IRA-International Journal of Applied Sciences
ISSN 2455-4499; Vol.04, Issue 03 (2016)
Institute of Research Advances
Pg. no. 358-378
http://research-advances.org/index.php/IRAJAS

ABCD analysis of Dye-doped Polymers for Photonic Applications

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Type of Review: Peer Reviewed.
DOI: http://dx.doi.org/10.21013/jas.v4.n3.p1

How to cite this paper:
Aithal, S., & Aithal, P. (2016). ABCD analysis of Dye-doped Polymers for Photonic Applications. *IRA-International Journal of Applied Sciences* (ISSN 2455-4499), 4(3), 358-378. doi:http://dx.doi.org/10.21013/jas.v4.n3.p1

ABSTRACT

Photonics is a subject of scientific study on generating, controlling, harvesting and detecting the beam of photons or light with a purpose of creating, manipulating, storing, transmitting and detecting information using nonlinear optical properties of materials. This paper is a new attempt to integrate scientific research and social research by analysing the characteristics of dye-doped polymer films for photonics applications. The analysing framework called ABCD framework to analyse any business concepts, business systems, technology, strategy, engineering material, technology or even an idea systematically by identifying the advantages, benefits, constraints, and disadvantages under various determinant issues and listing the constituent critical elements under each construct. In this paper, as per the ABCD framework, the various determinant issues related to the use of dye-doped polymer films for photonic applications through focus group method are determined as affecting factors under : (1) Material Issues, (2) Application Issues, (3) Commercialization Issues, (4) Production/Service providers Issues, (5) Customer Issues, and (6) Environmental/Social Issues. The constituent critical elements of these factors are listed under the four constructs - advantages, benefits, constraints and disadvantages of the ABCD technique and tabulated. The analysis has brought about 204 critical constituent elements which satisfy the success of this analysis methodology.

Keywords: Nonlinear optical materials, Dye-doped polymer films, ABCD analysis, Constituent critical elements.

1. Introduction

Nonlinear optics is expected to play an important role in the field of photonics which is a multi-disciplinary new frontier of science and technology capturing the imagination of scientists and engineers worldwide due to its potential applications in optical communication, and optical computation. According to the definition, Photonics is the technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The range of applications of photonics extends from energy generation to detection to communication and information processing using nonlinear optical properties of materials. The major challenge of photonics is identifying a right material/device to optimally process the signals for a right application using material science and chemical engineering knowledge. Materials with exceptional nonlinear optical properties are critical to the continuing development of photonic and electro-optical devices, such as those used in optical communications, networking, Optical computation for signal processing, and data storage equipment. The nonlinear optical material is a general term for the materials efficiently makes the appearance of nonlinear phenomenon optically as the responses to optical wavelength conversion, optical amplification as well as the refractive index changes due to its intensity. Nonlinear optical materials are largely divided into inorganic and organic materials. In 1930, the nonlinear optical effect related to optical wavelength conversion was predicted, which was said to be the first finding knowledge about the nonlinear optical phenomenon. In 1960, laser oscillation using inorganic material was reported. Since then research of inorganic nonlinear optical materials were actively taken place, but now-a-days, probably there is no more that undiscovered [1]. With the rapid development of modern science and technology, information transmission capacity of communication increases day by day. Optical communication, which has advantages of large transmission capacity, high transmission velocity, excellent anti-jamming ability and good Signal-to-Noise value, is becoming the main method in communication research at present. Functions like optical switching and memory by non-linear optical effects, all depending on light intensity, are expected to result in the realization of a pivotal optical device in optical computing. This is a new data processing system that makes the maximum use of light characteristics such as parallel and spatial processing capabilities and high speed [2].

All-optical networks with good performances, such as big capacity, good transparency, wavelength routing characteristics, compatibility, and extensibility, has become the first choice of next generation of the wide-band net with a promising application. Accompanied by the deep research of wave division multiplex (WDM), switches have drawn more and more people's attention. In the existing optical-electronic-optical conversion apparatus of present communication net, disadvantages of slow switching speed and clock displacement have lead to a "bottleneck" of optical fiber communication systems. All-optical switches which can break through the transmission speed limits of electro-optical, acousto-optical, thermo-optical and micro-electro-mechanical switches, can serve as effective methods to solve these problems. Based on the third-order nonlinear optical (NLO) effect, phase all-optical switches use a controlled light to bring changes of refraction index and make phase difference when signal light passes through the sample and thus carry out the function of "on" or "off' of optical switches. Its nonlinear phase difference is proportional to $(2\pi/\lambda)n_2IL$, where I is intensity, L is the length of interaction of wave and n_2 is nonlinear refraction index. The properties, such as change speed, intensity loss, sensitivity to optical polarization and insert loss, all depend on third-order NLO materials used to synthesize apparatuses. At present, it is with great enthusiasm to an emphasis on exploring and synthesis of materials for all-optical switches based on the continual discovery of varies kinds of new materials. There are other applications of third-order NLO materials, including optical limiting devices, Q-switch, passive mode locking, optical operation and light storage etc. Laser weapons applied to military have special effects on optical-electro antagonism, aerial defense and military recovery. Laser blinding can make eyes blind temporarily or permanently, and laser can also destroy important apparatus in the satellite, such as detectors and sensors. As a result, laser protection materials and devices have become a focus. The purpose of laser protection is to protect people and devices from the damage of high intensity. These optical limiting devices are mainly based on the materials' third-order NLO properties, including self-focusing, self-defocusing, two-photon absorption, reverse saturable absorption and nonlinear scattering. Comparing to earlier laser protection devices, it has advantages of fast response, wide protected band, low optical limiting threshold, large damage threshold and high linear transmission, etc. The third-order NLO properties of materials can also be used in the compression (mode-locking) and shaping of laser pulses, optical bistability, etc. Third-order NLO materials also have many potential practical exciting applications and motivated scientists to continually explore new materials with high third-order NLO properties. The demands of materials for all-optical information process and high-speed all-optical switches include large nonlinear refraction index, small linear and nonlinear absorption coefficient, fast response and low propagation loss [1-3].

Photonic and electro-optical (in which information storage or processing involves the modulation and switching of light beams) devices are used in many applications which include :

- Electro-optic modulators
- Mach-Zehnder interferometers
- Optical switches
- Optical interconnectors
- Frequency doublers for high-power lasers
- Active waveguides
- Optical memory storage devices
- Optical computing devices
- Nonlinear directional couplers
- Nonlinear Bragg reflectors
- Optical limiters
- Photorefractive memories

Currently, a wide range of inorganic non-linear optical materials is available [2-3] with varied wavelengths, damage thresholds, and optical characteristics. The research focus is to develop materials that meet all requirements such as faster response, high laser damage threshold, and wide transparency range coupled with adaptability, processing ability, and the ability to interface with other materials. Further, robust growth in demand for high bandwidth fiber optic networking infrastructure and high-speed optical computing are expected to boost the demand for Non-Linear Optical Materials [1]. Doped inorganic nonlinear crystals are also shown optical limiting properties [4-7]. Studies showed that by means of heavy ion irradiation one can improve the material properties of both inorganic and organic nonlinear crystals [8-11].

It is well known that one can improve the performance of any system by comparing it with a hypothetical, predicted system of that kind called "Ideal system" [12]. 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 [13]. Many systems like an ideal gas, ideal fuel, ideal solution, ideal fluid, ideal engine, ideal switch, ideal voltage source, ideal current source, ideal diode, ideal transistor, and ideal amplifier are familiar to everybody since school days. Recently, ideal business system [13-14], ideal education system [15-17], ideal technology system [12], ideal strategy [18], ideal energy source [19], ideal banking system [20], and ideal library system [21] are studied and their input, system, output and environmental characteristics are discussed. The properties of the ideal nonlinear material are interesting to know. In table 1, we have summarized the ideal properties of the nonlinear optical material.

Table 1 . Ideal Properties of optical nonlinear material.

S. No	**Property**	**Value**
1	Nonlinear Susceptibility	Infinity (High)
2	Refractive index	Low & constant value
3	Dielectric property	Low
4	Material property	optimum
5	Material Processing	Easy
6	Colour	Transparent and colourless
7	Transmission range	Infinite
8	Durability	Life time without degradation
9	Laser damage threshold	High
10	Transmission range	Infinite
11	Material state	Solid (Film & Fiber)
12	Electro-optic Coefficient	Infinity (High)
13	Photoconductivity	Infinity (High)
14	Photorefractive co-efficient	Infinity (High)
15	Degradation with time	No
16	Cost	Zero
17	Availability	Abundant
18	Environmental degradation	Zero
19	Weight	Zero (Low)

From the year 1982, organic nonlinear optical material research got importance due to their advantages compared to the inorganic counterpart. It is found that organic compounds with the delocalized conjugated electrons which have excellent nonlinear optical property and high-speed responsiveness due to the high mobility of electrons. Based on predictions, the 21st century is said to be an age of photonics. As one of the basic technology of photonics, improvements in the wavefront control technology using organic nonlinear optical effects are considered very important and hence research on the organic materials with excellent nonlinear optical properties, and exceptional material properties have been studied. Present developments in the field of materials chemistry show that, though inorganic materials are still the choices for many devices, interest, and scope for organic materials are growing day-by-day in view of their adaptability to various kinds of applications. The field of organic molecular materials has transformed the use of materials in the modern world in the last 40 years, and it can be seen that organic molecules provide wonderful opportunities to materials researchers to design custom-tailored materials whose properties at the macroscopic /microscopic level reflect closely to the modeled or actual behavior of individual molecules. In other words, development of novel functional organic materials is a rapidly growing area of science, which probably can replace the traditionally used materials with cheaper and better-performing new ones in the near future, and also bring out some new applications [22-24]. Research also has shown that many organic crystals have better nonlinear susceptibility compared to inorganic crystals [25-26].

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.

2. Dye – Doped Polymers for Photonic Applications

Though the present best practice in Photonics technology is the usage of organic materials/dyes that exhibit exceptional nonlinear optical properties, these organic materials have few of the drawbacks inherent in the processing of comparable inorganic materials like of intense light induced degradation or bleaching and aggregation at higher dye concentration. In order to overcome these drawbacks and for effective use of highly nonlinear dyes, the strategic idea for the next practice is doping the dye molecules in the polymer matrix. This idea of dye-doped polymer material matrix may increase the concentration of absorptive or fluorescence centers as well as the opto-chemical and opto-physical stability [27–28]. A large number of organic compounds with delocalized electrons and conjugated double bond systems, and a large dipole moment has been studied to realize the susceptibilities far larger than the inorganic optical materials [29]. The organic compounds and dyes molecules with two basic structural families of acceptor/donor/donor/acceptor and donor/bridge/acceptor have shown high two photon absorption properties. Such information can be useful in the design of more efficient two-photon dyes for imaging and power-limiting applications. Organic dye doped polymer films are used for (1) Optical amplification, (2) Rewritable optical data storage, (3) optical information storage, (4) Spatial light modulation, (5) Optical power limiting [30-33], (6) Photonic switching [34], (7) Quasi-permanent all-optical encoding [35], (8) Two photon florescence microscopy [36], (9) Frequency up-converted lasing,

(10) Three dimensional optical storage, (11) Two photon induced optical imaging, (12) photosensitive media for holographic recording and optical computing, (13) Ultrafast all-optical devices. (14) Optical phase conjugation [37-39], (15) Optical parametric oscillator using four-wave mixing [40-41], and (16) controlling light by light through optical spatial solitons [42]. Many studies have been conducted to measure nonlinear optical properties like third harmonic generation properties [43], optical limiting studies [44] and optical phase conjugation using four-wave mixing studies [45] in various nonlinear dyes doped in polymer films. In this paper, we have made an attempt to analyse nonlinear dye-doped polymer films for nonlinear and photonic applications using recently developed analysis framework called ABCD analysis framework. The acronym ABCD stands for Advantages, Benefits, Constraints, and Disadvantages.

3. About ABCD Analysis

Various techniques are used to analyze the individual characteristics, system characteristics, effectiveness of a concept or idea, effectiveness of a strategy while studying the business value in the society. The individual characteristics or organizational effectiveness & strategies in a given environment can be studied using SWOT analysis, SWOC analysis, PEST analysis, McKinsey 7S framework, ICDT model, Portor's five force model etc. Recently introduced business analysis framework called ABCD analysis framework [46] is suitable for analysing business concepts, business systems, technology, business models or business idea in terms of determining various factors for chosen determinant issues under four constructs called advantages, benefits, constraints, and disadvantages. In the qualitative analysis using ABCD framework, the concept/system/strategy/technology/model/idea is further analysed by identifying constitutional critical factors. In the quantitative analysis using ABCD framework [47], the appropriate score/weightage is given to each constituent critical factor under each construct, through empirical research, the total score is calculated for each construct and by evaluating the scores, the concept/idea/system/technology/strategy can be accepted or rejected. Thus ABCD analysis framework can be used as a research tool in these areas and is a simple but systematic analyzing technique for business models/systems/concepts/ideas/technology/strategy analysis.

4. Literature Review on ABCD Analysis

In 2015, Aithal P.S. et. al. [46] developed ABCD analyzing framework to analyze any business model/strategy/concept/system and to study its effectiveness in providing value to its stakeholders and sustainable profit through expected revenue generation. Application of ABCD analysis results in an organized list of business advantages, benefits, constraints, and disadvantages in a systematic matrix. The entire framework is divided into various issues/area of focus and various business deployment factors affecting the business/concept can be identified and analyzed under each issue by identifying the suitable critical effective element. This analyzing technique being simple gives he guideline to identify and analyze the effectiveness of any business model, business strategy, business concept/idea, and business system.

Reshma et. al. [48], have analyzed the characteristics of "Working from Home" e-business model using 'ABCD Analysis Technique'. Based on various factors which decide the Working from Home system, a model of various factors and their constituent critical elements affecting under organizational objectives, employers point of view, employees point of view, customers/students point of view, environmental/societal point of view and system requirements are derived from a qualitative data collection instrument namely focus group method. It is found that the factors supporting advantages and benefits are more effective compared to constraints and disadvantages of this model so that working from the home model may become more popular from the perspective of employers and employees in the organization in the future.

ABCD analysis framework is used for analysing Black Ocean Strategy (BOS) concept [49]. The various factors & their constituent critical factors affecting the BOS concept adopted in some of the business organizations for quick relief from the problems are identified for organizational point of view, administrative point of view, employee point of view, operational point of view, business point of view and external issues point of view are determined under the four constructs - advantages, benefits, constraints, and disadvantages.

ABCD analysis framework has been used for analysis of a concept "Higher Education Stage Model". The characteristics of the concept are evaluated based on identifying and analyzing the advantages, benefits, constraints, and disadvantages. The result supported the logic of using ABCD analyzing technique in any concept/idea performance evaluation [50].

ABCD analysis framework is also used for analysing National Assessment and Accreditation Council (NAAC) accreditation process on higher education institutions [51]. The various features of the NAAC accreditation system is evaluated based on identifying and analyzing the advantages, benefits, constraints, and disadvantages of some of the chosen issues like organizational issues, Faculty performance issues, student development/progression issues, social/environmental/community engagement issues, Infrastructure And Learning resources, and Issues on Innovations Creativity and Best Practices. The affecting factors under these issues found out using focus group method and the constituent critical elements under each factor are identified. The result supported the logic of using ABCD analyzing technique in any System/concept performance evaluation.

In another paper on "Study on ABCD Analysis Technique for Business Models, business strategies, Operating Concepts & Business Systems", the author discussed the detailed ABCD framework for quantitative studies and explained how this framework can be used for four specific instances namely Business model, Business strategy, Operational concept and Functional system are outlined here. Finally, ABCD analysing framework is compared with other known analyzing techniques like SWOC, Competitive Profile Matrix (CPM) analysis, EFE & IFE Matrices, BCG analysing frameworks, Porter's Five Forces Model, and PESTLE Analysis [47].

Application of ABCD Analysis Framework on Private University System in India is another paper published using this model in which for six determinant issues related to the functioning of a University has been chosen. These are Organizational aspects, Students Progression, Faculty development, Societal & other stakeholders issues, Governance, Leadership, and Issues on Innovations and Best Practices. Four key issues were identified under each of these and critical constituent elements under these factors are worked out. Through this analysis, 192 critical constituent elements which satisfy the success of a private university have been explored [52].

Recently, another paper on "Study of New National Institutional Ranking Framework (NIRF) System using ABCD Framework, is published in which the ranking system is evaluated using four constructs Advantages, Benefits, Constraints, and Disadvantages, this system consider all determinant issues in key areas through analyzing the major issues and identifying the critical constituent elements and concluded that NIRF provides a comprehensive ranking suitable for higher educational institutions and it takes care of many small and subtle aspects comparable to quality assessment criterion of National Assessment and Accreditation Council. [53].

Apart from using ABCD framework for Qualitative analysis, in several research studies, ABCD analysis is limited and simplified to only listing of various advantages, benefits, constraints, and disadvantages of either concept, models, systems, strategies, technology, or ideas [54-60]. These studies on ABCD listing can be analysed in detail using ABCD framework either qualitatively or quantitatively for further research.

5. ABCD Analysis on Dye-doped Polymers

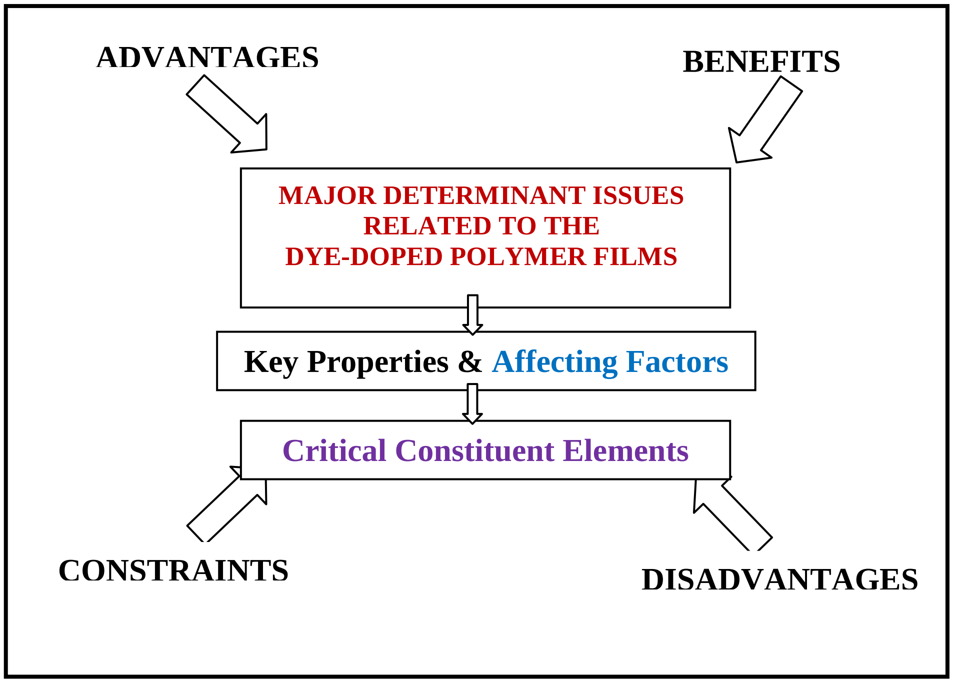

Figure. 1 . Block diagram of issues affecting the dye-doped polymer films for photonic applications as per ABCD framework.

Advantages, Benefits, Constraints and Disadvantages (ABCD) of a System can be used to analyze and understand the model/system in an effective way. As per this analysis technique, the effectiveness of a material system can be studied by identifying and analyzing the advantages, benefits, constraints, and disadvantages by considering various determinant issues related to the use of dye-doped polymers for photonic applications as shown in the block diagram (fig. 1). As per the ABCD framework, the various determinant issues related to the success of dye-doped polymer films in photonic applications identified using focus group method [61] are : (1) Material Issues, (2) Application Issues, (3) Commercialization Issues, (4) Production/Service providers Issues, (5) Customer Issues, and (6) Environmental/Social Issues.

(1) Material Issues :
The affecting factors under key properties like Processing for device fabrication, Third order susceptibility, Laser damage threshold, Electro-optic coefficient value, and Dielectric constant value are determinant factors under the constructs Advantages, Benefits, Constraints, and Disadvantages of the System.

(2) Application Issues :
The affecting factors under key properties like Optical limiting, Electro-optic modulators, Photorefractive memories, Optical switches, and Optical computer components are determined under the constructs Advantages, Benefits, Constraints, and Disadvantages of the System.

(3) Commercialization Issues :
The affecting factors under key properties like Easy to process, Low cost, High reliability, and Long life are determined under the constructs Advantages, Benefits, Constraints, and Disadvantages of the System.

(4) Production/Service providers Issues :
The affecting factors under key properties like Production cost, Performance, Durability, and Raw materials availability are determined under the constructs Advantages, Benefits, Constraints, and Disadvantages of the System.

(5) Customer Issues :
The affecting factors under key properties like Quality, Durability, Cost, and Availability are determined under the constructs Advantages, Benefits, Constraints, and Disadvantages of the System.

(6) Environmental/Society Issues :
The affecting factors under key properties like Environmental degradation, Social perception, Future scope, and Recycling are determined under the constructs Advantages, Benefits, Constraints, and Disadvantages of the System.

Each determinant issue has sub-issues called key properties used for analyzing the advantages, benefits, constraints and disadvantages, the four constructs of the framework. The factors affecting the various determinant issues of private university system for each key issue under four constructs are derived by a qualitative data collection instrument namely, focus group method [61-68], and are listed in table 2.

Table 2 . Analysis of the dye-doped polymer films for photonic applications using ABCD framework.

Determinant Issues	**Key Properties**	**Advantages**	**Benefits**	**Constraints**	**Disadvantages**
Material Properties Issues	Processing for device fabrication	Easy to fabricate as thin films	Microfilm component for device fabrication	Maintaining uniform thickness and surface	Low physico-chemical stability.
	Third order susceptibility	High third order susceptibility	Enhanced efficiency	Depending on film thickness	Bleaching of dye for long time
	Laser damage threshold	Effective performance at Low power laser	Suitable for low power devices	Sample may burn at high intensity laser beam	Low damage thresh old
	Electro-optic coefficient value	High at low applied electric field	High breakdown voltage	Applying external dc electric field is difficult	E-O coefficient varies with wavelength of laser beam
	Dielectric constant value	Low dielectric constant	No poling voltage required	Applying external dc electric field is difficult	Dielectric constant varies with wavelength of laser beam
Application Issues	Optical limiting	Limiting of High intensity laser light	Eye protection when	Limiter at all wavelengths	Nonlinear refraction property of

			working with laser beams		dye
	Electro-optic modulators	High electro-optic coefficient	Fast response	High voltage requirement for modulation	Low physico-chemical stability
	Photorefractive memories	High PR coefficient	High density storage at high retrieval speed	Doping is required to increase trapping centers	Temperature dependent properties
	Optical switches	Fast optical response	High figure of merit	Doping is required to increase charge centers	Slow time response
	Optical computer components	Easy to fabricate thin film & fibers	High speed response	Doping is required to increase charge centers	Low physico-chemical stability
Commercialization Issues	Easy to process	Easy to fabricate as thin films and fibers	Less expensive equipments required	Tedious process	Colour of dye decreases the transparency range
	Low cost	Less expensive	Easily available in the market	Low profit due to low cost	More competitors
	High reliability	Stable nonlinear properties	Used for longer period	Degradation of performance for longer period	Low phisico-chemical stability
	Long life	Stable nonlinear properties for long time	High laser damage threshold	Delicate for replacement	Not withstands at higher laser intensity
Production/Service providers Issues	Production cost	Low	Less expensive	Assembling	Periodical Replacement
	Performance	Higher susceptibility	Fast response	Anti-reflection coating	Degrades with time
	Durability	Long time	Less after sales service	Periodic service	Less life with 100 efficiency

	Raw materials availability	Easily available	Cheap	Uniform doping	Environmental degradation of dyes
Customer Issues	Quality	High nonlinear properties	Easy processing	Soft material	Bleaching of dye after several years
	Durability	Long life with expected performance	Worth investment	Maintaining outer surface of thin sample	Bleaching of dye after several years
	Cost	Low cost device	Low price	Periodic up gradation	Periodic replacement
	Availability	Easily available	Anywhere usage	Simple component	Supply of components
Environmental /Society Issues	Environmental degradation	No green gas emission	Low environment al effect	Careful handling	Dyes are poisonous
	Social perception	Advanced device for society	High speed device	Environment al effect	Low phisico-chemical stability
	Future scope	High performance devices	Advanced technology usage	Availability of dyes	Threat of better components based on nanotechnolog y
	Recycling	Possible	No degradation	Dye stability	Dye may degrade drinking water

6. Critical Constituent Elements as per ABCD model

The critical constituent elements of these factors are listed under the four constructs - advantages, benefits, constraints and disadvantages of the ABCD technique and tabulated in tables 3 to 6.

Table 3 : Advantages of dye-doped polymers for photonic applications

Sl. No.	**Issue**	**Factors affecting**	**Critical Constituent Elements**
1.	Material Issues	Easy to fabricate as thin films & fibers	Easy for spin coating
			Easy for hot press method
		High third order susceptibility	Non-centrosymmetric molecular structure
			Do not require electric poling
		Effective performance at Low power laser	Active for CW laser beam & pulsed laser beam
			Active for low power UV, visible, and IR region
		High at low applied electric field	Effective polarization
			High breakdown voltage
		Low dielectric constant	Polarization ability
			Electric field strength
2.	Application Issues	Limiting of High intensity laser light	High nonlinear absorption
			Wide transparency range
		High electro-optic coefficient	Variation of transmission amplitude
			High modulation index
		High Photorefractive coefficient	Refractive index variation with light intensity
			Charge transfer properties
		Fast optical response	Free carriers
			Optical bistability
		Easy to fabricate thin film & fibbers	Surface tension
			Strength of fibres
3.	Commercialization Issues	Easy to fabricate as thin films and fibers	Material property
			Tensile strength
		Less expensive	Easy availability
			Simple processes
		Stable nonlinear properties	Non-centrosymmetry
			Non-bleaching
		Stable nonlinear properties for long time	Material type
			Stable dye & polymer used
4.	Production/Service providers Issues	Low production cost	Easy component processing
			Availability of raw materials at low price
		Higher susceptibility	Quality of raw materials
			Organic nonlinear materials
		Long time	Functioning
			Same conversion efficiency
		Easily available	Abundant
			Low cost
5.	Customer Issues	High nonlinear properties	Non-centrosymmetry
			Efficiency
		Long life with expected performance	Faithfull operation
			Expected performance
		Low cost device	Low price

			Easy replacement
		Easily available	Abundant
			Continuous supply
6.	Environmental/ Society Issues	No green gas emission	Clean operation
			Clean environment
		Advanced device for society	Latest technology
			Environmental sustainability
		High performance devices	Efficiency
			Best output
		Recycling Possible	Low degradation
			Sustainability

Table 4 : Benefits of the dye-doped polymers for photonic applications

Sl. No.	**Issue**	**Factors affecting**	**Critical Constituent Elements**
1.	Material Issues	Microfilm component for device fabrication	Small device
			Simple device
		Enhanced efficiency	Best performance
			Better output
		Suitable for low power devices	Low cost
			Low input energy
		High breakdown voltage	Sustaining strong electric field
			High polarizability
		No poling voltage required	Natural nonlinearity
			Low cost
2.	Application Issues	Eye protection when working with laser beams	Low transmission at high intensity
			High laser damage threshold
		Fast response	Effective at nano and femto second regime
			High modulation index
		High density storage at high retrieval speed	High space charge field
			Refractive Index grating
		High figure of merit	High optical bistability
			Low noise for amplification
		High speed response	High speed grating
			High speed storage & retrieval
3.	Commercialization Issues	Less expensive equipments required	Simple and easy process
			Less and cheaper raw materials
		Easily available in the market	Abundant supply of raw materials
			Minimum raw materials requirement
		Used for longer period	Trouble free operations
			Minimum energy consumption
		High laser damage threshold	Durability
			No periodic material replacement
4.	Production/Service providers Issues	Less expensive	Low investment
			Small component size
		Fast response	Material property
			Amount of doping

		Less after sales service	No frequent breakdown
			Easy repairing/replacement
		Cheap	Simple raw materials
			Component in the form of thin film.
5.	Customer Issues	Easy processing	Simple process
			No special care needed
		Worth investment	No periodic replacement
			Return on investment
		Low price	Affordability
			High demand
		Anywhere usage	Simple operations
			Easy procurement
6.	Environmental/Society Issues	Low environmental effect	Emission
			Recycling
		High speed device	Technology
			Speed
		Advanced technology usage	Comfortability
			Better facilities
		No degradation	Poisonous gas
			Green house effect

Table 5 : Constraints of the dye-doped polymers for photonic applications

Sl. No.	**Issue**	**Factors affecting**	**Critical Constituent Elements**
1.	Material Issues	Maintaining thickness and surface	Viscosity
			Surface Tension
		Depending on film thickness	Noncentrosymmetry
			Doping concentration
		Sample may burn at high intensity laser beam	Phisico-chemical stability
			Power of input light
		Applying external dc electric field is difficult	Electric field intensity
			Film thickness
		High AC electric field is required for modulation	Material property
			Modulation index
2.	Application Issues	Limiter at all wavelengths	Material transmission range
			Nonlinear refractive index
		High voltage requirement for modulation	Electro-optic coefficient
			Modulating voltage strength
		Doping is required to increase trapping centers	Space charge
			Dye concentration
		Doping is required to increase charge centers	Nature of Dye
			Intensity variation of external light
3	Commercialization Issues	Tedious process	Thickness monitoring
			Uniform doping
		Low profit due to low cost	Less investment
			Low price
		Degradation of	Dye bleaching

		performance for longer period	Film cracking
		Delicate for replacement	Thin film
			Trouble free performance
4.	Production/Service providers Issues	Assembling	Delicate
			Simple processes
		Anti-reflection coating	Enhanced interaction of light
			Avoid reflection of light
		Periodic service	Film replacement
			Easy service
		Uniform doping	Proper solvent
			Uniform drying
5.	Customer Issues	Soft material	Polymer as backbone
			Film between glass plates
		Maintaining outer surface of thin sample	Antireflection coating
			Film between thin glass plates
		Periodic up gradation	Increases performance
			Easy
		Simple component	Susceptibility for damage
			Easy replacement
6.	Environmental/Society Issues	Careful handling	Fragile
			Complete replacement & recycling
		Environmental effect	Dyes are poisonous
			Degradability of dyes
		Availability of dyes	Nature of dye
			Supply of dye
		Dye stability	Component replacement
			Easy recycling

Table 6 : Disadvantages of the dye-doped polymers for photonic applications

Sl. No.	**Issue**	**Factors affecting**	**Critical Constituent Elements**
1.	Material Issues	Low physico-chemical stability.	Softness of film
			Fragileness/brittleness
		Bleaching of dye for long time	Reaction with atmosphere
			Reaction of dye with light beam
		Low damage threshold	Intensity of pulsed laser beam
			Choice of polymer base
			Dye concentration
		E-O coefficient varies with wavelength of laser beam	Material property with laser wavelength
			Nature of dye
		Dielectric constant varies with wavelength of laser beam	Polarizability
			Bandwidth
2	Application Issues	Nonlinear refraction property of dye	Material property
			Wavelength of light
		Low physico-chemical	Instability in electro-optic property

		stability	
		Temperature dependent properties	Thermal stability
			Working temperature range
		Slow time response	Optical bistability
			Effective intensity & wavelength range
		Low physico-chemical stability	Durability of components
			Assembling of components
3.	Commercialization Issues	Colour of dye decreases the transparency range	Transmission range of dye
		More competitors	Demand
			Profit
		Low phisico-chemical stability	Durability of device
			After sales support
		Not withstands at higher laser intensity	Dye bleaching
			Threshold intensity
4.	Production/Service providers Issues	Periodical Replacement	Durability
			Warranty
		Degrades with time	Aging of components
			Safe input intensity range
		Less life with 100 % efficiency	Warranty period
		Environmental degradation of dyes	Production easiness
			Demand for dye
5.	Customer Issues	Bleaching of dye after several years	Nature of dye used
			Operating light intensity range
		Bleaching of dye after several years	Dye property
			Faithful operation of device
		Periodic replacement	Cost of replacement
			Troubleless working time
		Supply of components	Demand
			Importance of component
6.	Environmental/Society Issues	Dyes are poisonous	Recycling the component
			Air tight system
		Low phisico-chemical stability	Optimum ingredients
			Softness & bleaching
		Threat of better components based on nanotechnology	Dye sensitized nanomaterials
			Nano-composites
		Dye may degrade drinking water	Recycling
			Usage of selective dyes

7. Conclusion

We have studied the application of dye-doped polymer films for nonlinear and photonics processes using ABCD analysis framework. The various determinant issues of related to the use of dye-doped polymer films in photonic applications identified using focus group method are : (1) Material Issues, (2) Application Issues, (3) Commercialization Issues, (4) Production/Service providers Issues, (5) Customer Issues, and (6) Environmental/Social Issues. The analysis identified the affecting factors for various determinant issues under four constructs advantages, benefits, constraints, and disadvantages.

The analysis has brought about 204 critical constituent elements which satisfy the success of this analysis methodology.

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