

Quantum (Second Harmonic) Efficiency and Conversion Coefficient for a Frequency Doubled He- Ne Laser.

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Abstract
It is the aim of this project to study the ability of producing second harmonic generation for a (10 mW) He-Ne laser and to test some optical properties for KDP crystal and to compare the results with those obtained in testing the same crystal with using a (18 mW) Laser Tube. It seems that the performance of visible radiation is more accurate rather than near IR radiation.
Keywords: Non- Liner Conversion Coefficient, Power Efficiency (P_2/P_1), Second Harmonic Generation (SHG).

1. Introduction

Second harmonic generation is a non- linear response in those media which exhibits birefringence operation whose intensity reaches almost (10^8 V/m). In non-linear media, pyroelectric materials show an electric polarization when the Temperature of a crystal is changed [1]. Thus a second Harmonic frequency of the light is changed from (ω) to (2ω), if the crystal has an induced electric polarization owning a component oscillating at (2ω)[2]. The relation between the polarization vector and the field strength in those media is:

$$\vec{P} = \epsilon_\circ x_1 E + \epsilon_\circ x_2 E_2^2 + \epsilon_\circ x_3 E^3 + \ldots \quad (1)$$

Where $\epsilon_\circ$ is the permittivity constant at space, $(\chi)_s$ are the non- linear susceptibility of the material through successive harmonic generation in the process[3]. Maxwell Equation for the non-linear media has a relative permeability $\epsilon = k\,\epsilon_\circ$,where k is the dielectric strength of the material.
Thus:

$$\nabla^2 E = \mu_\circ \in \frac{\partial^2 E}{\partial t^2} = \mu_\circ \frac{\partial^2}{\partial t^2}(\epsilon_\circ E + P) \ldots \quad .(2)$$

Here P is again the polarization vector. For first harmonic wave equation all polarization components oscillating at (2ω) must be induced to equation (1), as such [4]:

$$\nabla^2 E_2 = \mu_\circ \epsilon_\circ \frac{\partial^2}{\partial t^2}(E_\circ + x_1 E_2 + x_2 E_2^2 + \ldots) \ldots \quad (3)$$

Where this recognizes the refractive index at second harmonic generation as, n_1 and n_2, where n_2 is related to the susceptibility as:

$$n_2^2 = 1 + x_1 \ldots \quad (4)$$

Putting this in equation (3), we have:

$$\nabla^2 E_2 = \mu_\circ \epsilon_\circ \frac{\partial^2 E}{\partial t^2}(n_2^2 + x_2 E_1^2) \ldots \quad (5)$$

The detail of mathematical formalism take long and the second harmonic power of the light beam [if Laser] is related to the fundamental beam power as:

$$P_2 = \sqrt{\frac{\mu_\circ}{\epsilon_\circ}} \frac{\omega^2 x_2^2 l^2}{8\, n_1^2 n_2} P_1^2 \ldots \quad .(6)$$

Remembering that in classical EM theory: $P = \frac{E^2}{\nabla t}$ Where E^2 is the spot intensity of the light.
Here n_1 is called the fundamental refractive index and n_2 is second harmonic refractive index, occasionally, they are called [ordinary and extra ordinary refractive indices]. Making a few approximations to insert another parameter which the constant of the harmonic generation, related to the non-linear conversion coefficient (d_{ooe}) of the crystal as:

$$K = \frac{128\pi^2 \omega_1^2 (d_{00e}+)^2}{n_1 c^3} \sin^2\theta_m \ldots \quad (7)$$

Here $\theta_m$is called the birefringence angle of the crystal, obtained from Brags diffraction law analysis for the crystal where value is[6]:

$$\sin\vartheta_m = \frac{(n_2^{2\omega_1})^2[(n_1^{2\omega_1})^2 - (n_1^{\omega_1})^2]}{(n_1^{\omega_1})^2[(n_1^{2\omega_1})^2 - (n_2^{2\omega_1})^2]} \ldots \quad (8)$$

Combining equations (8) and (6) we get [7]:

$$P_2 = K P_1^2 \frac{l.l_a}{\omega_\circ^2} \ldots \quad .(9)$$

Here l is the crystal length, $\omega_\circ$ is the fundamental beam spot size and l_a is the laser aperture beam, related to the phase matching angle (θ_m) as[8]:

$$l_a = \sqrt{\pi}\frac{\omega_\circ}{p} \ldots \quad .(10)$$

Putting this in equation (9), we obtain:

$$P_2 = K P_1^2 \sqrt{\pi}\frac{l}{\omega_\circ \rho} \ldots \quad (11)$$

This will be the key equation for our calculations, since it combines both fundamental beam power $[P_1]$ and the second harmonic power $[P_2]$ and (ρ) is related to θ_m as:

$$\tan p = \frac{1}{2}(n_1^{\omega_1})^2 \left[\frac{1}{(n_2^{2\omega})^2} - \frac{1}{(n_1^{(2\omega_1)})^2}\right] sin^2\theta_m \text{.....................} \quad (12)$$

2- Results and Calculations

In the process, a birefringence crystal which is shown in figure (1) used having the following properties [9]:

1- Geometric dimensions: h =0.5cm, l=2cm, ω=7cm
2- Refractive index: n_°=1.5072,n_(e)=1.492
3- Optical properties:
   a. d_00e=1.316× 〖10〗^(-11) m/V …..
   b. phase matching angle (θ m)= (56.1)° ………..
   c. birefringence angle [Rad.]=0.0281

From these and for the ordinary light beam for a Typical He-Ne Laser (λ = 632.8nm), we could calculate the non-linear conversion coefficient K eqn. (9) to be 2.632× 〖10〗^(-11) (m/V). Having doing these, it is an easy matter to plot both (P_2) and Second Harmonic efficiency ρ_SH as the function of the fundamental beam power for available output (He-Ne) Laser powers ranging from (1-30)mW. Figure (1) shows the graph between the Second Harmonic power (P2) and the fundamental beam power P. Figure (2) shows variation of Second Harmonic efficiencies (P_2/P_1)as the function of λ.

3-Conclusions

Throughout the whole work, we observed that the new version of calculating the conversion efficiency and second Harmonic power have been prompted potentially. The version used was based on the idea of using low power He-Ne Laser to enhance mechanical and thermal effects. The figures show that:

1- The second Harmonic power is more stable at fundamental beam power ranging from (1-10) m Watts and the Fluctuation of raising up is starting nearly (20)mV.

2- 2- The Second Harmonic power is much efficient at near uv(360-4000nm beam wavelength reaching its mid – value at (650)nm which is almost close to the employed wave length of the laser radiation.

3- The present work have differentiated the Second Harmonic power as the function of refractive index from that of Storelu, by fixing the value of the non-Linear Conversion efficiency [K] and observing the changes in geometrical parameters of the KDP crystal with in the optical properties allowed.

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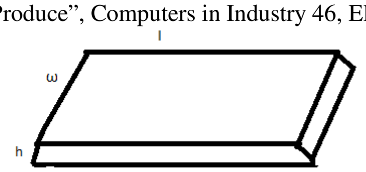

Figure1. A birefringence crystal dimensions.

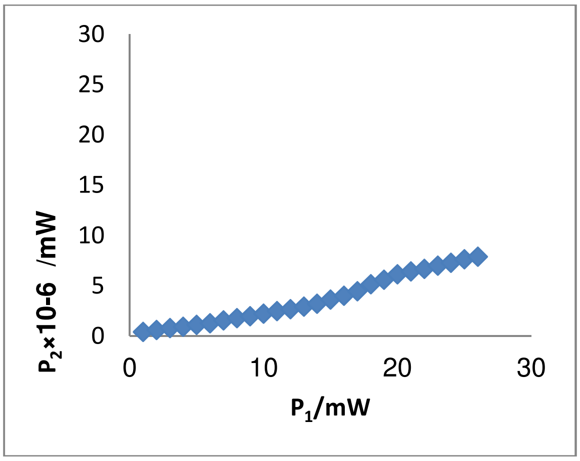

Figure2. The graph between the second Harmonic PowerP_2 and the fundamental beam P_1 .

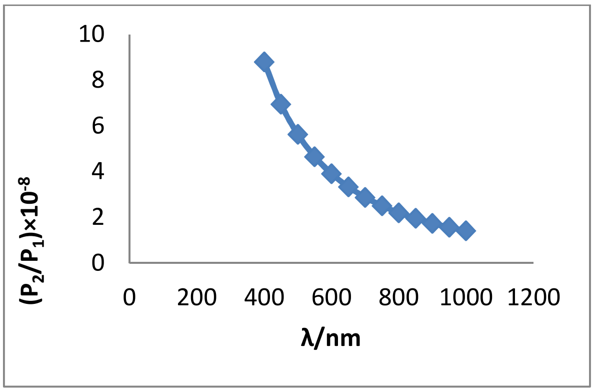

Figure 3. The variation of second Harmonic Efficiencies (P_2/P_1) as a function of λ.