Nonlinear effects
in anisotropic materials

MILESTONES

- 1961 – Discovery of Optical second harmonic generation.
- 1962 – Discovery of Stimulated Raman scattering.
- 1964 – Stimulated Brilloiun scattering. It is now an efficient technique to generate or amplify coherent optical radiation with small frequency shift.

Linear Optics vs Non Linear Optics

- Linear optics– 'Optics of weak light':

  Light is deflected or delayed but its frequency is unchanged.

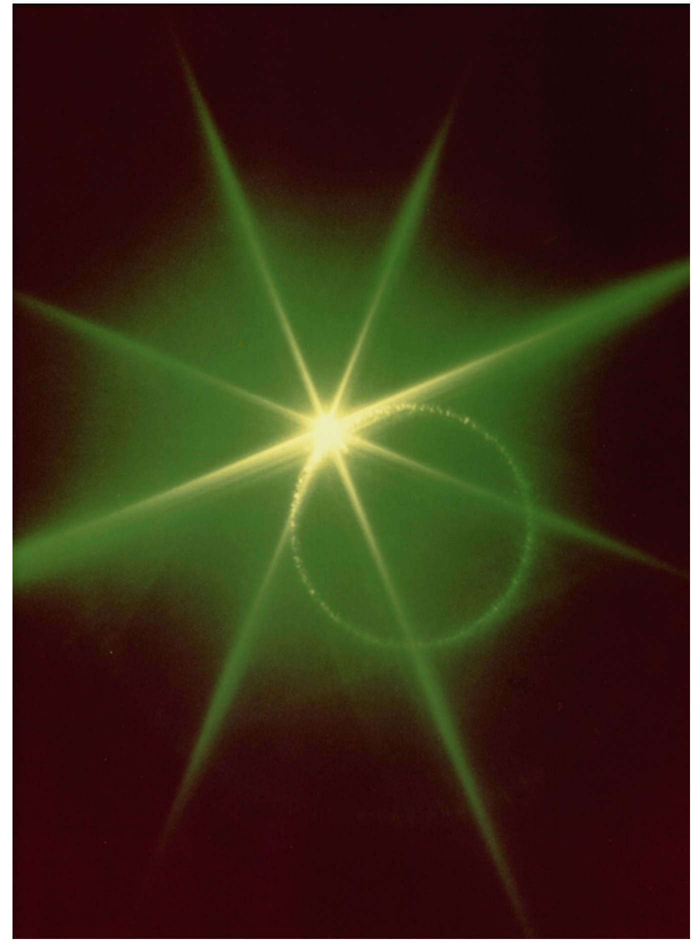
- Non-Linear optics–'Optics of intense light':

  We are concerned with the effects that light itself induces as it propagates through the medium.

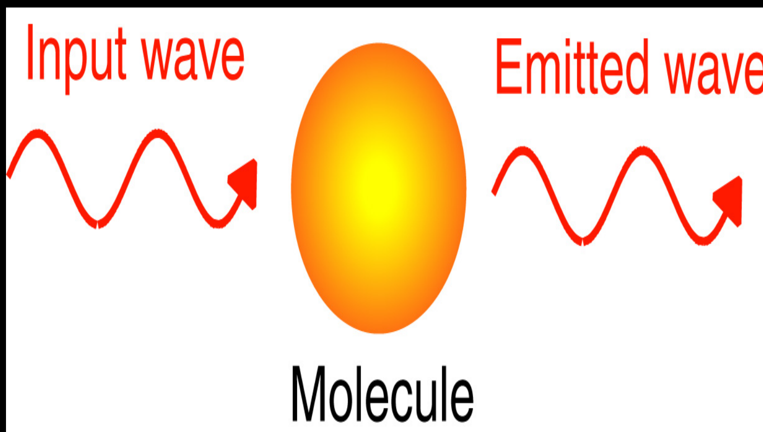
Non-Linear optics produces many exotic events

•Nonlinear optics allows us to change the color of a light beam, to change its shape in space and time, to switch telecommunica-tions systems, and to create the shortest events ever made by Man

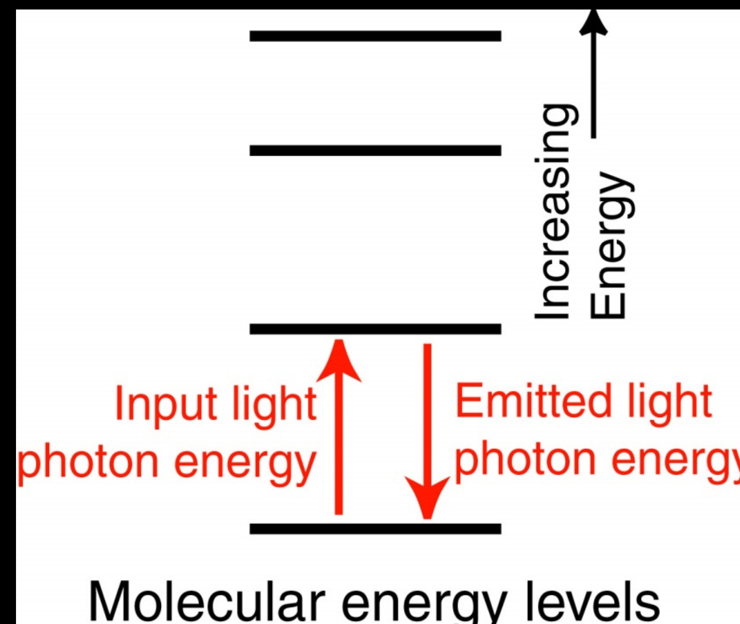
Ex: Sending infrared light into a crystal yielded this display of green light



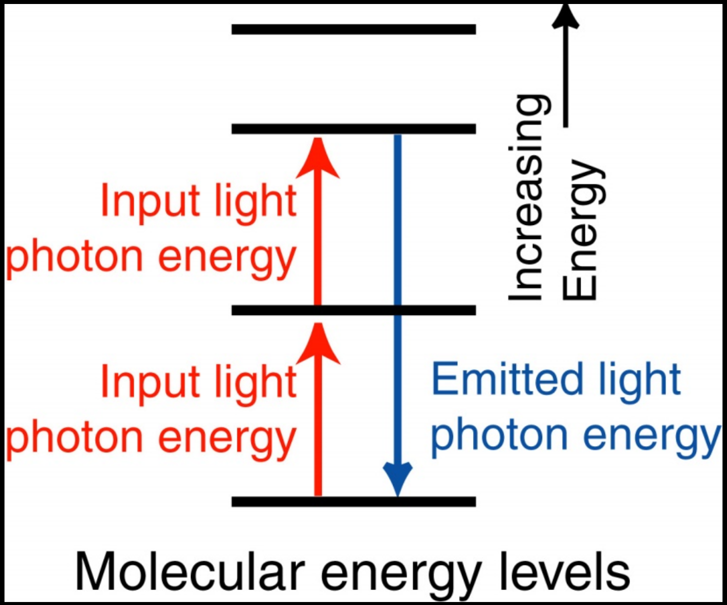
In Linear optics

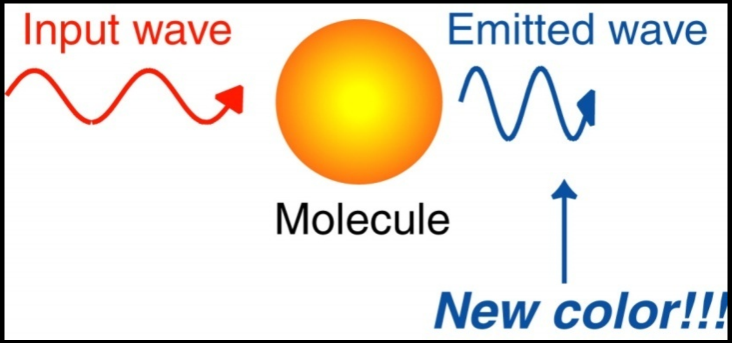


and then emits its own light wave that interferes with the original light wave.



In Non-Linear Optics





If irradiance is high enough vibrations at all frequencies corresponding to all energy differences between populated states are produced.

Importance of ‘NLO’

- Optical wave manipulation is one of the future technologies for optical processing.
- It has various applications in fiber-optic communications and optoelectronics which makes it an increasingly important topic among electrical engineers.

Polarization

- Linear
- Non-linear

- P: induced polarization of medium

  ε_0: dielectric constant of vacuum

  E: electric field

  $\chi^{(i)}$: succeptibilities of ‘i’ order.

Phenomenon Associated With Non-linear Optics

- Second harmonic generation.
- Sum frequency generation.
- Difference frequency generation.
- Optical parameter amplification.
- ‘N’ wave mixing.

Second Harmonic Generation

$$P = \varepsilon_0 \left[\chi^{(1)} E + \chi^{(2)} E^2 + \chi^{(3)} E^3 + \ldots \right]$$

What are the effects of such nonlinear terms?

Since $E(t) \propto E_0 \exp(i\omega t) + E_0^* \exp(-i\omega t)$,

$$E(t)^2 \propto E_0^2 \exp(2i\omega t) + 2\left|E_0\right|^2 + E_0^{*2} \exp(-2i\omega t)$$

↑ 2ω = 2nd harmonic!

Sum and Difference Frequency Generation

Suppose there are two different-color beams present:

$$E(t) \propto E_1 \exp(i\omega_1 t) + E_1^* \exp(-i\omega_1 t) + E_2 \exp(i\omega_2 t) + E_2^* \exp(-i\omega_2 t)$$

So:

$$E(t)^2 \propto E_1^2 \exp(2i\omega_1 t) + E_1^{*2} \exp(-2i\omega_1 t)$$ 2nd-harmonic gen

$$+ E_2^2 \exp(2i\omega_2 t) + E_2^{*2} \exp(-2i\omega_2 t)$$ 2nd-harmonic gen

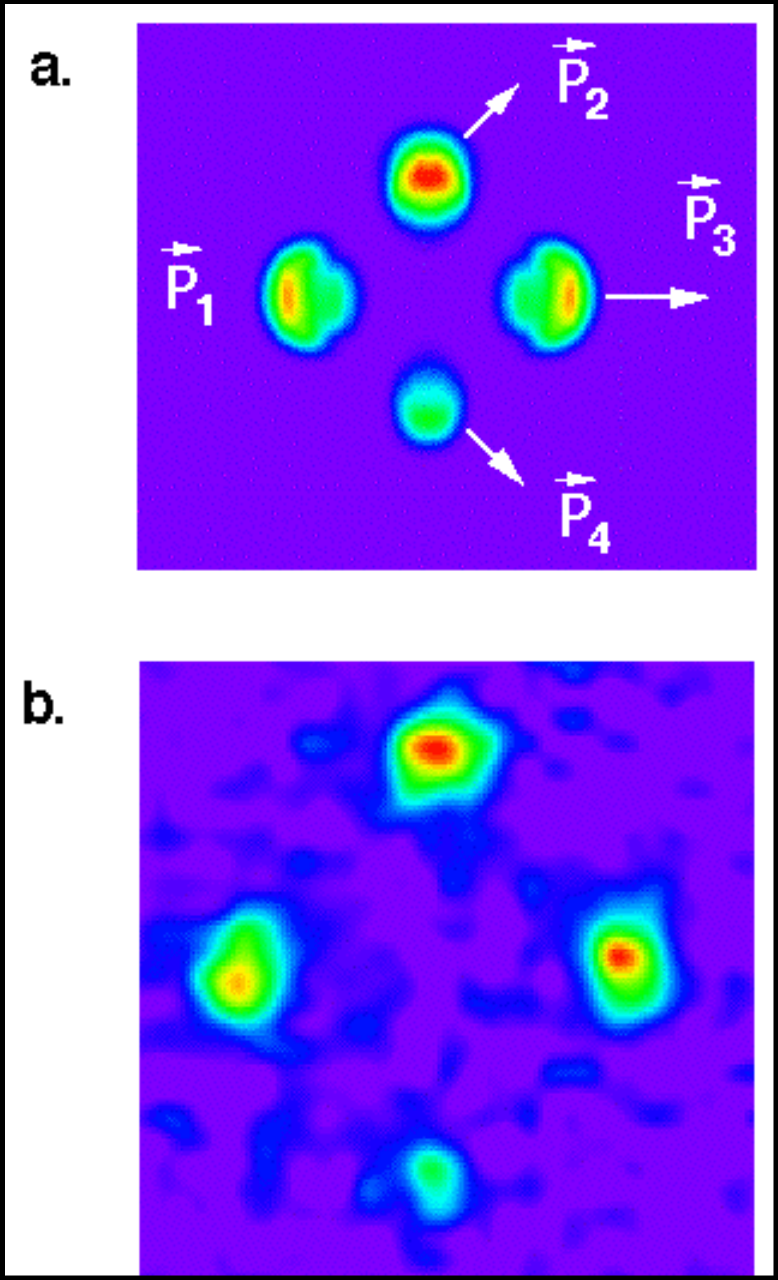
$$+ 2E_1E_2 \exp(i\left[\omega_1 + \omega_2\right]t) + 2E_1^*E_2^* \exp(-i\left[\omega_1 + \omega_2\right]t)$$ Sum-freq gen

$$+ 2E_1E_2 \exp(i\left[\omega_1 - \omega_2\right]t) + 2E_1^*E_2^* \exp(-i\left[\omega_1 - \omega_2\right]t)$$ Diff-freq gen

$$+ 2\left|E_1\right|^2 + 2\left|E_2\right|^2$$ dc rectification

Four Wave mixing (FWM)

In this three optical fields mix in a non-linear medium and create a four wave.



Materials applied in Non-Linear optics

Title	Transmission Range, mm	Typical Applications
LBO pumped by	0.16 - 3.3	High power lasers harmonics generation and OPO Nd:YAG harmonics
BBO with output in	0.19 - 3.3	- Solid State and Dye laser harmonics generation the range 200-532 nm; - OPO/OPA pumped by Nd:YAG harmonics with 295 - 3000 nm output
KTP	0.38 - 4.4	Harmonics generation in UV and VIS
KD*P	0.26 - 1.6	Harmonics generation in VIS
$LiNbO_3$	0.4 - 4.5	SHG and OPO pumped by Nd:YAG laser
$LiIO_3$	0.3 - 6.0	SHG and THG of Nd:YAG, DFM with output in 3 - 5 μm range
$AgGaS_2$ output in 3 -	0.53 – 12	Harmonics generation and DFM with wide tunable 9 μm, IR visualization
$AgGaSe_2$	0.73 – 18	SHG of CO_2 lasers, OPO with 3 - 12 μm output
GaSe	0.65 – 18	SHG of CO and CO_2 lasers, DFM with output in 7 - 16 μm
CdSe	0.75 – 25	DFM with tunable output up to 25 μm
$AgAsS_3$	0.6 – 13	IR visualization, DFM, OPO
Te	3.8 – 32	DFM with output in 15 - 30 μm

Tabela 4.1. Parametry niektórych materiałów nieliniowych

Materiał	n_2, m^2/W	α, cm^{-1}	τ_R, s	$\Delta n/\lambda\alpha$
Półprzewodnik GaAlAs ($\lambda = 810$ nm)	-10^{-15}	18	10^{-8}	2,5
Szkło SiO_2	10^{-20}	10^{-6}	10^{-14}	1000
Polimer PTS ($\lambda = 1{,}06$ μm)	10^{-15}	0,8	10^{-12}	100
Ciekły kryształ PCB	10^{-8}	10	10^{-3}	300

Tabela 4.2. Porównanie wartości nieliniowego współczynnika załamania i czasu narastania nieliniowości w ciekłych kryształach

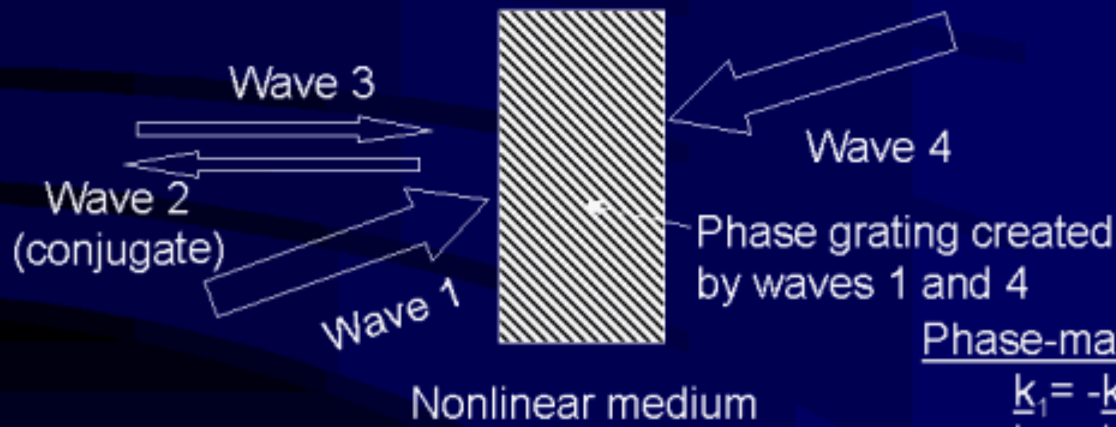
Typ nieliniowości		n_2, m^2/W	Czas τ_R
Elektronowa		10^{-16}	ps
Reorientacyjna	w fazie izotropowej	10^{-13}	100 ns
	w fazie nematycznej	10^{-8}	μs
	zjawisko Janossy'ego	10^{-6}	μs
Termiczna	w fazie izotropowej	10^{-10}	< 100 μs
	w fazie nematycznej	10^{-9}	> 100 μs

Applications:

- Optical phase conjugation
- Optical parametric oscillators
- Optical computing
- Optical switching
- Optical data storage

Optical phase conjugation

- An optical phase conjugator can be used to unravel distortions that occur in passing through a distorting medium
- Optical phase conjugation occurs when we have four wave mixing with all four waves of the same frequency



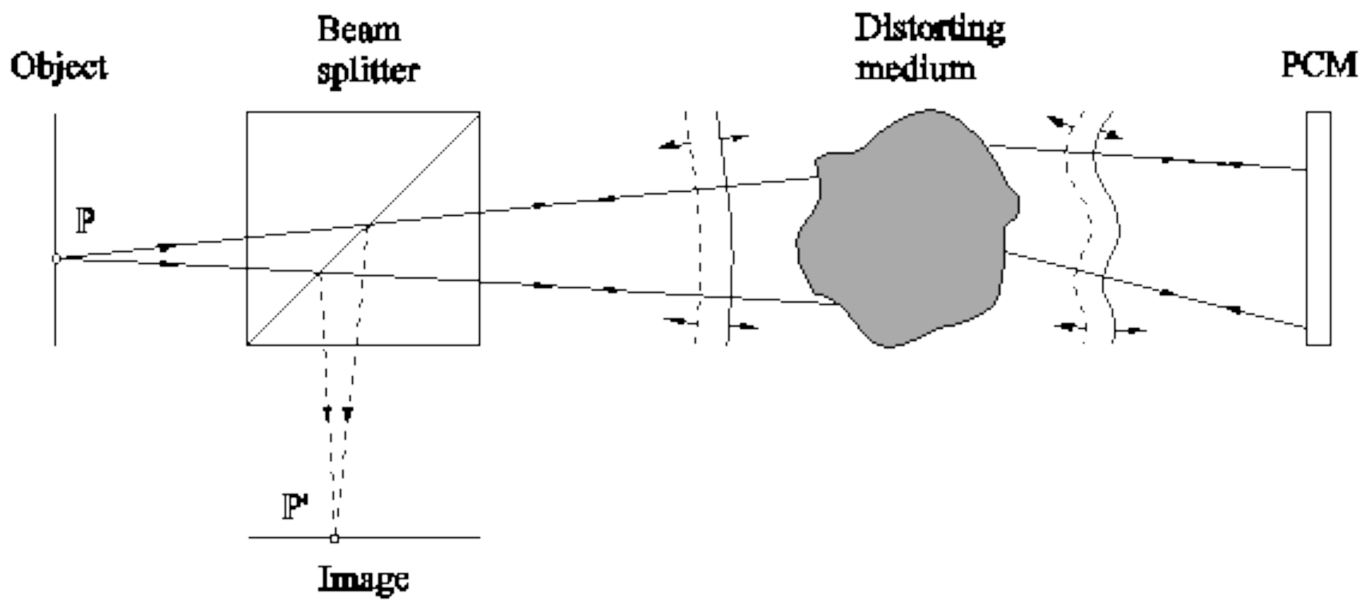
Phase-matching

$\underline{k}_1 = -\underline{k}_4$

$\underline{k}_2 = -\underline{k}_3$

- Waves 1 and 4 create an interference pattern
- This builds up an intensity dependent refractive index
- This looks like a phase grating
- Wave 3 creates a phase conjugate of wave 1

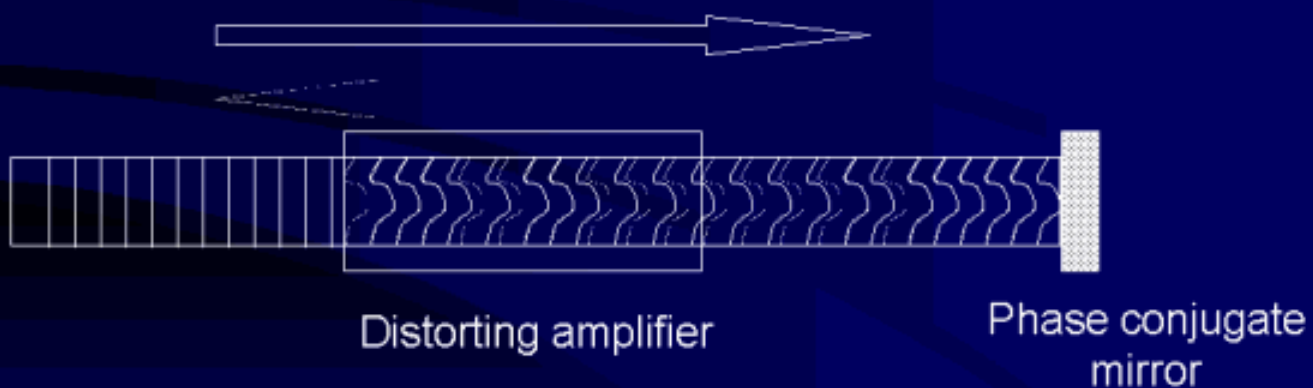
Imaging and Aberration correction using PCM



Basic two-pass geometry for imaging and aberration correction using a PCM(Phase conjugate mirror).

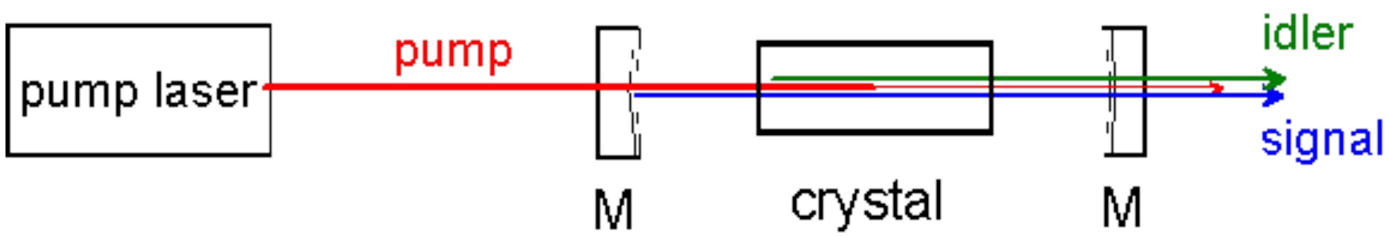
Image restoration by phase conjugation

- Severely distorted laser beams can be corrected for distortions in passing through imperfect optics
- High power amplifiers often distort laser beams
  - the distortions can be corrected by double passing the amplifier using a phase conjugate mirror



Optical Parametric Oscillators

- Converts the pump wave into two coherent light waves with longer wavelengths.
- Applications: Light detection and ranging (LIDAR), High-resolution spectroscopy, Medical research, Environmental monitoring, Display technology, and Precision frequency metrology.



Optical Computing

- Optical Techniques can provide a number of ways of extending the information processing capability of electronics.
- Large quantities of data can be generated from different resources and powerful computer is required to process them.
- Just electronics are not enough for this and therefore OPTICS can provide some solutions.
- Digital Optical computer requires the use of *nonlinear* optics.

Future Scope

- *The field of Nonlinear Optics today has grown into a vast enterprise with a considerable potential for technological applications.*
- *The nonlinear optical (NLO) materials needed for optimized components , however, have not yet been realized.*
- *New nonlinear optical materials and devices are in various stages of development.*
- *Organic nonlinear optical materials are thought to play a key role in the future of NLO.*
- ***"Purely optical information processing looms on the horizon".***