Chapter 1

INTRODUCTION
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1.1 Nanomaterials

In 1959, Richard Feynman, quoted “there’s plenty of room at the bottom” the brilliant concept of the nano. Nano structured materials include atomic clusters, thin films and bulk structures whose dimensionality is less than 100 nm, more typically less than 50 nm. In most of the cases, the physics of such nano structured materials were different from the macro scale of the same substance. The superior properties are the driving forces for the increased research interest in these materials. While the use of nanoscale dimensions with optimize properties is not new. The present mesoscopic physics of nanomaterials is mainly attributable to the pioneering work of Gleiter and coworkers in the early 1980s [1].

Importance of nanomaterials

- Tunable/tailorable chemical, mechanical and physical properties due to extremely fine grain size (1-100 nm).
- Superior formability and potential superplasticity.
- Posses high strength, toughness and ductility.
- Posses enhanced activity (extremely large specific area).
- Reduced thermal conductivity.
- Dispersoids can be utilized to further increase in strength.
- Reduced energy cost.

The control of composition, size, shape, and morphology of nano structured materials remains a foundation for the development and application of nanomaterials and nanoscale devices. The complex functions of these materials in devices and systems require further progress in the preparation and modification of nano structured
materials. Such advanced nanomaterials have attracted remarkable interest during recent years. Hence the development in the synthesis of nanomaterials has progressed a lot.

1.2 Synthesis of nanomaterials

During the last decade, various methods were developed for the synthesis of nanostructured materials which include nanoparticles, rods, prisms, bundles, wires, tubes etc. Till date synthesis of nanoscale materials with controlled properties is challenging for Material Scientists.

1.2.1 Bottom-up and top-down approaches

There are two ways of obtaining the nanomaterials, bottom-up and top-down methods.

Bottom-up synthesis involves the assembly of small (generally atomic or molecular) units into the desired structure. The wide variety of approaches aiming the achieving of this goal can be split into three categories: chemical synthesis, self-assembly and positional assembly.

In the bottom-up route, nano to micro scale patterned structures are assembled using interactions between molecules or colloidal particles. The approaches for the synthesis of nanomaterials using bottom-up approaches include the assembly of small units called nano building blocks into a nanostructure. Self-assembly is a bottom-up technique in which atoms or molecules arrange themselves into the order of nanoscale by physical or chemical interactions between the units.
Example: Wet chemical synthesis such as sol-gel, solution combustion, hydrothermal, solid state synthesis, evaporative decomposition, reverse micellar, etc.

- Less defects,
- Homogeneous chemical composition,
- Better short and long range ordering.

Top-down engineering involves a breaking of larger piece of material until a nanomaterials is obtained by chemical etching, milling or machining. Top-down lithographic approaches offer arbitrary geometrical designs and good nanometer-level accuracy. Lithography involves the patterning of a surface through exposure to light, ions or electrons, and then following etching and deposition of material on to that surface to produce the desired device.

Example: Ball milling, lithography, spray pyrolysis, laser ablation, etc.

1.2.2 Advantages and disadvantages

- Poly dispersity, formation of variable nano-sized particles
- Surface dislocations occur during attrition/slicing/ball milling
- During synthesis, crystallographic damage occurs to the processed patterns example: nanowires produced by this method often have surface defects which results in reduced conduction
- Morphology control of nanoparticles is difficult
- Introduces internal stress,
- Surface defects (i.e. imperfections)
- Contaminations
1.3 Phosphors

The word phosphor was first invented in the early 17th century by Vincenzo Casciarolo of Bologna. Casciarolo was an alchemist interested in the transformation of humbler materials into gold. He fired the stone in a oven planning to convert it into a noble metal, but no metals were found. Instead he found that the sintered stone was emitting red light in the dark after exposure to sunlight. The stone was called the “Bolognian Stone” or “Litheo phosphorus” and it became the first object of scientific study of the luminescent phenomena. Similar findings were reported from many places in Europe after the first discovery, and these light emitting stones were called phosphors [1, 2].

The credit for preparing the first phosphor should however go to the Japanese. It is reported that they have prepared phosphorescent paint from seashells [3]. In 1768 John Canton from Europe prepared a phosphor from oyster shells that had reacted with sulphur [1, 4].

Phosphors find extensive range of uses, from fluorescent lamp to luminescence immunoassay [1]. These materials convert one form of energy into visible radiation and hence, are called optical transducer. In the fluorescent lamp, phosphor materials convert UV radiation into visible radiation. Fluorescent lamp is made of glass tube consists of noble gas and Hg vapour are present in some optimized pressure [1]. In the electric discharge, Hg atoms are excited
to higher energy levels. When they return to ground state, it emits 254 and 185 nm wavelengths into visible radiation.

A phosphor material, ZnS cannot be used directly with Hg because of reaction between Hg and ZnS. There are three types of fluorescent lamps currently available in the market [2]. Among them, tricolour lamp phosphors are 60 wt.% $Y_2O_3:Eu^{3+}$, 30 wt.% $CeMgAl_{11}O_{19}:Tb^{3+}$ and 10 wt.% $BaMgAl_{10}O_{17}:Eu^{2+}$, where $Eu^{3+}$, $Eu^{2+}$ and $Tb^{3+}$ are activators. The green phosphor has been replaced by other two green phosphors, viz. $(La, Ce)PO_4:Tb^{3+}$ and $(Ce,Gd)MgB_5O_10:Tb^{3+}$ reduces the concentration of terbium oxide and hence, cost of the phosphor is improved [3]. Due to improved lumen output and greater radiation stability of tricolour lamp phosphors diameter of the fluorescent lamp could be reduced to 10 mm from 38 mm. This invention results in Hi-Tech compact fluorescent lamps with various sizes and shapes.

Phosphors with high brightness, fast response and long term stability are required for the progress of modern luminescence devices. The rare earth (RE) ions activated phosphors show good luminescent characteristics but some times not stable in high vacuum and corrosive gas emission under electron bombardment. Several reports dealing with synthesis technique and luminescent properties of RE doped nanoparticles have appeared previously [1]. Among these, the lanthanide doping phosphors is interesting because it may result in a sharp strong fluorescence due to characteristic emission of lanthanide
ions. Also luminescence quenching of lanthanide ions occurs at higher concentration in smaller particles. So it is of great advantage to dope more lanthanide (III) ions in the host lattice.

In order to get good luminescence, phosphor hosts should have the following characteristics. They should be compatible with the luminescent centers. i.e. accommodate the luminescent ions and allow them to involve in the luminescence process. Further, they should not react with the luminescent ions to form compounds. They should be stable during fabrication of lamps. They should be stable to highly energetic electrons, ultraviolet radiation and mercury (Hg) vapor.

The mercury-free fluorescent lamp is fundamentally a Xe discharge lamp with a phosphor layer inside the flat glass [2, 4]. This emission mechanism, based on Xe-gas discharge, has already been utilized in plasma display panels (PDPs). The mercury-free fluorescent lamp contains a mixture of Xe and Ne gases.

The fluorescent lamps are coated with phosphor by using a suspension activator concentration is of the order of 1–3 %. Therefore, high quality starting materials and a clean production process are prerequisite for obtaining luminescent materials with a high efficiency. Luminescent properties of lamp phosphors are affected by structure of hosts, activator, sensitizer, flux etc. The morphology, the chemical composition and its surface properties have also play an important role in the function for phosphors.
It is reported that the electrical and optical characteristics of very small particles are caused by quantum effects due to their high surface to volume ratio, which increases the band gap by reduction of the number of allowable quantum states in the small particles [5]. In addition, quantum confinement (QC) in nanocrystalline materials may result in an enhancement of their luminescence. Therefore, the recent research on luminescent nanomaterials provides challenges to both fundamental and advanced development of technologies in various areas of lightning systems [6].

1.4 Methods of preparation

Traditionally multi component ceramics have been prepared by solid state methods, which involve physical mixing of hydroxide, oxide, carbonate, nitrate or sulphate raw materials followed by high temperature treatment, for a lengthy period. This method results in powders with coarse grained, agglomerated structure with very low surface. High temperature leads to poor sintering behavior, inhomogeneous microstructure, possibly abnormal of grain growth and lack of control of cation stoichiometry. In order to obtain nanoscale ceramics at relatively low temperature, various chemical syntheses for new materials with proper morphology have been proposed and developed over the last few decades [7, 8].

1.4.1 Solid State method

Preparation of single phase compound is challenging by the conventional method. Hence, doping a low concentration of activator
has always been delicate. Thus, the conventional method involves inhomogeneity of the product, growth of particles to larger scale with low surface area, presence of defects. The problem of in homogeneity could be lessened by the use of wet-chemical. The problem of inhomogeneously could be mitigated by the use of wet chemical methods.

1.4.2 Hydrothermal synthesis

Water dissolves non-ionic compounds under high pressure and high temperature, it is considered as an excellent solvent for many ionic compounds. In hydrothermal synthesis, this property of water has been effectively exploited for the preparation of fine powders of metal oxides [9, 10]. Under these hydrothermal conditions, water plays two roles as pressure transmitting medium and solvent for the precursors. Such hydrothermal conditions effectively brings down the activation energy for the formation of final phase, which can also speed up the reaction between the precursors, otherwise it would occur only at very high temperatures [11, 12]. An autoclave is invariably employed to achieve hydrothermal conditions. The pressures attained are in the range of 10 to 150 kilo bar which depends on the chosen temperature of water (>373 K). Powders are either crystalline or amorphous depending on chosen hydrothermal conditions [13, 14]. Hydrothermal method has certain advantages as well as some disadvantages which are given below. Advantages: (i) Powders are formed directly from the solution (ii) possibility of
controlling the particle size and shapes by using different starting materials and hydrothermal conditions (iii) Resulting powders are highly reactive, which aid in low temperature sintering. Disadvantages: (i) Prior knowledge on solubility of starting materials is required (ii) Hydrothermal slurries are potentially corrosive (iii) Accidental explosion of the high pressure vessel cannot be ruled out.

1.4.3 Sol–gel synthesis

Sol–gel is the multi step process involving chemical and physical processes associated with hydrolysis, polymerization, gelation, condensation, drying and densification [15]. This process generally starts with the mixing of metal alkoxides or salts in water or in a suitable solvent (usually an alcohol) at ambient or slightly elevated temperatures [15, 16]. In sol gel process, controlling the pH of starting solution is very much important to avoid the precipitation as well as to form the homogenous gel, which can achieved by the addition of base or acidic solutions [17]. Apart from the above, organic compounds with hydrophilic functional groups in small molecules such as citric acid, succinic acid, oxalic acid, tartaric acid, acrylic acid, etc. and polymers like polyacrylic acid (PAA) and polyvinyl pynolidone (PVP) can be used with metal ion sources to form the sol [17-19]. The gel intermediate is further heated between 150°C and 300°C to eliminate volatile organic components, excess water, etc., which results the dried intermediate powders. Single phase nanocrystalline metal oxides are obtained after calcining of dried gel powder at 400-800 °C depends
on the precursor chemical nature [20, 21]. Advantages: (i) Low temperature processing and consolidation is possible (ii) Smaller particle size and morphological control in powder synthesis (iii) Sintering at low temperature also possible (iv) Better homogeneity and phase purity compared to traditional ceramic method. Disadvantages: (i) Raw materials for this process is expensive (in the case of metal alkoxides) compared to mineral based metal ion sources (ii) Products would contain high carbon content when organic reagents are used in preparative steps and this would inhibit densification during sintering (iii) Since several steps are involved, close monitoring of the process is needed.

1.4.4 Chemical co-precipitation

Co-precipitation synthesis is useful for the preparation of complex fluorides, because it does not require expensive starting materials; it results in smaller grains and more homogeneous distribution of dopant ion [22]. However, repeated washing in order to eliminate the anions coming from the precursor salts used, making the process complicated and very time consuming. And calcination is required to get crystalline phosphors.

Wet chemical methods are now available for simple oxide phosphor synthesis with much number of hosts. These methods are defined as not comprise of the normal mixing, calcinations and grinding operations. Wet chemical methods viz co-precipitation, hydrothermal, sol–gel, reverse micellar, surface modifier, etc. have
been employed to synthesize rare earth activated lamp phosphors. These wet-chemical methods dope rare earth activators uniformly. But, calcination is essential to get required material.

1.4.5 Solution Combustion Synthesis (SCS) method

Combustion method [23] is a wet-chemical method which does not require further calcinations and repeated heating. This method was accidentally discovered in 1988 in Prof. Patil's lab in India. It is an exothermic reaction and occurs with the evolution of heat and light. For combustion, when the mixture of fuel and oxidizer are ignited, combustion takes place. Stiochiometric compositions of metal nitrates and fuels are calculated based upon propellant chemistry. Thus, heat of combustion is maximum for O/F ratio 1 [24]. The valency of nitrogen is taken as zero because of its conversion to molecular nitrogen during combustion.

Solution combustion synthesis is an adaptable, simple and quick process which allows effective synthesis of a variety of nanosize materials.

Advantages of combustion synthesis

- Use of simple equipment
- Creation of high purity products
- Stabilization of meta stable phases and
- Formation of nanoscale size and varied shape materials.
- The combustion temperature of SHS is normally above 2000 °C
The size of the production powder by SHS is comparably large.

Though SCS is a simple technique for the preparation of phosphor materials this method also has some limitations such as

- Surface roughness and large aggregation are found in the prepared products.
- Preparation of fuels consumes more time and the yield obtained is very low.
- The fuels used during combustion are carcinogenic and liberates large amount of toxic gases.
- As SCS is exothermic if the temperature is not controlled it may lead to explosion.

The SCS reaction mainly depends on several processing parameters such as fuel, water content, flame temperature and gaseous products released during combustion [22].

1.4.6 Role of fuels

Fuel helps in burning the reaction mixture by breaking C-H bonds or gaining electrons. The ignition temperature of these fuels is low and is combustible due to the presence of N-N bond that decomposes exothermically to N₂ (N≡N) [22]. Example: carbohydrazide (CH), oxalyl dihydrazide (ODH), malonic dihydrazide (MDH), urea, glycine, etc.

1.4.7 Water content

During preparation of nanomaterials water is added to the reaction mixture for uniform dispersion of atoms. If excess of water is
left during combustion, the water content may reduce the flame temperature as a result complete burning of redox mixture does not takes place resulting in incomplete crystallization of the required compound. And surface area also decreases with increase in water content.

1.4.8 Importance of gaseous products

During combustion large amount of gases are released such as H₂O, CO₂ and N₂, etc. These gaseous products released during combustion helps in dissipating the heat released during combustion reaction. The increase in release of gaseous products increases the surface are of the material by creating micro and nano porous structure.

1.4.9 Flame temperature

The exothermicity of the redox mixture plays an important role in CS for the formation of the different phases of the compound. The flame temperature mainly depends on the decomposition of fuels, by releasing large number of gaseous products. As the amount of gas increases the flame temperature decreases.

1.4.10 Fuel-to-oxidizer ratio

The CS also depends on the fuel to oxidizer ratio. The rate at which CS takes place is when the stoichiometry or the equivalence ratio (φ = oxidizer/fuel) maintained unity, combustion may not take
place at all if the stoichiometry is not maintained. Highly crystalline nanomaterials can be obtained by increasing the amount of fuel so that no annihilation is required [22].

1.5 Principle of propellant chemistry

The stoichiometry of the redox mixture for combustion is calculated based on the thermo chemical concepts of propellant chemistry. In the combustion synthesis, the energy released from the exothermic reaction between the nitrates and the fuel at very low temperature. As an example, gun powder is generally a fine milled mixture of potassium nitrate, sulfur and charcoal, with the weight ratio of 75:10:15. Once ignited, it burns quickly, a strongly exothermic reaction, accompanied by a release of smoke. The overall reaction can be represented as follows.

\[
2\text{KNO}_3 + \text{S} + 3\text{C} \rightarrow \text{K}_2\text{S}(s) + 3\text{CO}_2(g) + \text{N}_2(g) \quad \text{............} \quad (1.1)
\]

i.e., gun powder $\rightarrow$ solid product + gaseous product + heat

It should be noted that the three ingredients of gunpowder are solid, among them; potassium nitrate acts as an oxidizer whereas both sulfur and charcoal act as fuels. This triggered an idea to develop a novel combustion method for synthesizing oxide ceramic powders. The concept is that, if mixtures composed of metal nitrates with a suitable fuel in an appropriate ratio are ignited and burnt to form ceramic oxides. Gunpowder generates a lot of gases when burned. As stated above, a theory for improving the combustion synthesis method
has been established accordingly. Use of suitable raw material in combustion synthesis ensures stability of the chemical composition and high quality of products. More importantly, it must be readily available and convenient to use. In addition, it should not react violently and should only produce non-toxic gases.

1.5.1 Historical perspective

Synthesis of materials involving spontaneous exothermic redox reactions traces its historical developments back to ancient ages. Earliest example like termite and carbothermal reaction comes from the Iron Age about 2000 years ago. The literature on the combustion process has been reviewed by many authors. In 1825, Berzelius found that amorphous zirconium metal burns to give oxide metal is quite resistant to ignition and does not quickly oxidize unless heated in its powdered above redness. Later, St. Deville and Troos discovered that zirconium form. Nitrides of other transition and rare earth metals were also prepared by combustion synthesis towards the end of the last and early part of 20th century. In 1902, Mutumann and Kraft found that powdered cerium burns violently in gaseous nitrogen with appreciable incandescence and that a cerium nitride results. However, it was Goldschmidt who discovered the self-propagating phenomena in exothermic solid-solid non-catalytic reactions.

In 1949, Alexander proposed the synthesis of nitrides of alkaline earth metals such as calcium nitride by a similar process. In the mid-1950s, researchers in the United State of America extended the
Combustion synthesis to produce various cermet compositions. Combustion synthesis of aluminum phosphide using the self-propagating principle was discovered in 1953. Equipment for self-propagating synthesis and different ways of ignition of batch of reactive material placed in a tubular container were described the process in the 1960s. The self-propagating solution combustion method developed by Patil et al. [25] has been used to prepare a variety of binary, ternary and quaternary metal oxides. The review on combustion synthesis by Patil et al. [26] classified the combustion synthesis into four types (a) self-propagating high temperature synthesis (SHS); (b) flame synthesis; (c) solution combustion and (d) redox compounds combustion process.

In 1972, Merzhanov et al. [27] discovered the “self-propagating high temperature synthesis (SHS) process for synthesis of refractory in organic compounds such as carbides, borides, nitrides, silicides and sulphides by using the combustion synthesis route. The SHS method, though self-propagating in nature, requires high temperature for ignition and can propagate only through a narrow zone. Most of SHS reactions are gasless because they produce minimal amounts of gas compared to explosives and propellants.

1.6 Importance of host phosphors used in solid state lighting

**Titanates:** Due to excellent chemical and thermal stability of titanates, they are considered to be one of the best host materials for luminescent centers. Titanates based phosphor has been widely used
in color television, flat panel display applications. Further, titanates hosts have been paid considerable attention because of their stable crystal structure, better physical and chemical stability, long persistence time, multi-color phosphorescence [28].

Calcium titanate (CaTiO$_3$) is a perovskite structured chemically and thermally stable material with excellent mechanical resistance. Because of these properties, this compound is considered as a candidate for a new phosphor or even a new host for powder lasers. The refractive index and melting point of CaTiO$_3$ are 2.4 at (632 nm) and 2220 K respectively. Further, CaTiO$_3$ is a promising, multipurpose luminescent host material due to the capability of obtaining multi-colors from various guest ions. In this host matrix, the octahedral (TiO$_6$) ion offers excellent mechanical resistance and stability to the phosphor material. In view of the practical importance and immense potential applications, we have chosen nano CaTiO$_3$ for the present work.

1.7 Photometric properties of white LEDs

1.7.1 Chromaticity coordinates

The widely reported chromaticity coordinates consist of $x$, $y$ and $z$ values. However, since the $z$ value is dependent on the $x$ and $y$ values given by $z = 1 - x - y$, it is not reported and instead a two dimensional chromaticity diagram of $(x, y)$ suffices. The perceived color is determined by looking at the corresponding coordinates on the standard CIE (Commission Internationale d’l’Eclairage - The
International Commission for Illumination) chromaticity diagram. CIE defines the international standards for color science, and the CIE 1931 color matching functions and chromaticity diagram are commonly used corresponding standards in both industrial production and scientific research [14, 15]. Each compound corresponds to an approximate response of each type of the red-, green-, and blue-sensitive retinal cones. Eqs. (1.1) – (1.3) are used to determine the strength of each perceived red, green and blue colors (i.e., X, Y and Z, respectively), where $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ are the color matching functions and $P(\lambda)$ is the spectral power density.

![Spectral distribution of color matching functions](image)

Fig. 1.1. Spectral distribution of color matching functions [16].

$$X = \int_{\lambda} \bar{x}(\lambda)P(\lambda) \, d\lambda$$

......(1.1)
\[ Y = \int_{\lambda} \bar{y}(\lambda) P(\lambda) \, d\lambda \] ....(1.2)

\[ Z = \int_{\lambda} \bar{z}(\lambda) P(\lambda) \, d\lambda \] ......(1.3)

The \((x, y)\) and \(z\) chromaticity coordinates are calculated from \(X, Y,\) and \(Z\) by normalizing them with respect to their sum using the Eqs. 1.4 - 1.6. Therefore, \(z\) can be extracted from \((x, y)\) as shown in equation.

The equal energy locus located in the center of the chromaticity diagram at \((x, y, z) = (1/3, 1/3, 1/3)\), but this might not be necessarily the desired operating point, which rather depends on the targeted application.

\[ x = \frac{X}{X + Y + Z} \] .....(1.4)

\[ y = \frac{Y}{X + Y + Z} \] .....(1.5)

\[ z = \frac{Z}{X + Y + Z} = 1 - x - y \] .....(1.6)

1.7.2 Colour temperature

The relation between the color and temperature stems from the blackbody radiation. The \((x, y)\) tristimulus coordinates of the blackbody radiators form the Planckian locus as shown in Fig. 1.2 and the color temperature of a light source is determined by looking at the coordinates of the corresponding blackbody radiation temperature,
whose unit is Kelvin [14]. However, in Fig. 1.2 the Planckian locus is only a small portion of the (x, y) chromaticity diagram and there exist many operating points outside the Planckian locus. If the coordinates of a light source do not fall on the Planckian locus, the correlated color temperature (CCT) is used to define the color temperature of a light source. CCT is calculated by transforming the (x, y) coordinates of the light source to (u', v') by using Eqs. (1.7) and (1.8) [6], and by determining the temperature of the closest point of the Planckian locus to the light source on the (u', v') uniform chromaticity diagram (Fig. 1.2) [19].

\[
\begin{align*}
    u' &= \frac{4x}{-2x + 12y + 3} \\
    v' &= \frac{9y}{-2x + 12y + 3}
\end{align*}
\] 

\[\text{......(1.7)}\]

\[\text{......(1.8)}\]

Fig. 1.2. (a) CIE 1931 (x, y) chromaticity diagram [16].
(b) Planckian locus shown in the (x, y) chromaticity diagram [17].
1.8. Review of literature

Now-a-days, efforts have been made for the synthesis of low cost and efficient luminescent materials by different synthesis process. Among the phosphor materials that are available in the market titanates doped with rare earths and transition metal ions are considered as a novel luminescent materials which are used for lamps, cathode ray tubes (CRTs), plasma display panels and dosimeters due to their stable crystal structure and high chemical and physical stability.

As can be seen from the brief review of literature, a very limited work has been reported on the synthesis and luminescence studies of solution combustion synthesized titanate host materials. Therefore, in the present work, rare earth doped calcium titanate nanophosphors were prepared by solution combustion method using urea as fuel.

1.9 Scope of the present work

Conventional incandescent and fluorescent lamps rely on either heat or discharge of gases. Both phenomena are associated with large energy losses that occur because of the high temperatures and large Stokes shifts involved [35, 36]. In 1996, a totally new lighting device was invented by Nichia Chemical Co. by means of a blue indium gallium nitride (InGaN) light emitting diode (LED) chip coated with
yttrium aluminum garnet yellow phosphor (Y₃Al₅O₁₂:Ce, YAG: Ce) [37]. Until now, the conventional white light sources have almost reached their physical limit of efficiency, as shown in Fig.1.3.

![Fig.1.3. Improvement of luminescence efficiency with years](image)

The luminescence efficiency of semiconductor based white LEDs can be improved by reducing the non radiative recombination of electron–hole pairs in the p–n junction and by introducing new structure to increase the quantum efficiency [38]. The reduction in the costs of white light makes them more competitive for the future. It is believed that LED based solid state lighting is the next generation lighting source for common illumination [39-41].

At present, RE based phosphors with efficiencies close to 100 % are employed in different fluorescent tubes, X-ray imaging, and color televisions [30, 31]. However, a good phosphor for excitation is not necessarily a good choice for excitation by semiconductor LED chips.
An intensive understanding of the nature and limitations of phosphors and the factors dominating the general trends in white light emitting diodes (WLEDs) is essential for evolving industrial applications.

Now-a-days, solid-state lighting (SSL) that uses light-emitting diodes (LEDs) for illumination has attracted more and more interest [39 - 41]. Therefore, the phosphor materials play a critical role in the innovation of solid-state lighting, which is expected to be the next illumination light sources. In this regard, titanates were chosen as host materials in this work. However, most titanate phosphors are prepared by the conventional solid-state reaction with mixing of each of starting material and grinding of the powder after calcinating them to make fine samples [45], which greatly reduce the luminescence properties of the phosphors.

Even though numerous techniques have been developed for the production of nano particles, flame processes are so far the most popular ones for the manufacture of commercial quantities of nano particles. Among low temperature techniques, combustion synthesis route has presented great commercialization potential with high production rates, broad temperature controllability, low cost, and synthetic flexibility on choosing host materials.