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CHARACTERISTICS OF IDEAL OPTICAL LIMITER AND REALIZATION SCENARIOS USING NONLINEAR ORGANIC MATERIALS

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Abstract:

The devices used for sensor protection against laser pulses are called optical limiters. The ideal optical limiter has the characteristics has a high linear transmission for low input (e.g. energy E or power P), a variable limiting input E or P, and a large dynamic range defined as the ratio of the E or P at which the device damages (irreversibly) to the limiting input. Such devices can also be used as power or energy regulators. However, since the primary application of the optical limiter is for sensor protection, and damage to detectors is almost always determined by fluence or irradiance, these are usually the quantities of interest for the output of the limiter. Getting ideal limiting response turns out to be possible using a wide variety of materials; however, it is very difficult to get the limiting threshold as low as is often required and at the same time have a large dynamic range. Because high transmission for low inputs is desired, the material/device must have low linear absorption. These criteria lead to the use of two-photon absorption (2PA) and nonlinear refraction phenomena in practice. Any material (both inorganic or organic) which shows nonlinear absorption can be used for practical limiters. Unfortunately, except in the IR region, 2PA coefficients of inorganic solids are too small for most of these applications which look to protect against nanosecond sources. Organic materials have the potential for larger nonlinearities and are being actively investigated. In addition, if small linear absorption can be tolerated, reverse saturable absorbers can be effective. Here the transmitted fluence is reduced so that the energy of a long pulse is limited as well as a short pulse as long as the pulse width is less than excited-state decay times. In this paper, we have anslysed the characteristics of the ideal optical limiter and reviewed the recent efforts by many researchers on the realization of best optical limiter using nonlinear organic materials.

Index Terms: Ideal Optical Limiters, Practical Optical Limiters, Organic Material Optical Limiters& Optical Limiters for Photonics

1. Introduction:

The word 'Ideal system' refers to the system which has ideal characteristics i.e., perfect in every way. It is what the mind pictures as being perfect. The characteristics of the present system can be improved towards the characteristics of the ideal system by doing research and innovation [1-2]. The concept of an ideal gas, ideal fluid, ideal engine, ideal switch, ideal voltage source, ideal current source, ideal semiconductor devices like ideal diodes, ideal transistors, ideal amplifiers etc. have been defined and taken as standards to improve the quality and performance of such practical devices or systems. Similarly, Ideal business system [3-4], Ideal education system [5-7], ideal technology [8], ideal strategy [9], ideal energy source [10], ideal banking [11-13], ideal software [14], and ideal library [15] are also defined and their input characteristics, System characteristics, output characteristics, and environmental characteristics are studied. It is found that, by keeping such hypothetical devices or systems in mind, researchers have continuously been improving the characteristics/properties of practical devices / systems to upgrade their performances. Hence, ideal properties of a device or a system can be used to upgrade or improve its properties towards reaching 100% efficiency. By comparing the properties/characteristics of a practical device/system with its ideal counterpart, one can find out the possible modifications in that device /system towards reaching the objective of achieving such an ideal system [2].

The field of nonlinear optics has been rigorously investigated for over fifty years. Since its beginning in 1960, after invention of the first Laser by T. H. Maiman [16], the field has grown to encompass a widely diverse array of phenomena such as second harmonic generation first observed by P.A. Franken, et al. in 1961, [17], the electro-optic (Pockel's) effect [18], sum and difference frequency generation [19], third harmonic generation [20], stimulated scattering [21], multi-photon absorption [22], and nonlinear refraction [23]. Each of these effects has the potential to be used for some practical application. For example, second harmonic generation is extremely useful in doubling frequency of lasers to expand their spectral coverage, while optical parametric processes similarly expand spectral range through difference frequency generation. Second harmonic generators and optical parametric oscillators represent applications that have reached some level of maturity in that they exist as commercially available products. The development of other nonlinear optical processes are either still in their infancy or stagnant in their progress. The most notable example is the intensity-dependent refractive index and intensity-dependent absorption, which hold great promise in device applications but the development of which has stalled due to the lack of suitable materials [24].Since the discovery of self-focusing in materials with an intensity-dependent refractive index, and the realization of the ability of these materials to produce intensity dependent phase shifts, all-optical devices have been a topic of rigorous investigation. Early theoretical and experimental results spurred interest in optical analogs to transistors, logic gates, switches, routers, multiplexers, de-multiplexers, and much more. The research has continued as an information-hungry society demands more information and faster transmission rates requiring high speed, increased bandwidth networks. As the internet reaches into the home of the average consumer and optical communication networks approach the tens or hundreds of gigahertz speeds, system begins to push the limits of electronic devices. Increasingly, system designers will turn to all-optical systems that are free of the data-rate constraints imposed by the use of electronic devices to transmit and receive signals [25].

In this paper, we have anslysed the characteristics of the ideal optical limiter and reviewed the recent efforts by many researchers on the realization of best optical limiter using nonlinear inorganic, organic, and nano materials using different configurations.

2. Characteristics of Ideal Optical Limiter:

Optical limiting is one of the important applications of third order optical nonlinearity of materials. Nonlinear optical materials can be used for protecting sensors against high-intensity laser pulses and high-power laser beams. Devices developed for this purpose are called optical limiters. An optimum practical optical limiter can be designed and fabricated by predicting and studying the characteristics of an ideal optical limiter. An ideal optical limiter is a photonic device or component has ideal optical limiting characteristics. It can take any intensity input laser beam both continuous wave (CW) or pulsed wave of any time duration. It has to process such incident light beam internally using nonlinear properties of the medium and provide output laser beam of constant intensity or fluency. The input-out characteristics of an ideal optical limiter is shown in Figure 1. It shows high linear transmission for low input power or energy and constant output power or energy for a large variable range of input above limiting input threshold power or energy so that such device can be also used for power or energy regulation. In practice, it is possible to realize ideal limiter characteristics at least above certain minimum input power or energy is possible using different nonlinear materials which show high nonlinear susceptibility, even though it is difficult to achieve both requirements of low limiting threshold and large constant output range simultaneously. In practice, to get high transmission at low input power or energy, the limiting material used should show low linear absorption [26-27]. Based on the above discussion, we can list the characteristics of an optimum practical optical limiter as follows:

- ✓ Must possess high linear transmittance with wide transmission range.
- ✓ Should have low limiting threshold level (the input power/energy corresponding start of saturation).
- ✓ Should show fast response time (CW, nano to femto second signals).
- ✓ Should show broadband limiting response through the entire visible spectral region.
- ✓ Should have low light scattering inside the material medium.

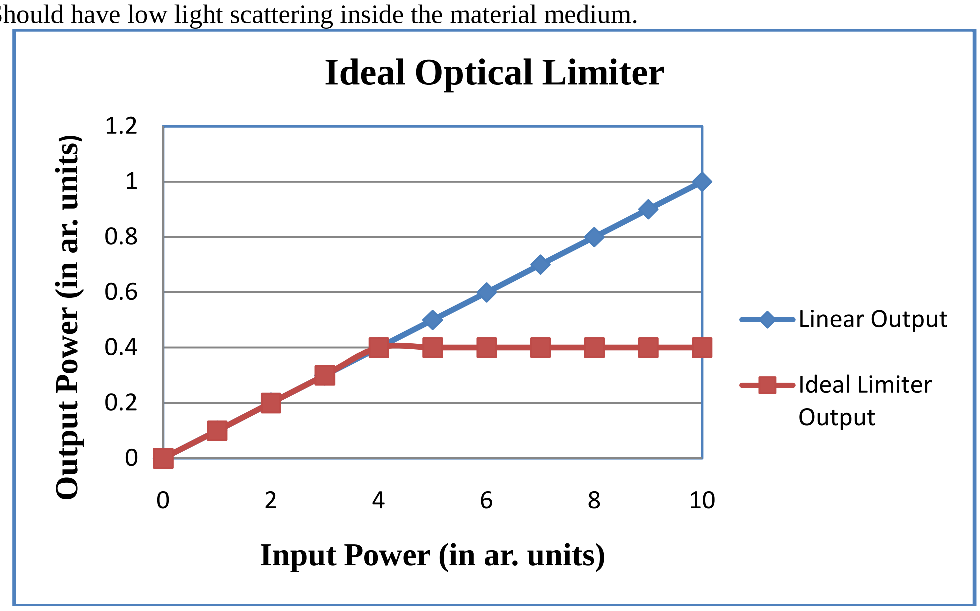

Figure 1: Input-output characteristics of an ideal optical limiter

Thus an optimum practical limiter is a device which shows linear transmission characteristics below a threshold level and fixes the output to a constant level above it, thus providing safety protection to sensors or human eyes.

2.1 Model of Ideal Optical Limiter System:

Ideal optical limiter model is developed by considering various characteristics under 4 categories such as Input conditions, Systems requirements, Output conditions and Environmental conditions. These characteristics are analysed with an objective to achieve the goal. An ideal optical limiting system shall have characteristics which can be predicted and classified. Based on various factors which decide the ideal optical limiting system characteristics, a model consisting of the input conditions, output conditions, system requirements, and environmental conditions is developed by using focus group method [28-34]. The block diagram of such ideal optical limiting system and interconnection of various components is shown in figure 2. The ideal properties of a device can be used to improve the properties of the practical device with an objective to achieve 100% efficiency.

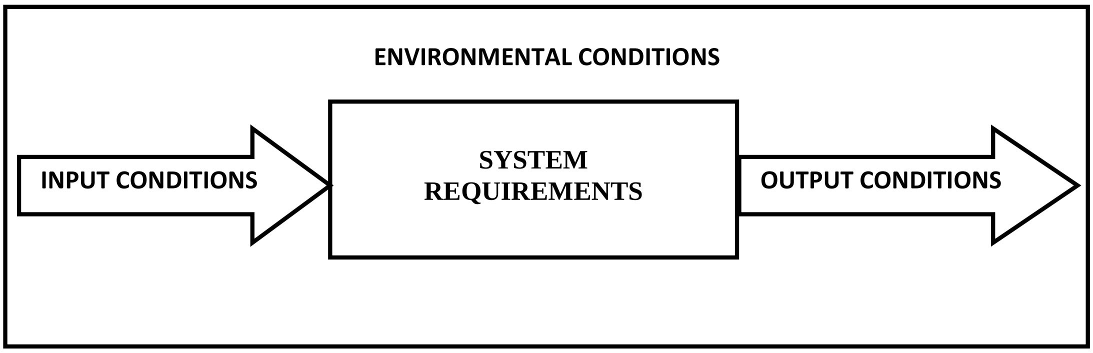

Figure 2: System model of Ideal optical limiter characteristics.

A. Input Conditions for Ideal Optical Limiter:

- ✓ An ideal limiter device should capable of taking input light beam of any intensity without any material damage.
- ✓ An ideal limiter device should capable of accepting input light beam without any reflection or scattering from incident surface.
- ✓ Any variation in the input intensity or power between zero to infinity should maintain constant output intensity irrespective of input intensity variations.
- ✓ An ideal optical limiter device should capable of taking input light beam of any wavelength/frequency of entire electromagnetic spectrum.
- ✓ An ideal optical limiter device should capable of taking input light beam of continuous wave or of a pulsed wave of any time duration.

B. System Requirements:

- ✓ An ideal optical limiter possesses high linear transmittance with wide transmission range throughout electro-magnetic spectral bandwidth. i.e., it should have infinite bandwidth.
- ✓ The transmission characteristics of an ideal limiter vary depending on the incident intensity due to nonlinear properties of the active limiting material.
- ✓ The nonlinear material medium used for fabrication of ideal limiter should have very high nonlinearity for entire bandwidth.
- ✓ The nonlinear material medium used for fabrication of ideal limiter should limit any laser beam of any power of both CW and pulsed.
- ✓ The nonlinear material medium used for fabrication of ideal limiter should not degrade the quality of output beam.
- ✓ An ideal optical limiter should show immediate response time to CW, nano, pico, or femto second signals).
- ✓ An ideal optical limiter should have zero light scattering inside the nonlinear material medium and other optical components used.
- ✓ An ideal optical limiter may use any type of third harmonic nonlinearity including nonlinear absorption or nonlinear refraction and correspondingly either Type 1 or Type 2, or Type 3 optical limiting configurations.
- ✓ An ideal optical limiter is a simple and easily portable system.
- ✓ Depending on the application, the output threshold level (power/energy) of an ideal limiter should be controlled at any level between zero to infinity and the efficiency of the system is always 100%.

C. Output Conditions:

- ✓ An ideal optical limiter shows linear transmission characteristics below a threshold level and fixes the output to a constant level above it.
- ✓ The output intensity/fluency of ideal optical limiter is independent on the wavelength and pulse duration of the laser beam.

- ✓ An ideal optical limiter should have low limiting threshold level (the input power/energy corresponding start of saturation at output).
- ✓ In the case of the ideal optical limiter, the output power/energy level is fixed at a constant value irrespective of variations in input power/energy between zero to infinity.
- ✓ An ideal optical limiter provides high-quality Gaussian output beam of constant amplitude irrespective of the quality of input laser beam.
- ✓ The ideal optical limiter system will be sustainable for a long time at desired output without any maintenance.

D. Environmental Conditions:

- ✓ An ideal limiter should provide constant output for any environmental conditions like changes in temperature, pressure, and aging.
- ✓ An ideal limiter should provide constant output irrespective of its location in the photonic device, or its geographical location and the performance should same with time or replacement of material used for optical nonlinearity.
- ✓ An ideal limiter should be a low-cost device and the value it creates through its usage in photonics should far above than its cost.
- ✓ The Ideal optical limiter device operates in a low-cost environment. It does not need an expensive location, a huge amount of infrastructure and huge investment.

The above 25 characteristics are together constitute necessary conditions of an ideal optical limiter. The ultimate objective of any nonlinear materials research for optical limiters is to find a suitable material which can show optical limiter characteristics close to ideal optical limiter characteristics. Thus an ideal limiter is a device which shows linear transmission characteristics below a threshold level and fixes the output to a constant level above it, thus providing safety protection to sensors or human eyes.

3. Practical Optical Limiters:

To reach close to the above characteristics of an ideal limiter, the practical optical limiters can make use of nonlinear materials which show both nonlinear absorption and nonlinear refraction. For optimum nonlinear absorption, the nonlinear material can make use of two-photon absorption property or reverse saturation absorption property and nonlinear refraction property simultaneously. Practical optical limiters usually will have three regions in their input-output characteristic curve with linear region, active region, and saturation region as shown in figure 3. Organic materials are potential candidates for larger nonlinearities and are getting importance to be used as effective nonlinear absorbers by showing sometimes the combined effect of two-photon absorption and reverse saturation absorption in addition to effective nonlinear refraction through thermal nonlinearity [35-41]. Due to their high resultant third harmonic susceptibility, organic materials including dyes are considered to be suitable candidates for practical optimum optical limiters.

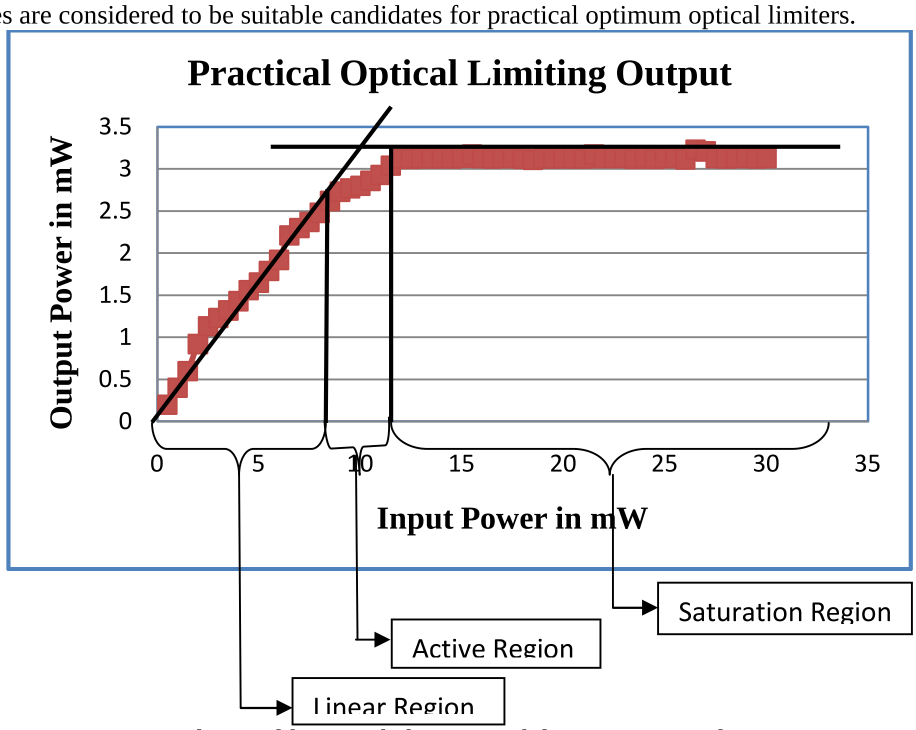

Figure 3:A Practical optical limiting behaviourwith linear, active and saturation regions.

3.1. Principles of Practical Limiters:

The first practical optical limiters for continuous (CW) lasers were based on thermal lensing effect in absorbing liquids. Thereafter, two-photon absorption, self-focusing in Kerr liquids, nonlinear scattering from carbon particle suspensions (i.e. diluted India ink) and among other processes have been suggested for pulsed laser sources [42]. Typically, it is desirable for a practical limiter to keep its transmitted focusable energy below about 1 mJ even for inputs energy up to many millijoules, while maintaining a linear transmittance of nearly 50%. As per the definition of optical limiter, it has to protect the human eye. While it is relatively easy to provide protection against a single wavelength, the presently available tunable high-power laser sources require practical limiter which works over a broad wavelength band. The device itself must also have a high damage threshold [43]. To meet all these demanding specifications of ideal limiter, the research for realizing optimum practical limiter has progressed on two areas. The first is to design and characterize new limiting materials, while the other is to design new optical geometries that maximize the range of protection using available materials [42].

Optical limiting effect used for practical limiters results from intensity dependent optical nonlinear processes like nonlinear absorption (NLA), nonlinear refraction (NLR), nonlinear scattering (NLS), photo refraction (PR), and optically induced phase transitions. The origins of such nonlinearities vary widely. For example, nonlinear absorption may be associated with two-photon absorption, excited state absorption, or free-carrier absorption. Nonlinear refraction may arise from, any of the mechanisms like molecular reorientation, excitation of free charges, the electronic Kerr effect, photo-refraction, or optically-induced thermal heating of the material. Optically-induced thermal heating or plasma generation in the medium will typically gives rise to Induced scattering. Optically-induced phase transitions are also usually of thermal origin [44].

3.2 Types of Optical Limiters:

Active & Passive Limiters: Active optical limiters work based on induced scattering of the laser beam from the material medium, whereas passive optical limiters makes use of third harmonic optical property like nonlinear absorption or nonlinear refraction.

Type 1, Type 2 & Type 3 Optical Limiters: These are passive optical limiters and based on the position of nonlinear material on focus point, away from focus point towards the detector side, and away from focus point with respect to detection side are classified into Type 1, Type 2, and Type 3 optical limiting configurations respectively. Type 1 optical limiter make use of nonlinear absorption property of the limiting material, Type 2 optical limiter make use of nonlinear refractive defocusing property of the limiting material, and Type 3 optical limiter make use of nonlinear refractive focusing property of the limiting material [45].

Tandem Optical Limiters: These optical limiters make use of multiple nonlinear elements in the device geometry to make use of combined effect of these individual effects as well as to enhance the range of effective bandwidth.

Reflective Optical limiters: Reflective optical limiter blocks light beam with excessively high total energy by reflecting them back to space, instead of absorbing them so that the output energy remains constant.

Energy Spreading Types Optical Limiters: These limiting devices work using principles of self-focusing, self-de-focusing, induced scattering, induced refraction, or induced aberration.

Energy Absorbing Type Optical Limiters: These limiting devices work using principles of nonlinear absorption or optical bistability. Nonlinear absorption includes Two-Photon Absorption (TPA), Excited State Absorption (ESA), and Free-Carrier Absorption (FCA).

Cascaded Optical Limiters: By cascading many limiting elements in a single geometry, one can decrease the activating threshold and damage threshold while increasing the limiting bandwidth. The cascaded optical limiter shows a low activating threshold, a high optical damage threshold, and broadband limiting properties [44].

3.3 Optical Limiting Configurations:

Type 1 Optical Limiting Configuration: In this experimental setup, the nonlinear sample is placed in a fixed position at the focus of the Z-scan setup. The emergent beam from the nonlinear sample is collected to a photo detector by means of a collecting lens to measure the output power (figure 4). By fixing the sample position at the focus, the input power is varied and output power is noted. Such experimental setup is named as *Optical limiting without an aperture* or *Type 1 optical limiting*. This type of optical limiting configuration will make use only the nonlinear absorption property of the nonlinear sample. In this case, both self-focusing and self-defocusing materials can be used as nonlinear sample [45].

Type 2 Optical Limiting Configuration: This experimental setup is designed only for self-defocussing nonlinear materials used as nonlinear sample. The nonlinear sample is placed in a fixed position at the valley point of Z-scan plot of the Z-scan setup and an aperture of fixed hole size is used between the nonlinear sample and the collecting lens before measuring output intensity by photo detector (figure 5). The input laser intensity is varied systematically and the corresponding output intensity values are measured by the photo detector. Such experimental setup is named as *Optical limiting with an aperture for negative nonlinearity* or *Type 2 optical limiting*. This type of optical limiting study will take care of nonlinear refraction property of the nonlinear sample [45]

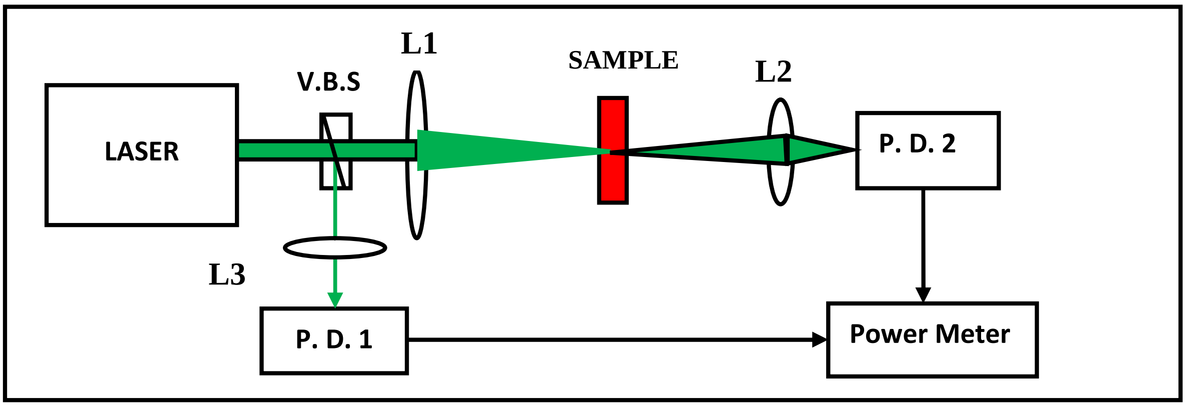

Figure 4: Experimental configuration of Type 1 optical limiter.

Type 3 Optical Limiting Configuration: This experimental setup is designed only for self-focussing nonlinear materials used as nonlinear sample. The nonlinear sample is placed in a fixed position at the peak point of Z-scan plot of the Z-scan setup and an aperture of fixed hole size is used between the nonlinear sample and the collecting lens before measuring output intensity by photo detector (figure 6). The input laser intensity is varied systematically and the corresponding output intensity values are measured by the photo detector. Such experimental setup is named as *Optical limiting with an aperture for positive nonlinearity* or *Type 3 optical limiting*. This type of optical limiting study will take care of nonlinear refraction property of the nonlinear sample.

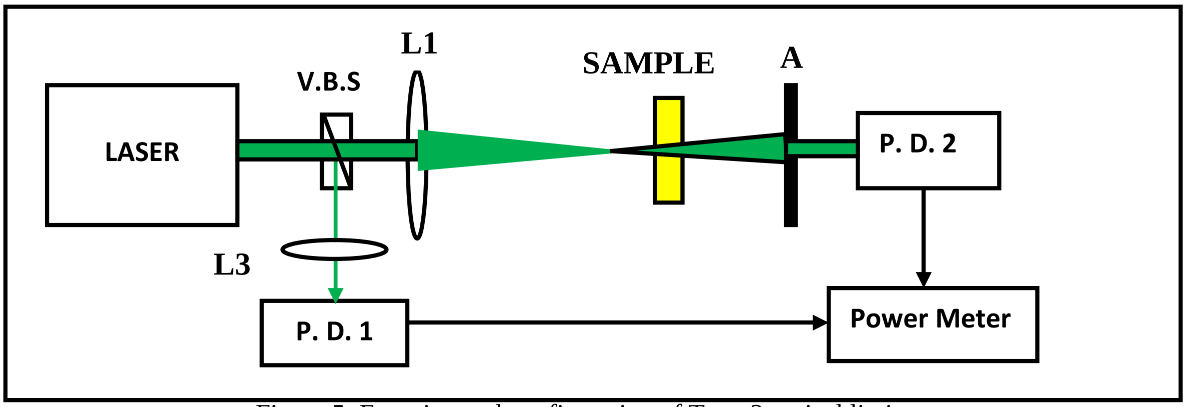

Figure 5: Experimental configuration of Type 2 optical limiter

Many techniques are used to measure nonlinear refraction which includes Nonlinear interferometry, three-wave mixing, degenerate four-wave mixing (DFWM), beam distortion, nearly-degenerate ellipse rotation, beam deflection, and third-harmonic generation for direct or indirect measurement. Similarly, various techniques used to measure nonlinear absorption include transmittance, calorimetry, photoacoustic, and pump-probe methods. However, the Z-scan technique can be used for measuring both nonlinear absorption and nonlinear refraction simultaneously but separately.

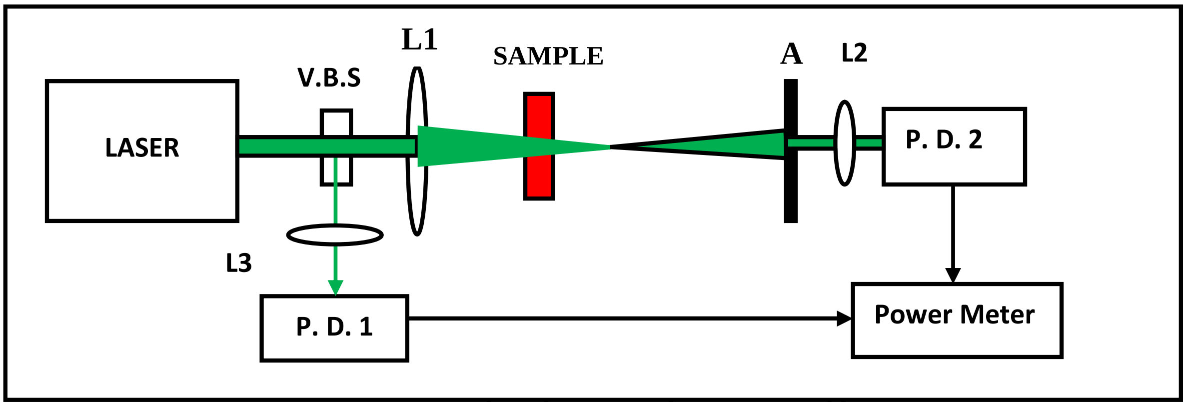

Figure 6: Experimental configuration of Type 3 optical limiter.

3.4 Methodology of Study of Optical Power Limiting:

The practical optical power limiters can be optimized by defining and identifying the characteristics of an ideal limiter. The minimum criteria identified for a material to act as an effective practical optical power limiter are:

- ✓ Having high linear transmittance with broad transmission range.
- ✓ Having low limiting threshold level (the input corresponding to the breakpoint in the curve).
- ✓ Having fast response time (e.g. picoseconds or faster).
- ✓ Having broadband limiting response (e.g. the entire visible spectrum).
- ✓ Low optical scattering inside the material.

Effective optical power limiting can be achieved in many materials by means of various nonlinear optical mechanisms which include self-focusing, self-defocusing, light-induced scattering, light-induced refraction, light-induced aberration, excited state absorption, two-photon absorption, multi-photon absorption, photo-refraction, and free-carrier absorption.

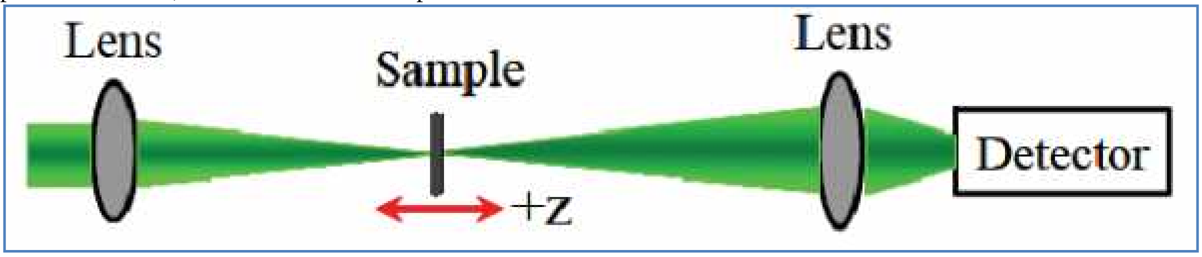

Figure 7: Open aperture Z-scan measurement configuration.

The experimental set-up for the demonstration of optical limiting under both CW illumination as well as pulsed illumination are very similar to the z-scan geometry. The schematic representation is shown in figure 7. A variable beam splitter or variable beam filter is used to vary the input power. The continuous wave laser/ pulsed laser beam of wavelength 532 nm with suitable power is used as the excitation source. The laser beam is focused normally onto the sample by a convex lens of suitable focal length. The dye-doped polymer sample has to be moved forth and back along the optic axis in order to change the position of the focal point of the lens with respect to the sample. The dye-doped film sample is placed after the focal point to get the optimum result. A lens of suitable diameter is used to collect the output beam coming out of the sample. This beam is then made to fall on a photo detector. The intensity of the input laser beam is varied systematically and the corresponding output intensity values are measured by the photo detector. In order to study the optical limiting behavior of the dye sample, the sample is moved along the direction of the laser beam at the various position around the focus of the lens (z = 0) forward and backward. The transmittance is recorded using a power meter. It is found that the limiting occurs when the sample is placed beyond the focus of the lens. Hence the sample is placed beyond the focus of the lens i.e. closer to the valley point. The output power should be noted for different input power. The graph has to be drawn between transmitted output intensity/power versus input intensity/power to study the optical power limiting behaviour of the sample [46-47].

4. Various Materials Used for Optical Limiters:

Wide varieties of organic and inorganic materials are prepared and examined to achieve efficient optical limiting. Different approaches have been developed towards better optical limiting based on, e.g., electro-optical, magneto-optical, and all-optical mechanisms. The all practical optical limiters rely on materials that exhibit one or more of the nonlinear optical mechanisms like two-photon absorption (TPA), thermal defocusing and scattering, nonlinear refraction, excited state absorption (ESA), free carrier absorption, photo-refraction, nonlinear refraction, induced scattering etc. Integrating two or more of these mechanisms has also enhanced optical limiting, like self-defocusing in conjunction with TPA, TPA in one molecule with RSA in another molecule. Different experimental configurations like cascaded limiters are also studied to achieve a large figure of merit and dynamic range [24].

Inorganic Materials: Many inorganic materials have been studied for their third harmonic susceptibility measurements to be used as effective optical limiters. Dhanuskodi et al. studied two-photon absorption and optical limiting in tristhiourea cadmium sulphate [48],Rai et al. reported two-photon absorption in TeO_2-PbO glasses excited at 532 and 590 nm [49], Tan et al. reported optical-limiting properties of neutral nickel dithiolenes [50], Liaros et al. have reported broadband near infrared optical power limiting of few layered graphene oxides [51], and Fischer et al. studied excited-state absorption and optical limiting in Zinc Phthalocyanine [52]. The femtosecond optical limiting properties of monoclinic copper niobate is reported by Priyadarshani et al. [53], Nagaraja et al. have reported the influence of annealing on the linear and nonlinear optical properties of Mn doped ZnO thin films examined by z-scan technique in CW regime [54], and Woldu et al. nonlinear optical properties of (1− x) $CaFe_2$ O_4–x$BaTiO_3$ composites [55]. Van Stryland et al. [56] have reported a comprehensive study on optical limiting with semiconductors and in GaAs [57]. Aithal et al. have studied optical limiting studies in photorefractive pure and iron-doped Bi_{12} SiO_{20} crystals [58], Cook et al. studied optical limiting with lithium niobate [59]. Similarly, optical limitation of mid-IR radiation in inorganic vanadium dioxide films [60], carbon disulfide [61], and magnesium ferrite [62] are also reported. Inorganic metal clusters have shown many advantages like (1) large number of constituent atoms of a cluster can be easily changes, (2) Various co-ordination geometries and structure types can be exploited to achieve desired nonlinear susceptibility. (3) The linear absorption spectral properties can be tailored and modified via oxidation/reduction and ligand substitution of the clusters.

Organic Materials: Organic materials have many advantages over inorganic materials. In view of the technological applications of the organic materials, the current research focus is in five technical areas, which are (1) Structural and multifunctional materials, (2) Energy and power materials, (3) Photonic and Electronic Materials, (4) Functional organic and hybrid materials, (5) Bio-derived and bio-inspired materials. Organic nonlinear materials are currently finding importance due to their advantages and benefits for photonics device fabrication. Some of the benefits of organic nonlinear optical materials are:

- ✓ **Easy to Process**: Because they do not require electric poling or the preparation of large single crystals, these materials are easier to process than inorganic optical materials.
- ✓ **Lower cost**: The ease of processing directly translates into a lower cost to fabricate.
- ✓ **High Second and Third Order Susceptibility**: This technology exhibits exceptional performance in doubling and tripling the frequency of light passing through it, making it at least comparable to inorganic materials.
- ✓ **Low Dielectric Constant**: An optical material with a high dielectric constant requires a larger poling voltage in order to polarize the dipole moment and can suffer changes in the refractive index. This technology requires no poling voltage and maintains its refractive index.
- ✓ **High Electro Optic Coefficient**: Materials with a high electro-optic coefficient are more suitable for electro-optic modulation for high-speed devices.
- ✓ **Colorless**: It is believed that the clarity of the doubling material will prevent the absorption of visible light, allowing a wide variety of light frequencies to be doubled.
- ✓ **Resistant to Laser Damage**: The tripling material can be exposed to 4,32,000 20-nanosecond pulses at 20 Hz without any evidence of damage to the organic material, making it ideal for use in photonic applications.

Many organic materials like dye doped gels [63], dye-doped liquid crystals [64], metallo-phthalocyanine/silica gel glass composites [65], Phthalocyanines [66], metalloporphyrin derivatives [67], zinc phthalocyanines [68], azobenzene [69], and many new organic-polymer composite film [70] have been studied for their attractive features including few magnitude of higher efficiency of nonlinear susceptibility. More interest has been shown in dyes and dye-doped polymer films for their optimum responses to broad band optical limiting properties which include carmine dye [71], Mercurochrome dye [72], oil red O azo dye [73], disperse red 1 dye [74], propane hydrazides [75], methylene blue [76], acid blue29 [77], sudan red B [78], Fluoroalkylated BODIPY Dyes [79], azo dyes [80], congo-red and crystal-violet dyes [81], and Rhodamine 6G doped silica and polymeric samples [82].

Nanomaterials: Optical limiting study is carried out in many nanostructures including in pulsed laser deposited VO_2 nanostructures [83], CdS nanowires [84], nano spinel ferrites [85], C 60 doped poly (ethylacetylenecarboxylate) [86], carbon nanotubes [87], gold-decorated graphenenanocomposites [88], endohedral fullerenes [89], heteroleptic Mo3S7 clusters [90], cadmium metasilicate nanowires [91], Cu/CuO Nanostructures [92], Mn doped ZnO nanoparticles [93], graphene–PbSnanohybrid [94], Fe doped CdSe nanoparticles [95], copper doped lithium tetraborate nanoparticles [96], CdS nanoparticles [97], double wall carbon nanotube–Fullerene hybrids [98], C60 and C70 solutions [99], gold nanorod thin films [100], silver-containing nanoparticles [101], β-BaB2O4 nanoparticles [102].

5. Conclusion:

Even though ideal systems are hypothetical systems, which cannot be realized completely in practice, gives a broad idea on how the practical systems can be improved continuously to reach ideal system characteristics. The ideal system characteristics of technology, business, education, banking, electrical energy, software, computing and strategy, discussed in this review, under input characteristics, system characteristics, output characteristics, and external characteristics shows an opportunity to the scientists and engineers to develop such practical systems further with an objective to reach the goal.

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