Green Light Laser

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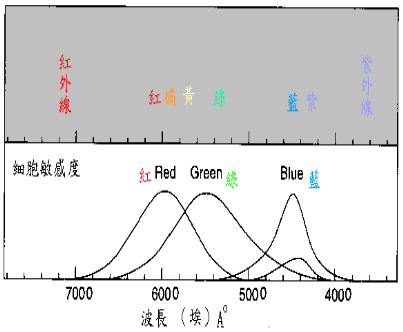
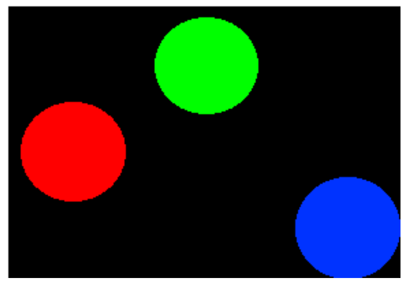
Outline

- Introduction
- Structure of Green Light Laser
- Nd:YAG
- Bichroic Mirror
- Nonlinear Crystal
- Frequency Doubling
- Reference

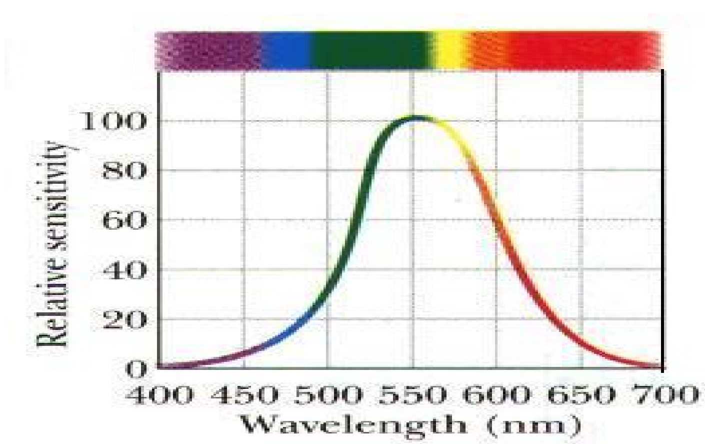
Introduction

- The three original colors: red, green and blue.





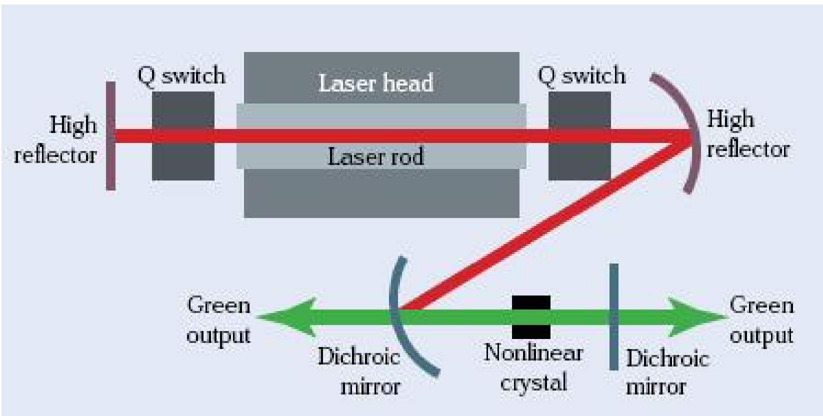
Introduction cont’



Introduction cont'

- As we see in the preceding slide, people eyes are more sensitive to green lights than red lights.
- For the same brightness experience, the green light requires less power than the red light does.
- Lower power assumption and more health consideration.

Structure of Green Light Laser

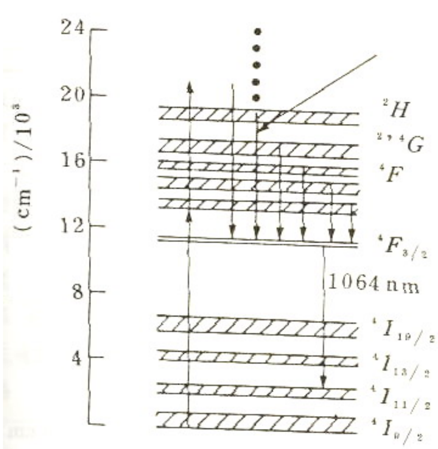


Simple structure for diode-pump solid state green laser

Nd:YAG 釹石榴石雷射

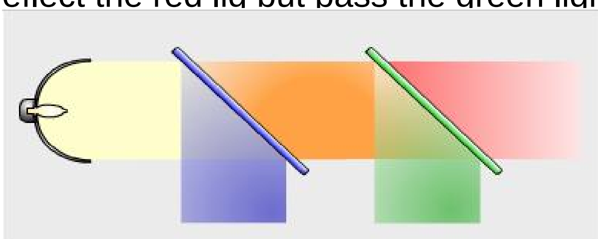
- Yttriam Aluminum Garnet(乙鋁石榴石) crystal doped with Nd ion.
- Four energy level system.
  - Laser radiation from the second level to the third level
  - Different wavelength depending on the energy gap(643nm,1046nm,1319nm…etc)

Nd:YAG cont'



Dichroic Mirror

- Dichroic mirror:
  - A mirror used to reflect the specified wavelength and pass the others.
  - The dichroic mirror used for green light laser is to reflect the red lig but pass the green light.



Nonlinear Crystal

- Potassium Dihydrogen Phosphate (KDP) and Potassium Dideuterium Phosphate (KD*P) are among the most widely-used commercial NLO materials. They are commonly used for doubling, tripling and quadrupling of Nd:YAG laser at the room temperature. In addition, they are also excellent electro-optic crystals with high electro-optic coefficients, widely used as electro-optical modulators, Q-switches, and Pockels cells, etc .

Nonlinear Crystal cont'

- Potassium Titanium Oxide Phosphate ($KTiOPO_4$,鉀鈦磷), or KTP, is an efficient nonlinear optical crystal in the visible to infrared spectral region with relatively low cost. It has large nonlinear coefficient. The effective nonlinear optical coefficient of KTP deff at 1064nm is more than 1.5 times that of BBO. It's damage threshold is near 1 GW/cm2 for 1 Hz 10 ns pulses at 1064nm. However, it is now limited to moderate to low power applications due to it's gray-tracking problem. Recently we have developed gray-tracking-improved KTP (i-KTP) which has significantly raised the gray-tracking trigger power.

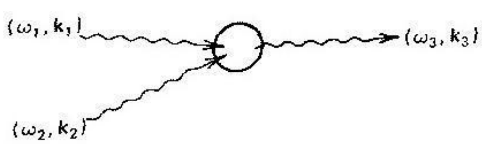
Frequency Doubling

- Why frequency doubling is needed?
  - Nd:YAG generates a far-infrared light with 1064nm wavelength. The green light wavelength is 500~550 nm. By applying frequency doubling, the wavelength is cut down to half (530nm) which falls in the range of green light.

Frequency Doubling cont’

- Sum-frequency generation:
  - Wave interaction in a nonlinear medium leads to wave mixing. The result is the generation of waves at sum and difference frequencies. Sum-frequency generation is one of the nonlinear optical effects first discovered in the early days.

Frequency Doubling cont’

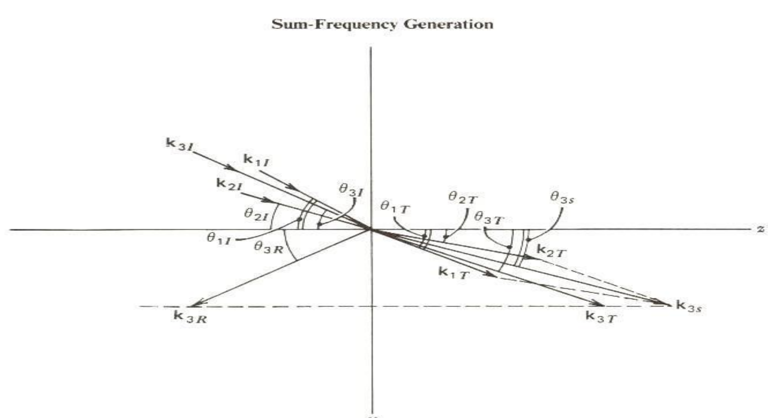


Schematic description of sum-frequency generation

Frequency Doubling cont'

- For effective energy transfer from the pump waves at ω_1 and ω_2 to the generated waves at ω_3 , both energy and momentum conservation must be satisfied.
  - For energy conservation: $\omega_3 = \omega_1 + \omega_2$
  - For momentum conservation: $k_3 = k_1 + k_2$

Frequency Doubling cont'



Description of wavevectors of various waves involved in sum-frequency generation in a semi-infinite nonlinear medium with a boundary surface at $z = 0$.

Frequency Doubling cont'

- An immediate consequence of matching of the field components at the boundary is that at each   ,all the wavevector components parallel to the boundary must be equal. For the sum-frequency wave, we have

$$k_{3I,x} = k_{3R,x} = k_{3T,x} = k_{3s,x}$$

$$k_{3I}\sin\theta_{3I} = k_{3R}\sin\theta_{3R} = k_{3T}\sin\theta_{3T}$$

$$= k_{3s}\sin\theta_{3s} = k_{1T}\sin\theta_{1T} + k_{2T}\sin\theta_{2T}$$

$$= k_{1I}\sin\theta_{1I} + k_{2I}\sin\theta_{2I}$$

we may view this as the nonlinear Snell law.

Frequency Doubling cont'

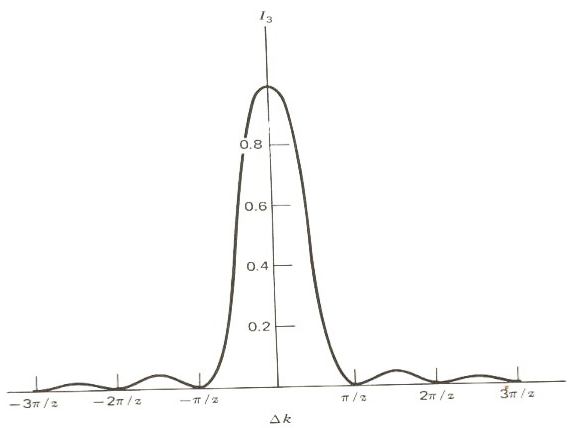
- Phase mismatch consideration is defined as:

$$\Delta k = k_{1T} + k_{2T} - k_{3T}$$

- Due to phase mismatch, the intensity I_3 takes the form

$$I_3(z) = \frac{2\pi\omega_3^2}{c\sqrt{\varepsilon(\omega_3)}\cos^2\theta_{3T}}\left|\wp_3^{(2)}\right|^2\left[\frac{\sin(\Delta kz/2)}{\Delta kz/2}\right]^2 z^2$$

Frequency Doubling cont'



Frequency Doubling cont'

- All above are sum-frequency based analysis, and can be applied to frequency doubling just replace $\omega_1 \omega_2$ with ω and ω_3 with 2ω

  However, the second-order harmonic generation isn't so easy.

  Two equations and their corresponding figures are show.

Frequency Doubling cont'

$$P_{2\omega}(z) = P_{\omega}(0)\tanh^2\left[C\left(P_{\omega}(0)/A\right)^{1/2} z\right]$$

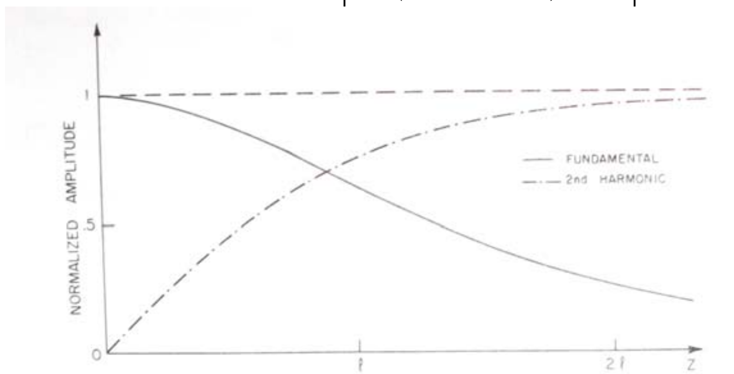
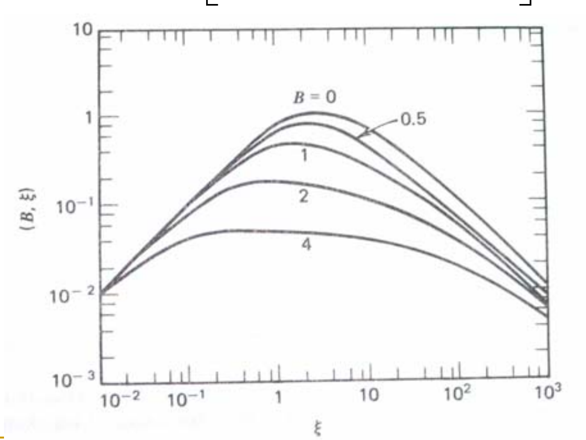


Fig. 7.1 Decay and growth of the normalized fundamental and second harmonic amplitudes, respectively, for the perfect phase-matching case. (After Ref. 1.)

Frequency Doubling cont'

$$\eta = \tanh^2\left[\frac{C^2 P_{2\omega}(0) k_{\omega} l h_0(\xi)}{\pi}\right]^{1/2}$$



Reference

- The Principles of Nonlinear Optics, Y.R. Shen
- http://www.redoptronics.com/
- Nonlinear Fiber Optics Govind P.Agrawal