Self-Focusing in non-linear crystals and its causes

Introduction:

When polarization in a material is no longer linear function of electric field then only non-linear effects come into play where the associated polarization can be given as:

$$P_i = \chi_{ij}^{(1)}E_j + \chi_{ijk}^{(2)}E_jE_k + \chi_{ijkl}^{(3)}E_jE_kE_l + \chi_{ijklm}^{(4)}E_jE_kE_lE_m + \cdots \qquad (1)$$

where$\chi_{ij}^{(1)} \chi_{ijk}^{(2)}E_jE_k + \chi_{ijkl}^{(3)}E_jE_kE_l + \chi_{ijklm}^{(4)}E_jE_kE_lE_m$is the first-order susceptibility tensor and $\chi_{ijk}^{(2)}$ is the second-order susceptibility tensor and so on. It should be noted that these susceptibility tensors are responsible for various frequency generation. This assignment concentrates on self-focusing phenomena which is a self-action effect and is associated with even order of non-linear susceptibility tensors starting from $\chi_{ijkl}^{(3)}, \chi_{ijklmn}^{(5)}, \ldots.$; the refractive index associated with the material is given as:

$$n = n_0 + n_2|E|^2 + n_4|E|^4 + \cdots \qquad (2)$$

In eqn. (2) we can see that the second term is $|E|^2 \propto I$ (intensity) therefore we can re-write it as:

$$n = n_0 + n_2 I + n_4 I^2 + \cdots \qquad (3)$$

Fig.1 shows the behaviour of a laser beam with gaussian intensity on a non-linear crystal, so as we know intensity is max at the center therefore it corresponds to the highest refractive index and it results in lower velocity of light in the central region as compared to the peripheral region through this relation:

$$n = \frac{c}{v} \qquad (4)$$

where 'n' is the refractive index and 'c' is the velocity of light in vacuum and 'v' is the velocity of light in the medium.

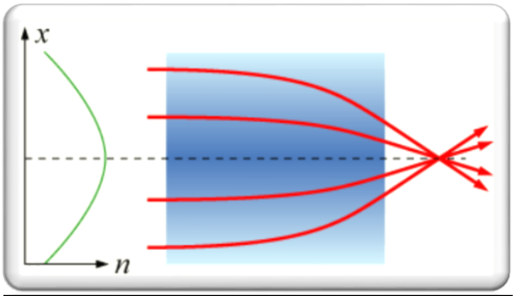


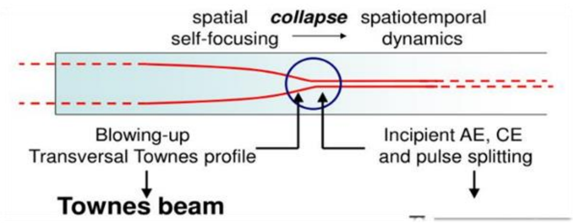
Fig.1: Depicting light induced refractive index gradient in the non-linear

Kerr-induced self-focusing:

Kerr-induced self-focusing was experimentally verified by study the interaction of ruby laser with glasses and liquids. Self-focusing beams have been found to naturally evolve into a Townes profile regardless of their initial shape. Self-focusing occurs if the radiation power is greater than the critical power.

$$P_{cr} = \alpha \frac{\lambda^2}{4\pi n_0 n_2} \qquad (5)$$

where, 'λ' is the radiation wavelength in vacuum and 'α' is a constant which depends on the initial spatial distribution of the beam.



Developed techniques to overcome damage caused due to self-focusing:

(a) Chirped pulse amplification:

This technique of chirped pulse amplification was developed to overcome the nonlinearities and damage of optical components that self-focusing would produce in the amplification of femtosecond laser pulses. It is a technique for amplifying an ultrashort laser pulse up to the petawatt level, with the laser pulse being stretched out temporally and spectrally, then amplified, and then compressed again.

The ultrashort laser pulse is stretched out in time prior to introducing it to the gain medium using a pair of gratings that are arranged so that the low-frequency component of the laser pulse travels a shorter path than the high-frequency component does. After going through the grating pair, the laser pulse becomes positively chirped, that is, the high-frequency component lags behind the low-frequency component, and has longer pulse duration than the original by a factor of 1000 to 100000.

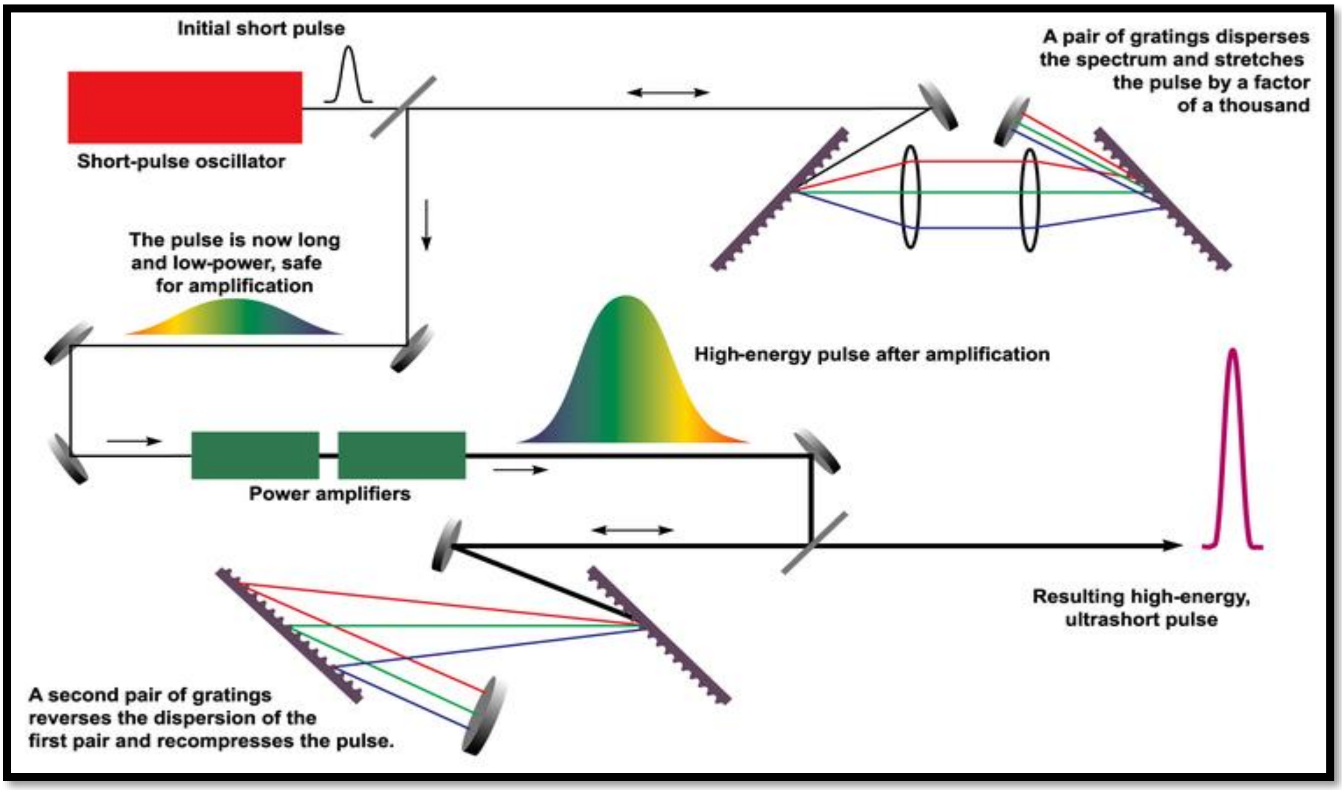


Fig.2: Schematic of chirped pulsed amplification.

Then the stretched pulse, whose intensity is sufficiently low compared with the intensity limit of gigawatts per square centimeter, is safely introduced to the gain medium and amplified by a factor of a million or more. Finally, the amplified laser pulse is recompressed back to the original pulse width through reversal of the process of stretching, achieving orders-of-magnitude higher peak power than laser systems could generate before the invention of CPA.

Refrences:

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2. Self-Focusing of Optical Beams/R. Y. Chiao[1] , T. K. Gustafson[2] , and P. L. Kelley[3]
3. Wikipedia/Chirped_pulse_amplification