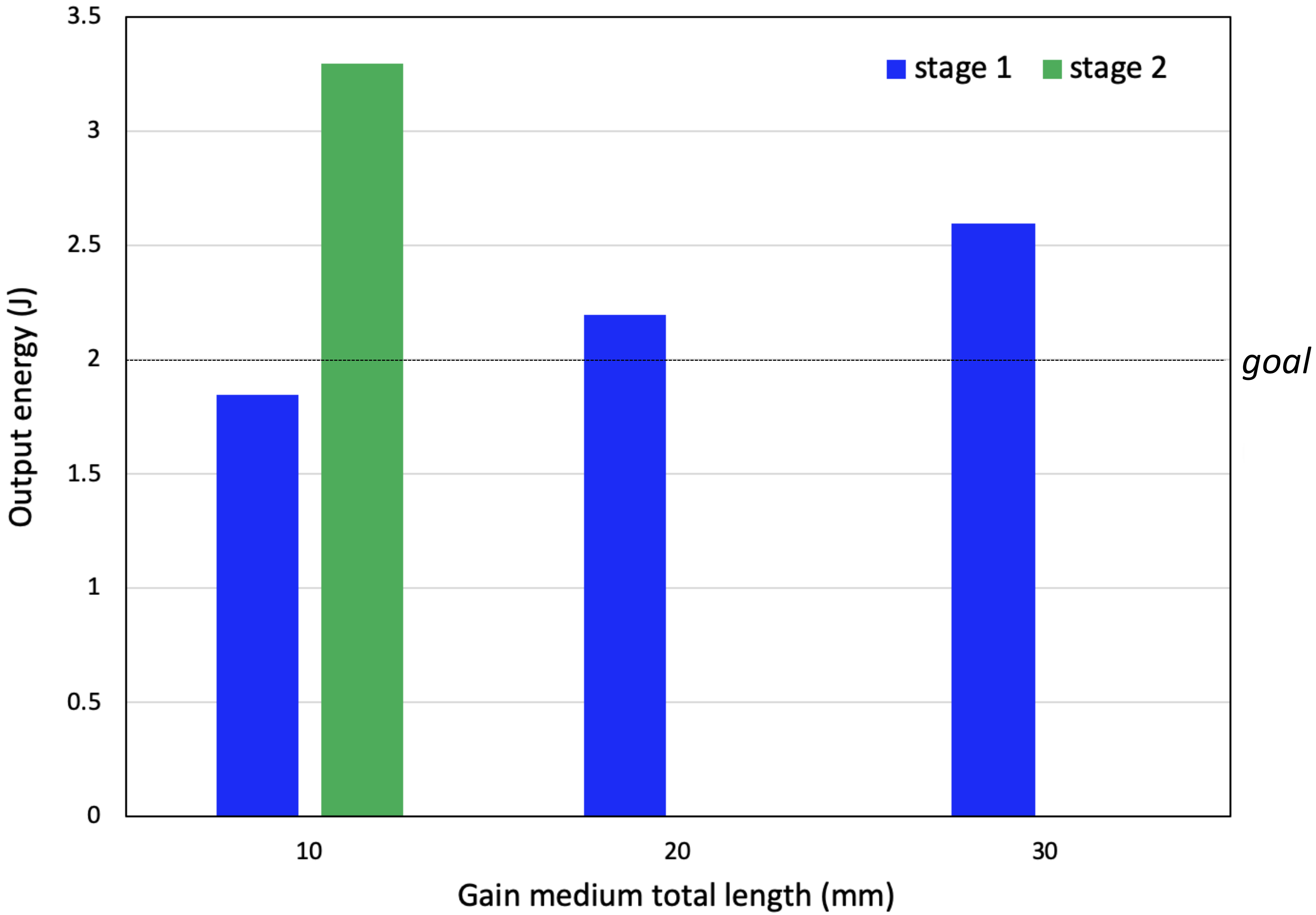


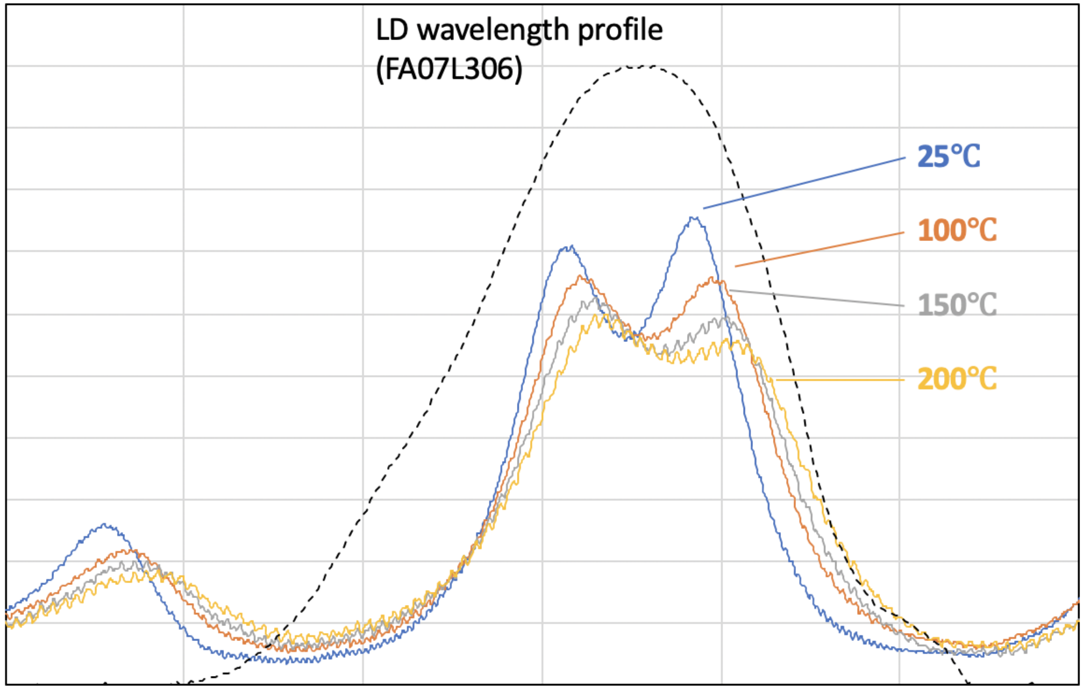
2 X 4 LD



8. Conclusion

Initial calculation overestimate the output energy because :

absorption was not wavelength dependent
pump LD spectrum was not taken into account



This work is a first estimate of these effects :

Gaussian spectrum is used
Real absorption spectrum (@25°C) is used
Wavelength-averaged absorption is calculated

The effect on absorption is substantial :
absorption efficiency drops by 40% for short crystals to 25% for longer ones.

In consequence, amplification is also reduced :
single stage amplification is possible if using 8 pump modules. This might be too much for thermal management….

In near future, real LD spectrum will be used for these estimations.
This effect of spectrum should be fully included in the absorption part of the model

Thank you for your attention