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RESEARCH OPPORTUNITIES FOR USE OF ORGANIC DYE-DOPED POLYMERS AND NANOMATERIALS-DOPED POLYMERS IN OPTOELECTRONICS AND PHOTONICS

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Abstract:

Presently the major focus of research in nonlinear optical materials is diverted on three areas of interest which include (1) Optical switching for all-optical devices, (2) Optical limiting for the protection of Eyes and photo detectors, and (3) Optical phase conjugation. All-optical switches which can break the transmission speed limits of electro-optical, acousto-optical, thermo-optical, and micro-electro-mechanical switches, can function as effective tools to solve these problems. The third-order nonlinear optical (NLO) effect based all-optical switches can be used to control light to bring changes in refractive index and hence phase difference when signal light passes through the sample and thus carry out the function of "on" or "off' of optical switches. Optical limiting is a process of controlling the intensity of laser beam beyond certain specified intensity and has applications in sensor and eye protection. Optical phase conjugation using degenerate four-wave mixing configuration has been demonstrated and analysed in many organic and inorganic materials using a light beam of pulsed or continuous-wave (CW) lasers. However, organic dyes, dye-doped polymer films, and nanomaterials-dopedpolymersshow many favourable chemical, physical and opticaldevice related issues necessary tomake an organic all-opticalswitch foroptoelectronic and Photonics. In this paper, we have suggested the use of organic dyes, dye-doped polymers, and nanomaterials-doped polymers for some of the new areas of further research and commercialization of the inventions.

Index Terms: Photonic Device Using Organic Dyes.Dye-Doped Polymers, Nanomaterial-Doped Polymers, New Research Opportunities In Organic Photonics & Organic All Optical Switch.

1. Introduction:

The advents in nonlinear optics are expected to contribute majorly to the field of photonics which is emerging as a multi-disciplinary new frontier of science and technology capturing the imagination of scientists and engineers worldwide because of its potential applications in the field of optical communication, and optical computation. Photonics is the technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The wide range of applications of photonics extends from energy generation to detection and to communication to information processing using nonlinear optical properties of materials. The major challenge of photonics is identifying a right configuration in right material and developing a right device to optimally process the signals for a right application using the knowledge, skills, and experience in material science and chemical engineering. Materials with exceptional nonlinear optical properties are critical to the continuing development of photonics, optoelectronics, and electro-optical devices, such as those used in optical communications, optical networking, optical computation for signal processing, and data storage equipments. The nonlinear optical material is a general term used for the all class of materials which show efficient and effective nonlinear phenomenon optically as the responses to realize the applications like optical wavelength conversion, optical amplification, refractive index changes etc. which are intensity dependent. Nonlinear optical materials are largely divided into inorganic and organic materials. In 1930, the nonlinear optical effect related to optical wavelength conversion is predicted, which is said to be the first finding knowledge about the nonlinear optical phenomenon. In 1960, for the first time, laser oscillation using inorganic material is reported. Since then research of inorganic and organic nonlinear optical materials are actively taken place, but nowadays, probably there is no more that undiscovered except optimization of these phenomenon using the suitable material.Thus, the present focus of research in nonlinear optical materials focus on three areas as (1) Optical switching for all-optical devices, and (2) Optical limiting for the protection of Eyes and photodetectors, and (3) Optical phase conjugation [1-5].

All-optical switches which can break the transmission speed limits of electro-optical, acousto-optical, thermo-optical, and micro-electro-mechanical switches, can function as effective tools to solve these problems. The third-order nonlinear optical (NLO) effect based all-optical switches can be used to control light to bring changes in refractive index and hence phase difference when the input signal light passes through the nonlinear optical sample and thus carry out the output function of "on" or "off' of optical switches. It is found that many properties, such as change speed, intensity loss, sensitivity to optical polarization and insert loss, etc. depend on third-order nonlinear properties of the material used for the fabrication of the device.

Optical limiters are the devices used for sensor protection against high intensity laser beam/pulses. The ideal optical limiter has the characteristics of having a high linear transmission for low input level for a variable input energy E or power P, and a large dynamic range of transmission defined as the ratio of the E or P at which the device damages (irreversibly) to the limiting input. Such devices can also be called as energy or power regulators. The primary application of the optical limiter is for sensor protection, and damage to detectors and is almost always determined by fluence or irradiance of input radiations, which are usually the quantities of interest for the output of the optical limiter. One of the main applications of the optical limiter is in avoiding laser blinding. Laser blinding can make eyes of human beings blind temporarily or permanently, andalso the laser beams can destroy important apparatus in the satellite, such as detectors and sensors. The purpose of laser protection is to protect people and devices from the damage of high intensity laser light beam. Hence, laser protection materials and devices are finding importance in photonics research. 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. It is well known that 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, excited state absorption (ESA), nonlinear refraction, free carrier absorption, photo-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 [6-10].

Optical phase conjugation (OPC) by degenerate four-wave mixing (DFWM) is another important technique used in Photonics and Optoelectronics which have applications in optical image processing, image transmission, optical filtering, optical information storage, and laser resonators. In the case of optical phase conjugation, when two counter-propagating and intense light beams interact with a nonlinear medium, together with a less intense third beam, the medium generates a fourth beam, which will be in phase conjugation of the third beam. This configuration of generation of OPC light beam is called four-wave mixing [11]. The unique feature of the generated pair of phase-conjugate beams in the nonlinear medium is that the aberration influence contained in the forward (signal) beam passed through (nonlinear medium can be automatically compensated by the phase-conjugated backward beam propagating through the same disturbing medium. Such degenerate four-wave techniques are frequently used in nonlinear spectroscopy, phase conjugation mirrors, real-time holography. Optical phase conjugation by means of degenerate four-wave mixing has been demonstrated in many organic and inorganic materials using a light beam of pulsed or continuous-wave (CW) lasers. However, organic dyes, dye-doped polymer films, and nanomaterials-doped polymers show many favourable chemical, physical and opticaldevice related issues necessaryto make an organic all-optical switch for optoelectronic and Photonics.

2. Present Knowledge of Organic Molecules for Photonics:

Organic materials show many advantages compared to inorganic materials and hence getting attraction in many areas including Structural and multifunctional materials, Photonic and Electronic Materials, Energy and power materials, Functional organic and hybrid materials, and 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 compared to inorganic nonlinear optical materials are [12]:

- ✓ **Easier for Processing:** Organic materials do not require electric poling while forming thin films or for the preparation of large single crystals. Hence these materials are easier to process than inorganic optical materials.
- ✓ **Reduced Cost**: The simple and easiness in organic material processing reduce the cost of fabrication of optical components.
- ✓ **High Nonlinear Susceptibility**: Organic material based photonic components exhibit improved performance of second harmonic and third harmonic frequency generation efficiency and hence makes them outstanding as comparable to inorganic materials.
- ✓ **Optimum Dielectric Constant**: The nonlinear optical materials with a high dielectric constant require higher poling voltage in order to polarize the dipoles and hence having a low magnitude of variations in the refractive index. On the other hand, organic materials require no poling voltage and maintain its optimum value of refractive index.
- ✓ **Higher Electro-Optic Coefficient**: Organic materials shows higher electro-optic properties and hence are more suitable for electro-optic modulation for high-speed devices.
- ✓ **Wide Transparency Range:** Many nonlinear organic materials prevent the absorption of visible light, allowing a wide variety of light frequencies to be doubled.

- ✓ **Higher Laser Damage Threshold**: The organic nonlinear materials can be exposed to higher intensity laser pulses without any evidence of damage, making it ideal for the use in photonic applications.

2.1 Organic Dyes Doped in Solids: Many organic dyesare used in photonic applications including optical switching, optical limiting, and optical phase conjugation by doping them in gels [13], liquid crystals [14], silica gel glass composites [15], many new organic-polymer composite film [16], and polymeric sample matrix for their attractive features including few magnitude of higher efficiency of nonlinear susceptibility. Recently out group has studied nonlinear optical properties of DASPB dye doped PMMA-MA polymer films, Disperse Orange (DO-25) dye doped in PMMA-MA polymer films, and Disperse Yellow (DY-7) dye doped in PMMA-MA polymer films, for optical limiting and optical phase conjugation properties using both continuous wave (CW) and pulsed lasers [17-33].

2.2. Nanomaterials Doped in Polymers Films: Optical limiting study is carried out in many nanostructures including in pulsed laser deposited VO_2 nanostructures [34], CdS nanowires [35], nano spinel ferrites [36], C 60 doped poly (ethylacetylenecarboxylate) [37], carbon nanotubes [38], gold-decorated graphenenanocomposites [39], endohedral fullerenes [40], heteroleptic Mo3S7 clusters [41], cadmium metasilicate nanowires [42], Cu/CuO Nanostructures [43], Mn doped ZnO nanoparticles [44], graphene–PbSnanohybrid [45], Fe doped CdSe nanoparticles [46], copper doped lithium tetraborate nanoparticles [47], CdS nanoparticles [48], double wall carbon nanotube and fullerene hybrids [49], C-60 and C-70 nonosolutions [50], gold nanorod thin films [51], silver-containing nanoparticles [52], β-BaB_2O_4 nanoparticles [53].

3. Opportunities for Future Research:

The invention of new materials with superior quality and characteristics is often responsible for major advances in new technologies. The high speed, high degree of parallelism of optics will lead gradually to optoelectronic systems to be converted into photonic systems where an increasing number of functions or all functions will be implemented optically. The development of photonic technology is expected to be largely rely on the progress achieved in fabricating new optical materials with optimum performance. In this chapter, the results present studies on linear absorption, nonlinear absorption, nonlinear refraction, optical limiting, and optical phase conjugation using degenerate four wave mixing are depicted and discussed.

The major challenge seems to be the collective effort required to solve many issues related to collaborative physical, chemical, and optical-device related issues necessary to fabricate an organic all-optical switch device from any chosen materials. Such efforts and skills may not be available in a single institution. The collaborative effort by several institutions and researchers supports further developments in the field and the emergence of reliable photonic devices for practical applications. Based on the opportunities for further research and support for commercialization of the inventions, the following new areas & possibilities for further research are suggested.

3.1 Suggestion for Developing all-Optical Device: An all-optical device allows one optical signal to control by another optical signal, i.e. control of light by light. These devices are used in ultra-fast communication systems based on all-optical signal processing and in also used in the fabrication of all-optical computers to eliminate the need for optical-electrical-optical (OEO) conversions. Dye-doped polymer films can be effectively used for this purpose. The major types of all optical ultra-fast communication devices are light sources, all-optical gates, and wavelength converters [54-55]. All optical devices including optical switches can be constructed with optimum switching properties using nanoparticles sensitized dye-doped polymer films [56-57].

3.2 Suggestion Towards Improving The Efficiency: Nanoparticles based dye sensitization may improve the charge carriers and polarization property of the dye-doped polymer films so that one can improve the efficiency of nonlinear optical properties [58–59]. Following research results have supported such predictions:

- ✓ Wenqiang Zou1et. al. [60] showed that the overall up-conversion by the dye-sensitized nanoparticles is comparatively enhanced (by a factor of ∼3,300) due to increased absorptivity and hence broadening of the absorption spectrum of the up converter material. Such proposed concept can be extended to a wide band of the solar spectrum by using a set of organic dye molecules with overlapping absorption spectra acting as awide broadband antenna system, connected to suitable up converters [60].
- ✓ It is also found that the mobile quantum dots (QDs) functionalized with thiol ligands in the electrolyte are used to fabricate dye–sensitized solar cells. The QDs works as mediators to receive and re–transmit the signal to sensitized dyes, thus amplifying photon collection of sensitizing dyes in the visible energy range and enabling frequency up–conversion of low-energy photons to higher-energy photons for dye absorption [61].
- ✓ It is also found that the sensitization by dye molecules on gold nanoparticles caused six-fold enhancement of the anti-Stokes emission of gold nanoparticles [62].
- ✓ In another investigation, plasmonic aluminium (Al) nanoparticles (NPs) were used to enhance the optical absorption of dye-sensitized solar cells. The Al nanoparticle increases the light absorption in solar cells using localized surface plasmon (LSP) phenomenon and also the chemical stability to iodide/triiodide electrolyte [63].

- ✓ Dye-sensitized solar cells (DSSCs) have tremendous research attraction during the past several years and their efficiency has recently jumped to ~ 15% [64].
- ✓ Solution-Processed Silver Nanoparticles are used in Dye-Sensitized Solar Cells to improve the efficiency of the photon to electron conversion process [65].

3.3 Suggestion Towards Improving Laser Damage Threshold: Even through organic materials have better laser damage threshold compared to the inorganic counterpart, while working with high power pulsed lasers, there is always a possibility of material damage or dye bleaching for a long time exposure. Researchers have the opportunity to study the possibility of improving laser damage threshold of dye-doped polymer films. Again by using suitable methods including embedding nanoparticles in the dye-doped polymer film, one can study the possibility of improving the laser damage threshold of these samples. It is also found that irradiation of high frequency light on the sample improves laser damage threshold properties [66].

3.4 Suggestions Towards Improving Physical and Chemical Properties Which are Favorable for Material Property: The physical properties and chemical properties of dye-doped polymers can be improved by means gamma ray irradiation [67]. Similarly one can study the effect of electron beam irradiation and heavy ion irradiation on dye-doped polymer films and its impact on the optical performance behavior of the doped films.

3.5 Study of Electron Beam Irradiation and Ion Irradiation on Nonlinear Optical Properties as Well as Other Material Properties of Dye-Doped Polymer Films: It is well known that the process of systematic and controlled irradiation of energetic electrons and lighter ions modifies and improves dielectric and optical processes in nonlinear optical materials [68-70]. As a continuation of the effort of improving the third harmonic efficiency of dye-doped polymer films, one can study the detailed process of modifying the physio-chemical properties further by means of systematic research on electron/ion beam irradiation study on nonlinear optical properties of dye-doped polymers.

3.6 Suggestion for Fabrication of Dye-Doped Polymer Optical Flber: Dye-doped polymer waveguide structures and devices have been found to be suitable for optical integrated circuits and short distance communications. Although optical flber networks are mainly made up of silica optical flbers (SOFs), dye-doped polymer-optical-fiber (POF) -based systems are seriously being considered for short-distance communication. This is due to the competitive ability of POF in device handling, flexibility of usage, and cost-effectiveness with respect to silica fibers [71]. Even though a higher loss factor is a major handicap for POF, recently developed techniques for decreasing losses in poly(methyl methacrylate) (PMMA) –based POF have raised much interest in this field [72-73]. The availability of inexpensive sources in the visible region has increased the use of POF in data communication over local area network systems. The implementation of short distance optical communication in the visible region needs the discovery of suitable optical amplifiers working in this region. [74-75]. Good quality dye-doped polymer optical fibers can be used for this purpose. It is shown that the performance and stability can be improved in the case of Rhodamine 6G doped polymer optical fiber as an amplifying medium [76].

3.7 Exploring the Possibility of Improving the Performance of All Optical Devices Using Nanophotonics: Nanophotonics is an emerging area where nanotechnology is used to change the physical and chemical properties of photonic materials or the effectiveness of photonic processes. Even though it is a multi-disciplinary integrated effort, future photonic components and devices will be different in terms principle, look, size, functions, features, and performance leading to optimum systems to support the major application areas like optical communication, optical computation, and Optical medical equipment. Nanotechnology is already proven as general purpose technology and its advantages in tailoring the physio-chemical properties both at fundamental and applied areas are already established a new field of technology nanophotonics. This new area has further hope to scientists and engineers to miniaturize and optimize the speed-bandwidth problems in all-optical photonic devices [77]. Hence by using nanotechnology and discovering an effective way of tailoring the properties of nanomaterial-doped polymer films, one can further continue and take the present research to the next stage.

4. Conclusion:

The various suggestions for developing all optical devices using dye-doped polymer films and using nanoparticles sensitized dye-doped polymer films; Suggestion towards improving the efficiency of the charge carriers and polarization property of the dye-doped polymer films; Suggestion towards improving laser damage threshold dye-doped polymer films and using nanoparticles sensitized dye-doped polymer films; Suggestions towards improving physical and chemical properties which are favorable for material property; Possibility of electron beam irradiation and ion irradiation on nonlinear optical properties as well as other material properties of dye-doped polymer films; Suggestion for Fabrication of Dye-Doped Polymer Optical Flber; and exploring the possibility of improving the performance of all optical devices using nanophotonics are explored as future research opportunities for new researchers.

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