Chapter - 2

## 2.1. Introduction of RE doped Lanthanum phosphor:

Recently various phosphor materials have been actively investigated to improve their luminescent properties and to meet the development of different display and luminescence devices. There are some requirements of phosphor material to use in a different display and luminescence devices.

### 2.1.1 Physical requirements:

The morphology (phosphor particle size and shape), particle size distribution (PSD), body color and rheology are the important physical requirements as display phosphors. The rheology of a paste or slurry depends on size and shape of particles, binders and vehicles used in past formulations. Currently, most the displays are manufactured by depositing phosphor particles by settling, slurry, dusting, screen printing or ink jet process. The morphology, PSD and phosphor thickness not only affect the display manufacturing process but also influence the performance of the display. Preparing phosphor in presence of various flux materials can modify its morphology and improve the luminescent characteristics. The spherical shape of the phosphor particles helps to minimize the quantity of binder as well as vehicles required in coating process. It is also known that screens with smaller size phosphor particles have higher packing density and better performance.

### 2.1.2. Optical requirements:

The following optical properties of phosphors need to be optimized in various display applications:

**a) Excitation**

For example, PDP phosphors should have a high conversion coefficient under VUV excitation. The photon energy from the plasma discharge is essentially absorbed by the phosphor matrices and then transferred to luminescent centers. Since the emission from plasma discharge (Xe/Xe*) is limited to two dominant spectral lines at 147 and 172nm, most of the common luminescent materials do not have absorb at these wavelengths. Depending on the ratio of gas mixture, the intensity of the two lines varies. Same principles apply to UV (254nm from Hg vapor) excited lamp phosphors being used in LCD backlight applications.

**b) Emission and Brightness**

Brightness from a phosphor is a key of its performance in a display. Ideally, phosphor materials should have high quantum efficiency (QE), high reflectivity for visible light. Phosphors with higher QE not only minimize the power consumption but also reduce the cost of electronics required to operate the display. Phosphors in current use have achieved QE up to 95%. The emission of individual phosphors (R,G,B) should satisfy the NTSC requirements.

**c) After Glow Decay or Persistence**

For display applications, one has to consider short as well as long time persistence behavior of phosphors. Short time persistence value, defined as the time for the decay to reach 10% of the initial brightness, should be between 6 and 9 ms. The long time persistence component should contribute less than 0.25% to the initial brightness after 2 to 10s after the termination of excitation. The origin of the long persistence is similar to that of fluorescence, but the metastable state to ground state transition is forbidden. Emission occurs when thermal energy raises the electron to a state from which it can de-excite; therefore, this process or phosphorescence is temperature-dependent.

**d) Color Coordinates/ Gamut and Color Temperature**

The color purity of a phosphor depends on the spectral energy distribution of the emission. Generally the color purity can be determined by measuring its x, y coordinates on a standard CIE color chart. The color gamut of a phosphor is represented as an area in the CIE 1931 chromaticity diagram with the curved edge representing the monochromatic colors.

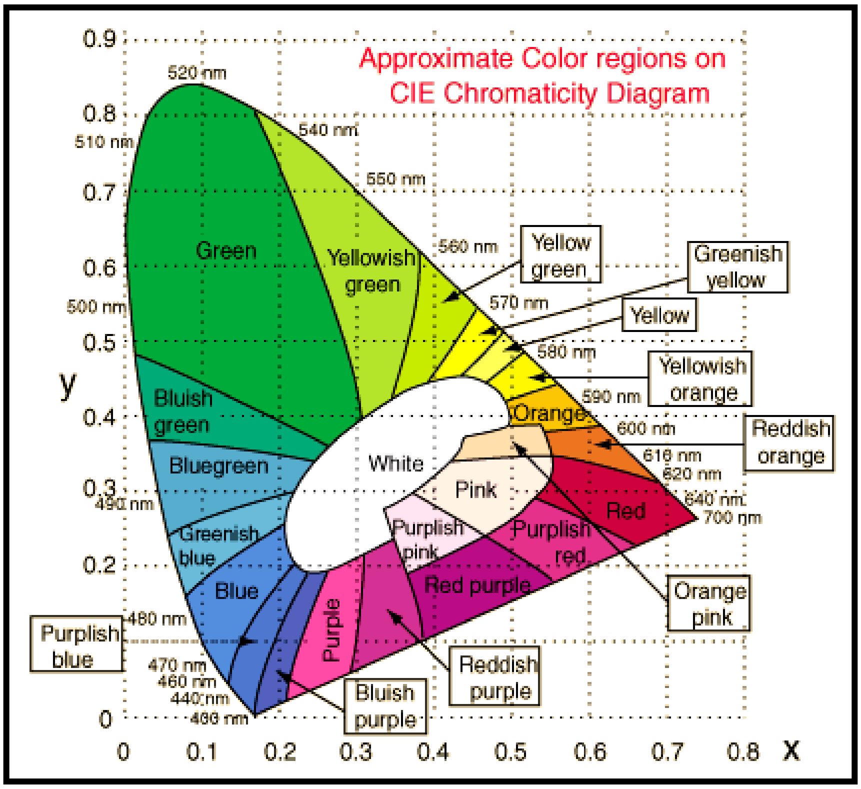


**Fig.2.1.2a CIE 1931 Chromaticity Diagram**

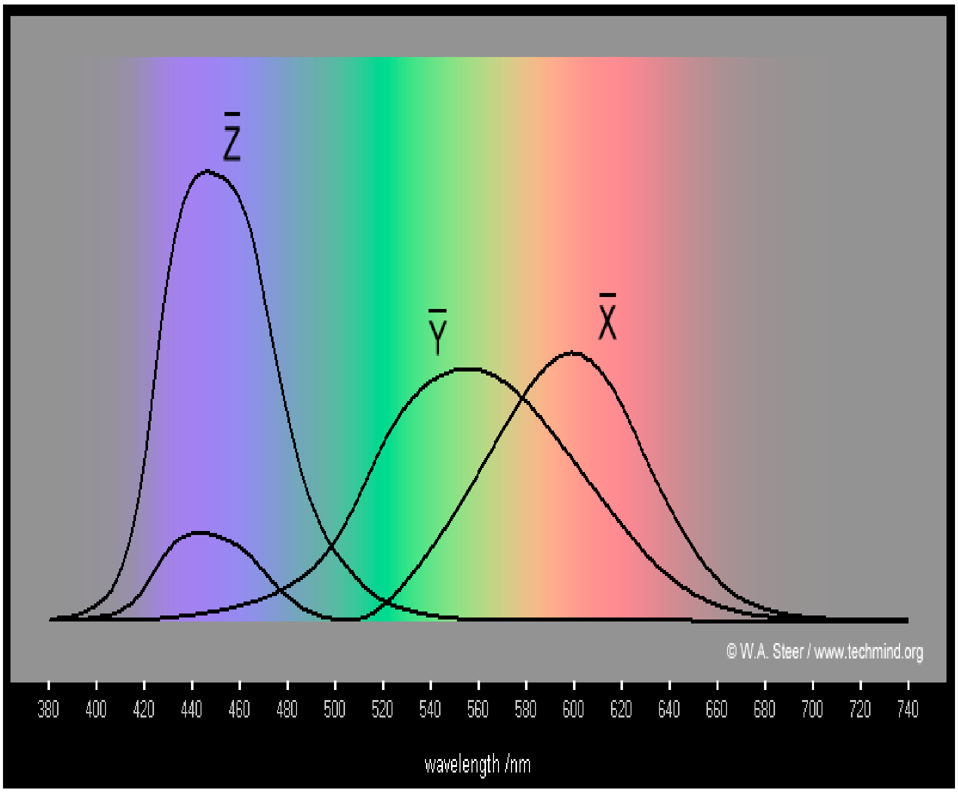


**Fig.2.1.2b CIE 1931 Color matching functions for 2° observer**

Gamut areas typically have triangular shapes because most color reproduction is done with three primaries. Color temperature is a simplified way to characterize the spectral properties of emissions from phosphors. In reality the color of spectral energy distribution is determined by how much each point on the spectral curve contributes to the total output; the color temperature of most color TVs is in the 6,500 to 9,500 K range. Higher color temperatures are due to higher brightness and color saturation.

**Degradation**

The degradation is related not only to optical exposure or solarization or surface damage but also to thermal or heating processes. The degradation of phosphor starts during the manufacturing process and continues during display operation. Various factors responsible for the degradation aremorphology of phosphor particles, crystal structure, surface defects, stability of activators, location in the lattice and oxidation state of activators, and manufacturing processes.

### 2.1.3 Phosphor parameters:

a) **Purity of raw materials**

Even a small amount of impurities, sometimes change phosphor characteristic drastically, therefore the raw materials used must be of high purity. One must exercise all cautions to choose pure raw materials to form the phosphor and prevent further contamination from occurring during the preparation processing to form the phosphor.

b) **Raw materials blend ratio**

The completeness of the solid state reaction depends on the relative diffusion rate of the reacting species. The rate of reaction between the two solids is an exponential one, rapid in the beginning but slowing as the components are used up. An asymptote is gradually approached but the reaction never becomes 100 % complete. Thus we always end up with an unreacted component. Any such impurity affects the efficiency of the so-produced phosphor. Therefore in formulating a phosphor composition, one always employs a small excess of the anion reactant so as to avoid the presence of strongly absorbing cationic species in the end product. The excess components either vaporize during the firing or are consumed to create bi-product. They can sometimes be washed away after the reaction and we get the resulting phosphors very close to the stoichometric composition.

**2.1.4 Lanthanum Phosphor:**

Inorganic compounds doped with rare earth ions form an important class of phosphors as they possess a few interesting characteristics such as excellent chemical stability, high luminescence efficiency, and flexible emission colors with different activators

The reduction of particle size of crystalline system can result in remarkable modification of their properties which are different from those of micro sized hosts because of surface effect and quantum confinement effect of nanometer materials.

In recent years, great effort has been devoted to the controllable synthesis of rare earth-doped nanoparticles driven primarily by the fact that doped nano crystalline phosphors yielded high luminescence efficiencies. With rapidly shrinking size, nanomaterials display novel shape and size-dependent properties for their extremely small size and relatively large specific surface areas. Based on these unique and fascinating properties, rare earth doped nanocrystalline materials may play an important role in display devices, optical telecommunication, solid-state lasers, and so on. Therefore, the development of a facile synthetic method toward high quality rare earth nanocrystals with uniform size and shape is very important for the exploration of new research and application fields.

Rare-earth-doped phosphors are known to emit at distinct and different wavelengths in the electromagnetic spectrum and have been widely used in color cathode ray tubes (CRT), tri-phosphor fluorescent lamps, X-ray intensifying screens and newly developed vacuum mercury-free lamps, as well as various types of displays such as plasma display panels, field emission displays and projection TVs. Recently, breakthroughs in inorganic light emitting diodes (LEDs) technology are significantly catalyzing the development of energy-efficient solid-state lighting (SSL) with long lifetime. Solid-state lighting technology has now already penetrated in a variety of specialty applications, in effect; LEDs have completely changed the “world of luminance”, for example automobile brake lights, traffic signals, liquid crystal displays and mobile backlights, flashlights and all manner of architectural spotlights. Laser detection phosphors [LDP] are used to detect the presence of lasers in the infra-red region by converting the energy to visible. Storage phosphors react to a broad spectrum of infra-red but require daylight or UV to charge up the phosphor first. Exposure to infra-red will cause the energy to be released resulting in a gradual drop in output. "Anti-Stokes" phosphors directly convert the energy from infra-red to visible with a continuous output. They do not exhibit the same broad response to infra-red though. Nanophosphors are being extensively investigated due to potential applications during last few years along with nano technology development.

The rare earth phosphates have technological importance. Lanthanum phosphate ($LaPO_4$) possesses various properties of technological importance.

- Very low solubility in water.
- High thermal stability.
- High refractive index.

$LaPO_4$ has been found to be a suitable and effective deboning material for high-temperature oxide/oxide composites, however, the properties of lanthanide compounds depend strongly on their composition and morphology. In addition, $LaPO_4$ based luminescent materials are currently used in devices such as cathode ray tubes and fluorescent lamps, with the luminescent properties being affected by the size and morphology of the $LaPO_4$ particles. To achieve a deeper understanding of the size-dependent properties and the synthesis conditions (e.g., temperature) on $LaPO_4$ particles, studies on the shape control of $LaPO_4$ nanocrystals have been performed. $LaPO_4$ powder can be synthesized from direct solid–liquid reaction of lanthanum oxide and phosphoric acid. Although it is a simple and effective synthesis route, the shape of the particles is hard to control and the morphology is heterogeneous. Other synthesis methods, such as sol–gel or template based methods are capable of controlling the size, morphology, and crystallization degree of nanoparticles. The experimental process, however, is quite complex.

## 2.2. Crystal structure of $LaPO_4$:

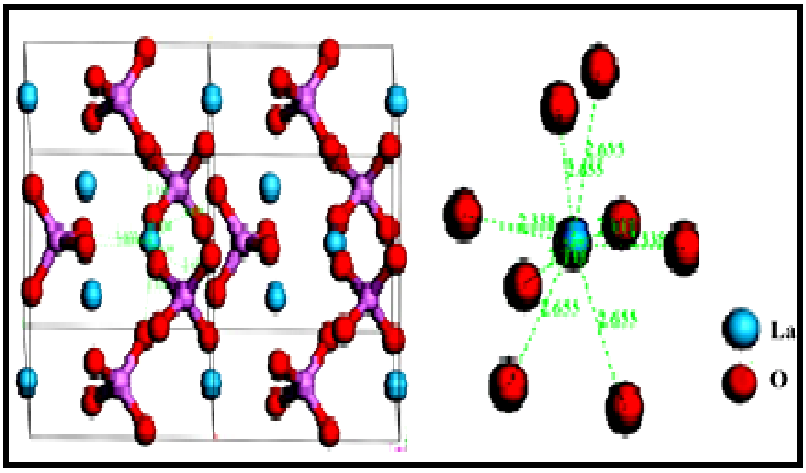


**Fig.2.2a Structure of hexagonal $LaPO_4$**

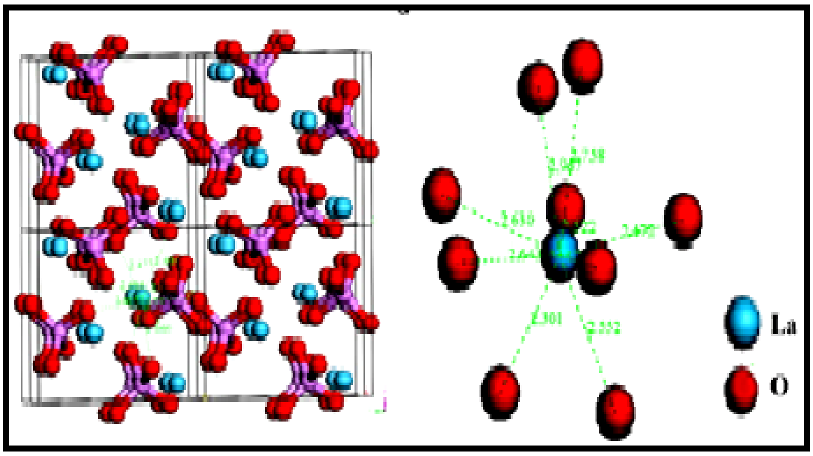


**Fig2.2b Structure of monoclinic $LaPO_4$**

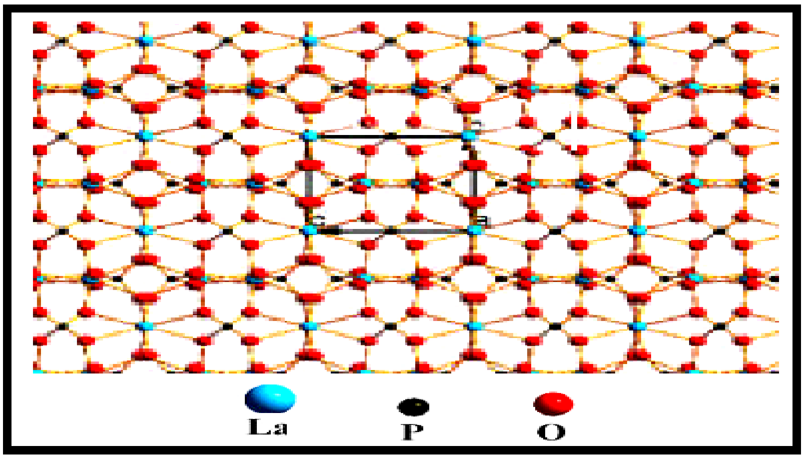


**Fig.2.2c Structures of hexagonal $LaPO_4$ (Packing view along a-axis)**

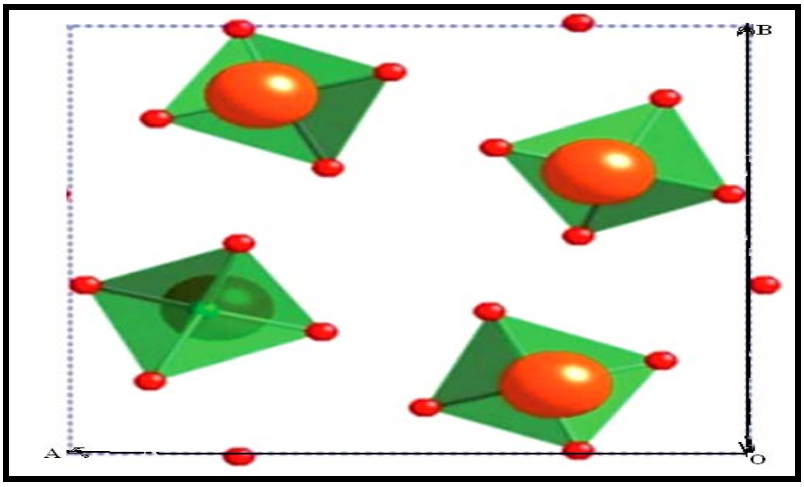


**Fig.2.2d Structure of hexagonal $LaPO_4$ (Packing view along c-axis)**

$La^{3+}$ ions are shown in orange (large spheres) and $PO_4$ tetrahedral shown in green.
In general, phosphates tend to form compounds of higher complexity at higher phosphorus contents by corner sharing an oxygen ion between adjacent $PO_4$ tetrahedra. In $LaPO_4$, the tetrahedral are isolated from each other and hence there are no direct P–O–P interactions between adjacent tetrahedral. The structure of $LaPO_4$ consists of isolated $PO_4$ tetrahedral that are corner sharing only with $LaO_9$ polyhedral. In $LaPO_4$ all the four P–O bonds in the $PO_4$ tetrahedron are equivalent and are of the terminal type due to the isolated arrangement of the tetrahedral.

## 2.3. Introduction of rare earth elements:

The rare earth elements (REE) are a group of 17 chemical (metallic) elements which appear in the periodic table. The group consists of the 15 lanthanide elements along with Yttrium and Scandium. They share many similar properties, which is why they occur together in geological deposits. The 17 REEs are found in all REE deposits but their distribution and concentrations vary. They are referred to as ‘rare’ because it is not common to find them in commercially viable concentrations. REEs generally fall into one of two categories – light rare earths (LREE) and heavy rare earths (HREE), with varying levels of uses and demand. REE mineral deposits are usually rich in either LREE or HREE, but rarely contain both in significant quantities.

**<u>Heavy Rare Earths</u>**

- Europium (Eu)
- Gadolinium (Gd)

- Terbium (Tb)
- Dysprosium (Dy)
- Holmium (Ho)
- Erbium (Er)
- Thulium (Tm)
- Ytterbium (Yb)
- Lutetium (Lu)
- Yttrium (Y)

**Light Rare Earths**

- Lanthanum (La)
- Cerium (Ce)
- Praseodymium (Pr)
- Neodymium (Nd)
- Samarium (Sm)

Rare earths are commercially defined to include 17 elements that have similar chemical properties. Rare earths are mined primarily from bastnasite, monazite, and xenontime ores, and ionadsorption clay. Naturally mixed in with many other elements, rare earths must be concentrated through a series of separation processes to distill the rare earth elements from the ore. The two principal means of separating rare earths are solvent extraction and ion exchange.

**La (Lanthanum):**

Lanthanum, a silvery white soft metal is one of the most reactive rare earth elements. When exposed to air, Lanthanum oxidizes quickly. It has a wide variety of uses in many commercial applications. It is used in carbon lighting, camera and telescope lenses, electron microscopes, cast iron, and lighter flints. Lanthanum has biological and chemical applications as well, serving as a catalyst in petroleum cracking and as a phosphate binder in the treatment of hyperphosphatemia.

**Ce (Cerium):**

Cerium, the most abundant of all the rare earth metals, is a highly reactive, malleable and ductile, silvery-colored metal. It oxidizes very rapidly at room temperature, especially in moist air.

**Pr (Praseodymium):**

Praseodymium is a soft, malleable silvery metal. It is used primarily in rare earth magnets and pigments.

**Nd (Neodymium):**

Neodymium is one of the more reactive of the rare earths, tarnishing rapidly when exposed to air. It is soft and silvery in color. Magnets containing Neodymium are among the strongest and lightest manufactured today. Neodymium is also a key component in Misch metal, used to make flint for lighters.

**Sm (Samarium):**

Samarium is a rare earth metal with a bright silver luster. Although it is relatively stable in air, it eventually forms a grayish-yellow layer of oxidation. Samarium is commonly used with other rare earths in carbon-arc lighting. It is also used with Cobalt to make permanent magnets.

**Eu (Europium):**

Europium, the most reactive of all the rare earth elements, rapidly oxidizes in air. It ignites in air between $150^0$C - $180^0$C, and is quite ductile. There are not many commercial uses for Europium metal, but Europium oxide is frequently used in television sets and fluorescent lamps.

**Gd (Gadolinium):**

Gadolinium is silvery white and has a metallic luster. It is relatively stable in dry air, but in moist air it quickly forms a coating of oxidation which spalls off. Gadolinium has an extremely high thermal neutron capture cross-section, but its fast burn out rate limits its effectiveness as a nuclear control rod material. Because it is strongly paramagnetic, solutions containing Gadolinium are often used as intravenous radioactive contrast agents. It is also found in nuclear marine propulsion systems, compact discs and computer memory.

**Tb (Terbium):**

Terbium is a silver-white metal that is soft enough to be cut with a knife. It is malleable, ductile and reasonably stable in air. It is combined with other elements for use in solid-state devices. Terbium oxide is used in fluorescent lamps and color television tubes. Terbium is also used in rare earth magnets.

**Dy (Dysprosium):**

A silver metal with a bright luster, Dysprosium is soft, and can be machined without sparking if it is not overheated. Although it is relatively stable in air, it dissolves easily in mineral acids, giving off hydrogen. It should be noted that even small amounts of impurities can greatly affect Dysprosium's properties. Dysprosium is used in laser materials, nuclear control rods, compact discs, magnetic devices, and as a contrast agent in magnetic resonance imaging.

**Er (Erbium):**

Erbium is a malleable silvery metal. It is a trivalent element that is relatively stable in air and less prone to oxidation that many of the other rare earths. Oxidation is pink, and used to give color to art glass and jewelry. Erbium is also used in photographic filters, lasers and optical communications.

**Yb (Ytterbium):**

A malleable, ductile silvery soft metal, Ytterbium oxidizes in air, slowly dissolves in water, and rapidly dissolves in mineral acids. It has been used as a radiation source for portable X-ray machines when electricity isn't available. Ytterbium could also used to improve the quality of stainless steel.

**Lu (Lutetium):**

Lutetium is a silvery white trivalent metal. The heaviest and hardest of the rare earth elements, it is also fairly corrosion-resistant. Although it has relatively few commercial uses, it is used as a catalyst in petroleum cracking applications.

**Y (Yttrium):**

Yttrium is a silver, lustrous transitional metal, common in rare earth minerals. It is relatively stable in air. The element and its compounds have many commercial uses. Yttrium oxide is widely used to make phosphors that give the red color in television picture tubes. It is also used in the production of microwave filters, and cubic zirconia. Yttrium is used in specialty alloys for high temperature applications.

Rare earths have found an increasing range of practical applications in recent decades. Phosphors are a subgroup of the rare earth element market. Aside from phosphor applications, rare earths are used in automotive catalysts, metals and magnets, petroleum catalysts, glass polishing, and ceramics. There are three main applications: televisions (plasma and cathode ray tube), triphosphor fluorescent lamps, and x-ray intensifying screens.

“Rare earth phosphors” are a key component of compact fluorescent lamps (CFL) performance. Within CFL, cathodes seal the inside of each lamp end emit a flow of electrons that react with mercury vapor already present in the lamp. The reaction results in the emission of invisible ultraviolet (UV) radiation. To convert the UV radiation into visible light, manufacturers coat the inside of the lamp’s glass with powdered phosphors. Phosphors are elements that fluoresce when struck by UV rays, generating visible light.

Halophosphors are more abundant and much less costly than rare earth phosphors, but also less efficient and produce a lower quality light. Coating a lamp with a layer of rare earth phosphors in addition to or instead of halophosphors can increase efficacy, while dramatically improving color quality and lumen maintenance. The blend of phosphors used by the manufacturer determines, in part, the color correlated temperature (CCT) and the color rendition index (CRI).
The most important rare earth phosphors are Y, Eu, and Tb, which are used to emit light at the wavelengths (and therefore colors) to which our eyes are most sensitive. These three elements are used in different combinations of phosphors to emit blue, red, and green light. Tb is used for green light, while Eu and Y are used for blue and red. Very high levels of purity are necessary for these phosphors in lighting applications.

## 2.4 Synthesis of RE doped Lanthanum Phosphor:

**Steps to prepare phosphor:**

1) In solid-state reaction, the reactants are chemically reacting without the presence of a solvent. Therefore it is called dry media reaction or a solvent less reaction. It is also a chemical reaction in which solvents are not used. The solid state reaction route is the most widely used method for the preparation of polycrystalline solids from a mixture of solid materials. Solids do not react together at room temperature. It is necessary to heat the mixture of solid material to much higher temperatures about 1000 to 1300$^0$C to occur the reaction.
2) The feasibility and rate of a solid state reaction depends upon
   - Reaction conditions.
   - Structural properties of the reactants.
   - Surface area of the solids.
   - The reactivity of material.
   - The thermodynamic free energy change associated with the reaction.
3) First the reactants have been weighed in required amount and mixed together. Agate mortar and pestle are used for mixing the reactants. To form the homogeneous mixture sufficient amount of some volatile organic liquid like acetone or alcohol is added to the mixture. This forms a paste which is mixed thoroughly. During the process of grinding and mixing, the organic liquid gradually volatilizes and has usually evaporated completely after 10 to 15 minutes.
4) Quartz and silicon carbide are the most frequently used container materials for firing phosphors. For phosphors requiring higher firing temperatures alumina crucibles are employed. Box type furnaces are common for small scale production. For large scale production tunnel-type, continuous furnaces are required.
5) Firing is carried out either in air or in a controlled atmosphere. Two methods are employed for controlled atmosphere.
   - The reducing gas, nitrogen containing several percent of hydrogen is used.

- A small crucible containing phosphor is kept in a big crucible containing carbon.

6) Firing temperature range from 900-1200$^{o}$C for phosphate phosphors, 1000-1300$^{o}$C for silicates, and 1200-1500$^{o}$C for aluminates is used. A good furnace is used for heat treatment. Muffle furnace of sizes 25 X 25 X 25 cm is used for preparing the phosphors. The samples of synthesized phosphor are heated up to required temperature for three hours in a furnace. The furnace has a very precise temperature controller with a resolution of $\pm 1^{o}$C. A mechanical protection system is provided so that the input current to the heating elements would be cut-off, once the temperature reaches to required value.

7) The final product of SSR is usually in the form of a powder or a sintered, polycrystalline piece.

8) Solid State Reaction method provides large ranges of selection of starting materials like, oxides, carbonates, etc. Since, solids do not react with each other at room temperature.

9) Thermodynamic and kinetic factors are important in Solid State Reaction method. This synthesis route is very easy and does not require expensive as well as sophisticated equipments.

10) The major advantage of Solid State Reaction method is the final product in solid form is structurally pure with the desired properties depending on the final sintering temperatures. In this method no toxic or unwanted waste is produced. The powders produced from SSR method is very fine as well as the cross contamination is very less. This method is also very convenient for large scale production of phosphor in the industry.

**2.4.1 Synthesis $LaPO_4$ & $LaYPO_4$ Phosphors:**

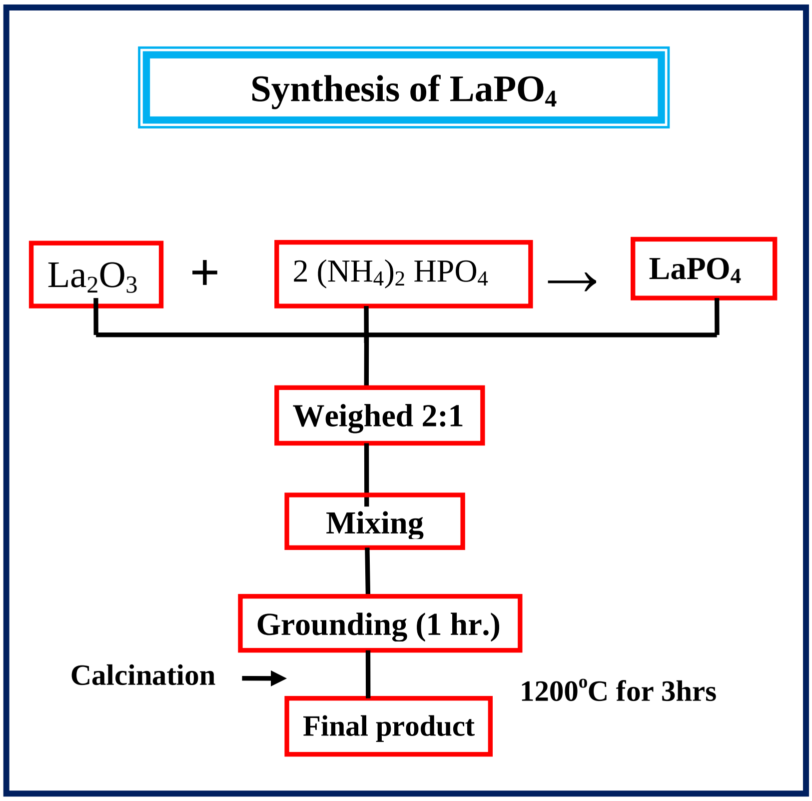


Fig.2.4.1a Synthesis of $LaPO_4$ phosphors

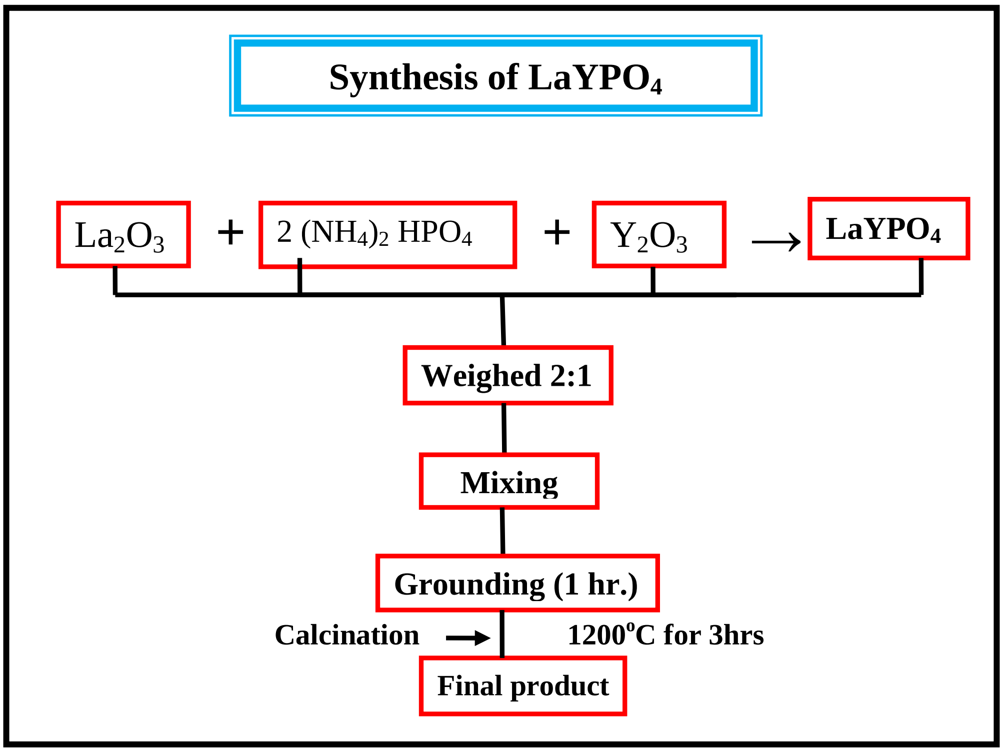


Fig.2.4.1b Synthesis of $LaYPO_4$ phosphors

**2.4.2 List of material used for the preparation of phosphors:**

- Lanthanum Oxide ($La_2O_3$).
- Ammonium Diahydrogen Phosphate ($(NH_4)_2$ $HPO_4$ )
- Yttrium Oxide ($Y_2O_3$).
- Cerium Oxide ($Ce_2O_3$).
- Terbium oxide ($Tb_4O_7$).
- Gadolinium Oxide ($Gd_2O_3$).
- Europium Oxide ($Eu_2O_3$).

The samples of $LaPO_4$ and $LaYPO_4$ phosphor doped with rare-earth ions were prepared using solid state synthesis method. Stoichiometric proportions of raw materials namely, Lanthanum Oxide ($La_2O_3$), Yttrium oxide ($Y_2O_3$), Diammonium Hydrogen Phosphate [$(NH_4)_2$ H $PO_4$] with dopant rare earth materials are weighed and ground into a fine powder using agate mortar and pestle. The grounded samples were placed in an alumina crucible and fired at 1200$^o$C for 3 h in a muffle furnace with a heating rate of 5$^0$C/min. The samples are allowed to cool to room temperature in the same furnace for about 20 hours. The prepared samples were again powdered for taking the measurements.

## 2.5. Calculations for Prepared Phosphor materials:

### 2.5.1. Lanthanum phosphors ($LaPO_4$)

Lanthanum phosphors are prepared using different concentration of rare earth elements as a dopant. The results are presented in chapter-4.

Basic reaction:-

$$La_2O_3 + 2\ (NH_4)_2\ HPO_4 \rightarrow \mathbf{2LaPO_4} + 4NH_3\uparrow + 3H_2O\uparrow$$

Calculation of proportional weight of compounds for the preparation of required phosphors

**1) $LaPO_4$ base**

Basic reaction:-

$La_2O_3 + 2\ (NH_4)_2\ HPO_4 \rightarrow \mathbf{2LaPO_4} + 4NH_3\uparrow + 3H_2O\uparrow$

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Total weight = 589.94 gm.

To prepare 10 gm of material

Weight of $La_2O_3$ = 5.5229 gm.

Weight of 2 $(NH_4)_2$ $HPO_4$ = 4.4771 gm.

Total weight = 10.00 gm.

**2) $LaPO_4$: Ce (0.5 %)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + 2$CeO_2$ → **2$LaPO_4$**: Ce (0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of 2$CeO_2$ = 344.236 gm.

0.5 mole weight % of 2$CeO_2$ = 1.172 gm

Total weight = 591.112 gm.

To prepare 10 gm of material

Weight of $La_2O_3$ = 5.5120 gm.

Weight of 2 $(NH_4)_2$ $HPO_4$ = 4.4682 gm.

0.5 mole weight % of 2$CeO_2$ = 0.0198 gm.

Total weight = 10.00 gm.

**3) $LaPO_4$: Eu (0.5 %)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + $Eu_2O_3$ → **2$LaPO_4$**: Eu (0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Eu_2O_3$ = 351.917 gm.

0.5 mole weight % of $Eu_2O_3$ = 1.760gm

Total weight = 591.700 gm.

To prepare 10 gm of material

Weight of $La_2O_3$ = 5.5065 gm.

Weight of 2 $(NH_4)_2$ $HPO_4$ = 4.4637 gm.

0.5 mole weight % of $Eu_2O_3$ = 0.0297 gm.

Total weight = 9.9999 gm.

**4) $LaPO_4$: Tb (0.5 %)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + ½ $Tb_4O_7$ → **2$LaPO_4$**: Tb (0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of ½ $Tb_4O_7$ = 373.848 gm.

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 591.8092 gm.

To prepare 10 gm of material

Weight of $La_2O_3$ = 5.5055 gm.

Weight of 2 $(NH_4)_2$ $HPO_4$ = 4.4629 gm.

0.5 mole weight % of ½ $Tb_4O_7$ = 0.0316 gm.

Total weight = 10.0000 gm.

- ❖ The samples are prepared as Lanthanum phosphor **($LaPO_4$)** doped with Ce (0.5 %) and 0.1.0.5, 1.0, 1.5, 2.0 mole weight % of Tb.

**5) $LaPO_4$: Ce (0.5%), Tb (0.1%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + 2$CeO_2$ + ½ $Tb_4O_7$→ **2$LaPO_4$**: Ce (0.5%), Tb (0.1%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of 2$CeO_2$ = 1.7212 gm

0.1 mole weight % of ½ $Tb_4O_7$ = 0.3738 gm

Total weight = 592.035 gm.

To prepare 5 gm of material

Mole weight of $La_2O_3$ = 2.7517 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2306 gm.

0.5 mole weight % of 2$CeO_2$ = 0.0145 gm

0.1 mole weight % of ½ $Tb_4O_7$= 0.0032 gm.

Total weight = 5.0000 gm.

**6) $LaPO_4$: Ce (0.5%), Tb (0.5%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + 2$CeO_2$ + ½ $Tb_4O_7$→ **2$LaPO_4$**: Ce (0.5%), Tb (0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of 2$CeO_2$ = 1.7212 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 593.5312 gm.

To prepare 5 gm of material

Mole weight of $La_2O_3$ = 2.7448 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2250 gm.

0.5 mole weight % of $2CeO_2$ = 0.0145 gm

0.5 mole weight % of ½ $Tb_4O_7$= 0.0157 gm.

Total weight = 5.0000 gm.

**7) $LaPO_4$: Ce (0.5%), Tb (1.0%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + $2CeO_2$ + ½ $Tb_4O_7$ → **$2LaPO_4$**: Ce (0.5%), Tb (1.0%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of $2CeO_2$ = 1.7212 gm

1.0 mole weight % of ½ $Tb_4O_7$ = 0.7384 gm

Total weight = 595.4004 gm.

To prepare 5 gm of material

Mole weight of $La_2O_3$ = 2.7361 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2180 gm.

0.5 mole weight % of $2CeO_2$ = 0.0145 gm

1.0 mole weight % of ½ $Tb_4O_7$= 0.0314 gm.

Total weight = 5.0000 gm.

**8) $LaPO_4$: Ce (0.5%), Tb (1.5%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + $2CeO_2$ + ½ $Tb_4O_7$ → **$2LaPO_4$**: Ce (0.5%), Tb (1.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of $2CeO_2$ = 1.7212 gm

1.5 mole weight % of ½ $Tb_4O_7$ = 1.6076 gm

Total weight = 597.2696 gm.

To prepare 5 gm of material

Mole weight of $La_2O_3$ = 2.7276 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2111 gm.

0.5 mole weight % of $2CeO_2$ = 0.0144 gm

1.5 mole weight % of ½ $Tb_4O_7$= 0.0469 gm.

Total weight = 5.0000 gm.

**9) $LaPO_4$: Ce (0.5%), Tb(2.0%)**

Basic reaction:-

$La_2O_3 + 2\ (NH_4)_2\ HPO_4 + 2CeO_2 + ½\ Tb_4O_7 \rightarrow$ **$2LaPO_4$**: Ce (0.5%), Tb (2.0%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2\ HPO_4$ = 264.12 gm.

0.5 mole weight % of $2CeO_2$ = 1.7212 gm

2.0 mole weight % of ½ $Tb_4O_7$ = 7.4768 gm

Total weight = 599.1388 gm.

<u>To prepare 5 gm of material</u>

Mole weight of $La_2O_3$ = 2.7191 gm.

Mole weight of 2 $(NH_4)_2\ HPO_4$ = 2.2042 gm.

0.5 mole weight % of $2CeO_2$ = 0.0144 gm

2.0 mole weight % of ½ $Tb_4O_7$= 0.0624 gm.

Total weight = 5.0001 gm.

- The samples are prepared as Lanthanum phosphor **($LaPO_4$)** doped with Tb (0.5 %) and 0.1.0.5, 1.0, 1.5, 2.0 mole weight % of Ce.

**10) $LaPO_4$: Tb (0.5%), Ce(0.1%)**

Basic reaction:-

$La_2O_3 + 2\ (NH_4)_2\ HPO_4 + 2CeO_2 + ½\ Tb_4O_7 \rightarrow$ **$2LaPO_4$**: Tb (0.5%), Ce (0.1%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2\ HPO_4$ = 264.12 gm.

0.1 mole weight % of $2CeO_2$ = 0.0344 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 591.8436 gm.

<u>To prepare 5 gm of material</u>

Mole weight of $La_2O_3$ = 2.7526 gm.

Mole weight of 2 $(NH_4)_2\ HPO_4$ = 2.2313 gm.

0.1 mole weight % of $2CeO_2$ = 0.0003 gm

0.5 mole weight % of ½ $Tb_4O_7$= 0.0158 gm.

Total weight = 5.0000 gm.

**11) $LaPO_4$: Tb (0.5%), Ce(0.5%)**

Basic reaction:-

$La_2O_3 + 2\ (NH_4)_2\ HPO_4 + 2CeO_2 + ½\ Tb_4O_7 \rightarrow$ **$2LaPO_4$**: Tb (0.5%), Ce (0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of $2CeO_2$ = 1.7212 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 593.5312 gm.

To prepare 5 gm of material

Mole weight of $La_2O_3$ = 2.7448 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2250 gm.

0.5 mole weight % of $2CeO_2$ = 0.0145 gm

0.5 mole weight % of ½ $Tb_4O_7$= 0.0157 gm.

Total weight = 5.0000 gm.

**12) $LaPO_4$: Tb (0.5%), Ce(1.0%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + $2CeO_2$ + ½ $Tb_4O_7$→ **$2LaPO_4$**: Tb (0.5%), Ce (1.0%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

1.0 mole weight % of $2CeO_2$ = 3.4424 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 595.2516 gm.

To prepare 5 gm of material

Mole weight of $La_2O_3$ = 2.7368 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2186 gm.

1.0 mole weight % of $2CeO_2$ = 0.0289 gm

0.5 mole weight % of ½ $Tb_4O_7$= 0.0157 gm.

Total weight = 5.0000 gm.

**13) $LaPO_4$: Tb (0.5%), Ce(1.5%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + $2CeO_2$ + ½ $Tb_4O_7$→ **$2LaPO_4$**: Tb (0.5%), Ce (1.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

1.5 mole weight % of $2CeO_2$ = 5.1636 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 596.9728 gm.

To prepare 5 gm of material

Mole weight of $La_2O_3$ = 2.7289 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2122 gm.

1.5 mole weight % of $2CeO_2$ = 0.0432 gm

0.5 mole weight % of ½ $Tb_4O_7$= 0.0157 gm.

Total weight = 5.0000 gm.

**14) $LaPO_4$: Tb (0.5%), Ce(2.0%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + $2CeO_2$ + ½ $Tb_4O_7$ → **2$LaPO_4$**: Tb (0.5%), Ce (2.0%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

2.0 mole weight % of $2CeO_2$ = 6.8848 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 598.694 gm.

To prepare 5 gm of material

Mole weight of $La_2O_3$ = 2.7211 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2058 gm.

2.0 mole weight % of $2CeO_2$ = 0.0575 gm

0.5 mole weight % of ½ $Tb_4O_7$= 0.0156 gm.

Total weight = 5.0000 gm.

- ❖ The samples are prepared as Lanthanum phosphor **($LaPO_4$)** doped with Eu (0.5 %) and 0.1.0.5, 1.0, 1.5, 2.0 mole weight % of Tb.

**15) $LaPO_4$: Eu (0.5%), Tb(0.1%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + ½ $Tb_4O_7$+$Eu_2O_3$ → **2$LaPO_4$**: Eu (0.5%), Tb (0.1%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of $Eu_2O_3$ = 1.7600 gm

0.1 mole weight % of ½ $Tb_4O_7$ = 0.3738 gm

Total weight = 592.074 gm.

To prepare 5 gm of material

Mole weight of $La_2O_3$ = 2.7515 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2305 gm.

0.5 mole weight % of $Eu_2O_3$= 0.0149 gm

0.1 mole weight % of ½ $Tb_4O_7$= 0.0032 gm.

Total weight = 5.0001 gm.

**16) $LaPO_4$: Eu (0.5%), Tb(0.5%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + ½ $Tb_4O_7$+$Eu_2O_3$→ **2$LaPO_4$**: Eu (0.5%), Tb (0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of $Eu_2O_3$ = 1.7600 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 593.5692 gm.

<u>To prepare 5 gm of material</u>

Mole weight of $La_2O_3$ = 2.7446 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2248 gm.

0.5 mole weight % of $Eu_2O_3$= 0.0148 gm

0.5 mole weight % of ½ $Tb_4O_7$= 0.0157 gm.

Total weight = 4.9999 gm.

**17) $LaPO_4$: Eu (0.5%), Tb(1.0 %)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + ½ $Tb_4O_7$+$Eu_2O_3$→ **2$LaPO_4$**: Eu (0.5%), Tb (1.0%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of $Eu_2O_3$ = 1.7600 gm

1.0 mole weight % of ½ $Tb_4O_7$ = 3.7384 gm

Total weight = 595.4384 gm.

<u>To prepare 5 gm of material</u>

Mole weight of $La_2O_3$ = 2.7360 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2179 gm.

0.5 mole weight % of $Eu_2O_3$= 0.0148 gm

1.0 mole weight % of ½ $Tb_4O_7$= 0.0314 gm.

Total weight = 5.0001 gm.

**18) $LaPO_4$: Eu (0.5%), Tb(1.5%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + ½ $Tb_4O_7$+$Eu_2O_3$→ **2$LaPO_4$**: Eu (0.5%), Tb (1.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of $Eu_2O_3$ = 1.7600 gm

1.5 mole weight % of ½ $Tb_4O_7$ = 5.6076 gm

Total weight = 597.3076 gm.

To prepare 5 gm of material

Mole weight of $La_2O_3$ = 2.7274 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2109 gm.

0.5 mole weight % of $Eu_2O_3$= 0.0147 gm

1.5 mole weight % of ½ $Tb_4O_7$= 0.0469 gm.

Total weight = 4.9999 gm.

**19) $LaPO_4$: Eu (0.5%), Tb(2.0 %)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + ½ $Tb_4O_7$+$Eu_2O_3$→ **2$LaPO_4$**: Eu (0.5%), Tb (2.0%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of $Eu_2O_3$ = 1.7600 gm

2.0 mole weight % of ½ $Tb_4O_7$ = 7.4768 gm

Total weight = 599.1768 gm.

To prepare 5 gm of material

Mole weight of $La_2O_3$ = 2.7189 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2040 gm.

0.5 mole weight % of $Eu_2O_3$= 0.0147 gm

2.0 mole weight % of ½ $Tb_4O_7$= 0.0624 gm.

Total weight = 5.0000 gm.

- The samples are prepared as Lanthanum phosphor **($LaPO_4$)** doped with Eu (0.5 %), Ce(1.0%) and 0.1.0.5, 1.0, 1.5, 2.0 mole weight % of Tb.

**20) $LaPO_4$: Eu(0.5%), Ce (1.0%),Tb(0.1%)**

Basic reaction:-

$La_2O_3$ +2 $(NH_4)_2HPO_4$+½ $Tb_4O_7$+$Eu_2O_3$+2$CeO_2$→**2$LaPO_4$**:Eu (0.5%),Ce(1.0%),Tb(0.1%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of $Eu_2O_3$ = 1.7600 gm

1.0 mole weight % of 2$CeO_2$ = 3.4424 gm

0.1 mole weight % of ½ $Tb_4O_7$ = 0.3738 gm

Total weight = 595.5162 gm.

<u>To prepare 5 gm of material</u>

Mole weight of $La_2O_3$ = 2.7356 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2176 gm.

0.5 mole weight % of $Eu_2O_3$= 0.0148 gm.

1.0 mole weight % of $2CeO_2$ = 0.0289 gm

0.1 mole weight % of ½ $Tb_4O_7$ = 0.0031 gm.

Total weight = 5.0000 gm.

**21) $LaPO_4$: Eu(0.5%), Ce (1.0%),Tb(0.5%)**

Basic reaction:-

$La_2O_3$ +2 $(NH_4)_2HPO_4$+½ $Tb_4O_7$+$Eu_2O_3$+$2CeO_2$→**2$LaPO_4$**:Eu (0.5%),Ce(1.0%),Tb(0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of $Eu_2O_3$ = 1.7600 gm

1.0 mole weight % of $2CeO_2$ = 3.4424 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 597.0116 gm.

<u>To prepare 5 gm of material</u>

Mole weight of $La_2O_3$ = 2.7288 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2120 gm.

0.5 mole weight % of $Eu_2O_3$= 0.0147 gm.

1.0 mole weight % of $2CeO_2$ = 0.0288 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 0.0157 gm.

Total weight = 5.0000 gm.

**22) $LaPO_4$: Eu(0.5%), Ce (1.0%),Tb(1.0%)**

Basic reaction:-

$La_2O_3$ +2 $(NH_4)_2HPO_4$+½ $Tb_4O_7$+$Eu_2O_3$+$2CeO_2$→**2$LaPO_4$**:Eu (0.5%),Ce(1.0%),Tb(1.0%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of $Eu_2O_3$ = 1.7600 gm

1.0 mole weight % of $2CeO_2$ = 3.4424 gm

1.0 mole weight % of ½ $Tb_4O_7$ = 3.7384 gm

Total weight = 598.8808 gm.

<u>To prepare 5 gm of material</u>

Mole weight of $La_2O_3$ = 2.7202 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.2051 gm.

0.5 mole weight % of $Eu_2O_3$= 0.0147 gm.

1.0 mole weight % of $2CeO_2$ = 0.0287 gm

1.0 mole weight % of ½ $Tb_4O_7$ = 0.0312 gm.

Total weight = 5.0000 gm.

**23) $LaPO_4$: Eu(0.5%), Ce (1.0%),Tb(1.5%)**

Basic reaction:-

$La_2O_3$ +2 $(NH_4)_2HPO_4$+½ $Tb_4O_7$+$Eu_2O_3$+$2CeO_2$$\rightarrow$**2$LaPO_4$**:Eu (0.5%),Ce(1.0%),Tb(1.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of $Eu_2O_3$ = 1.7600 gm

1.0 mole weight % of $2CeO_2$ = 3.4424 gm

1.5 mole weight % of ½ $Tb_4O_7$ = 5.6076 gm

Total weight = 600.750 gm.

<u>To prepare 5 gm of material</u>

Mole weight of $La_2O_3$ = 2.7118 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.1983 gm.

0.5 mole weight % of $Eu_2O_3$= 0.0146 gm.

1.0 mole weight % of $2CeO_2$ = 0.0286 gm

1.5 mole weight % of ½ $Tb_4O_7$ = 0.0467 gm.

Total weight = 5.0000 gm.

**24) $LaPO_4$: Eu(0.5%), Ce (1.0%),Tb(2.0%)**

Basic reaction:-

$La_2O_3$ +2 $(NH_4)_2HPO_4$+½ $Tb_4O_7$+$Eu_2O_3$+$2CeO_2$$\rightarrow$**2$LaPO_4$**:Eu (0.5%),Ce(1.0%),Tb(2.0%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

0.5 mole weight % of $Eu_2O_3$ = 1.7600 gm

1.0 mole weight % of $2CeO_2$ = 3.4424 gm

2.0 mole weight % of ½ $Tb_4O_7$ = 7.4768 gm

Total weight = 602.6192 gm.

To prepare 5 gm of material

Mole weight of $La_2O_3$ = 2.7034 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 2.1914 gm.

0.5 mole weight % of $Eu_2O_3$= 0.0146 gm.

1.0 mole weight % of $2CeO_2$ = 0.0286 gm

2.0 mole weight % of ½ $Tb_4O_7$ = 0.0620 gm.

Total weight = 5.0000 gm.

**2.5.2. Lanthanum yttrium phosphate ($LaYPO_4$)**

Lanthanum yttrium phosphate is prepared using different concentration of rare earth elements as a doping. The results are presented in chapter-5.

Basic reaction:-

$La_2O_3 + 2\ (NH_4)_2\ HPO_4 + Y_2O_3 \rightarrow \mathbf{2LaYPO_4} + 4NH_3 \uparrow + 3H_2O + 1\frac{1}{2}O_2 \uparrow$

Calculation of proportional weight of compounds for the preparation of required phosphors

- ❖ The samples are prepared as lanthanum yttrium phosphor doped with 0.5 mole weight % of different rare earth elements.

**1)** Base compound **($LaYPO_4$)**

Basic reaction:-

$La_2O_3 + 2\ (NH_4)_2\ HPO_4 + Y_2O_3 \rightarrow \mathbf{2LaYPO_4} + 4NH_3 \uparrow + 3H_2O + 1\frac{1}{2}O_2 \uparrow$

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

Total weight = 815.75 gm.

To prepare 10 gm of material

Weight of $La_2O_3$ = 3.9941 gm.

Weight of 2 $(NH_4)_2$ $HPO_4$ = 3.2377 gm.

Weight of $Y_2O_3$ = 2.7681 gm

Total weight = 9.999 gm.

**2) $LaYPO_4$: Ce (0.5 %)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + $Y_2O_3$ + $2CeO_2$ → **$2LaYPO_4$**: Ce (0.5 %)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

Mole weight of $2CeO_2$ = 344.236 gm.

0.5 mole weight % of $2CeO_2$ = 1.172 gm

Total weight = 816.922 gm.

<u>To prepare 10 gm of material</u>

Weight of $La_2O_3$ = 3.98838 gm.

Weight of 2 $(NH_4)$2 $HPO_4$ = 3.2331 gm.

Weight of $Y_2O_3$ = 2.76415 gm

0.5 mole weight % of $2CeO_2$ = 0.01435 gm.

Total weight = 9.9999 gm.

**3) $LaYPO_4$: Eu (0.5 %)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + $Y_2O_3$ + $Eu_2O_3$ → **$2LaYPO_4$**: Eu (0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

Mole weight of $Eu_2O_3$ = 351.917 gm.

0.5 mole weight % of $Eu_2O_3$ = 1.760 gm

Total weight = 817.5095 gm.

<u>To prepare 10 gm of material</u>

Weight of $La_2O_3$ = 3.9855 gm.

Weight of 2 $(NH_4)_2$ $HPO_4$ = 3.23078 gm.

Weight of $Y_2O_3$ = 2.76216 gm

0.5 mole weight % of $Eu_2O_3$ = 0.021523 gm.

Total weight = 9.9999 gm.

**4) $LaYPO_4$: Gd (0.5 %)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + $Y_2O_3$ + $Gd_2O_3$ → **$2LaYPO_4$**: Gd (0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

Mole weight of $Gd_2O_3$ = 362.497 gm.

0.5 mole weight % of $Gd_2O_3$ = 1.812 gm

Total weight = 817.562 gm.

To prepare 10 gm of material

Weight of $La_2O_3$ = 3.9853 gm.

Weight of 2 $(NH_4)_2$ $HPO_4$ = 3.2306 gm.

Weight of $Y_2O_3$ = 2.7620 gm

0.5 mole weight % of $Gd_2O_3$ = 0.0221 gm.

Total weight = 10.0000 gm.

5) **$LaYPO_4$: Tb (0.5 %)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + $Y_2O_3$ + ½ $Tb_4O_7$ → **2$LaYPO_4$**: Tb(0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

Mole weight of ½ $Tb_4O_7$ = 373.848 gm.

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 817.619 gm.

To prepare 10 gm of material

Weight of $La_2O_3$ = 3.98498 gm.

Weight of 2 $(NH_4)_2$ $HPO_4$ = 3.23035 gm.

Weight of $Y_2O_3$ = 2.7618 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 0.02285 gm.

Total weight = 10.0000 gm.

- ❖ The samples are prepared as Lanthanum yttrium phosphate **($LaYPO_4$)** doped with Tb (0.5 %) and 0.5, 1.0, 1.5, 2.0 mole weight % of Eu.

6) **$LaYPO_4$: Tb (0.5%), Eu(0.5%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ +$Y_2O_3$+ ½ $Tb_4O_7$+$Eu_2O_3$→ **2$LaYPO_4$**: Tb (0.5%), Eu (0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

0.5 mole weight % of $Eu_2O_3$ = 1.7600 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 819.3792 gm.

**<u>To prepare 10 gm of material</u>**

Mole weight of $La_2O_3$ = 3.9764 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 3.2234 gm.

Mole weight of $Y_2O_3$ = 2.7559 gm

0.5 mole weight % of $Eu_2O_3$= 0.02148 gm

0.5 mole weight % of ½ $Tb_4O_7$= 0.02281 gm.

Total weight = 9.9999gm.

7) **$LaYPO_4$: Tb (0.5%), Eu(1.0%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ +$Y_2O_3$+ ½ $Tb_4O_7$+$Eu_2O_3$→ **2$LaYPO_4$**: Tb (0.5%), Eu(1.0%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

1.0 mole weight % of $Eu_2O_3$= 3.5200 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 821.1392gm.

**<u>To prepare 10 gm of material</u>**

Mole weight of $La_2O_3$ = 3.9679 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 3.2165 gm.

Mole weight of $Y_2O_3$ = 2.7499 gm

1.0 mole weight % of $Eu_2O_3$ = 0.0429 gm

0.5 mole weight % of ½ $Tb_4O_7$= 0.0227 gm.

Total weight = 9.9999gm

8) **$LaYPO_4$: Tb (0.5%), Eu(1.5%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$+$Y_2O_3$ + ½ $Tb_4O_7$+$Eu_2O_3$→ **2$LaYPO_4$**: Tb (0.5%), Eu (1.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

1.5 mole weight % of $Eu_2O_3$= 5.2788 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 822.898 gm.

**<u>To prepare 10 gm of material</u>**

Mole weight of $La_2O_3$ = 3.9594 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 3.2096 gm.

Mole weight of $Y_2O_3$ = 2.7440 gm

1.5 mole weight % of $Eu_2O_3$ = 0.0641gm

0.5 mole weight % of ½ $Tb_4O_7$= 0.0227 gm.

Total weight = 9.9999gm.

**$LaYPO_4$: Tb (0.5%), Eu(2.0%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ +$Y_2O_3$ + ½ $Tb_4O_7$+$Eu_2O_3$→ **2$LaYPO_4$**: Tb (0.5%), Eu(2.0%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

2.0 mole weight % of $Eu_2O_3$ = 7.0400 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 824.6592 gm.

**<u>To prepare 10 gm of material</u>**

Mole weight of $La_2O_3$ = 3.9510 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 3.2027 gm.

Mole weight of $Y_2O_3$ = 2.7382 gm

2.0 mole weight % of $Eu_2O_3$ = 0.0854gm

0.5 mole weight % of ½ $Tb_4O_7$= 0.0226 gm.

Total weight = 9.9999gm

- The samples are prepared as Lanthanum yttrium phosphate**($LaYPO_4$)** doped with Gd (0.5 %) and 0.5, 1.0, 1.5, 2.0 mole weight % of Eu

9) **$LaYPO_4$: Gd(0.5%), Eu(0.5%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ +$Y_2O_3$+ $Gd_2O_3$ +$Eu_2O_3$→ **2LaYPO$_4$**: Gd (0.5%)Eu (0.5%),

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

0.5 Mole weight % of $Gd_2O_3$ =1.812 gm

0.5 mole weight % of $Eu_2O_3$ = 1.7600 gm

Total weight = 819.322 gm.

To prepare 10 gm of material

Mole weight of $La_2O_3$ = 3.9767 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 3.2236 gm.

Mole weight of $Y_2O_3$ = 2.7561 gm

0.5 mole weight % of $Eu_2O_3$= 0.0215 gm

0.5 mole weight % of $Gd_2O_3$ =0.022 gm

Total weight = 10 gm.

**10) LaYPO$_4$: Gd (0.5%), Eu(1.0 %)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + $Y_2O_3$+ $Gd_2O_3$ +$Eu_2O_3$→ **2LaYPO$_4$**: Gd (0.5%), Eu (1.0%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm

Mole weight of $Y_2O_3$ = 225.81 gm

0.5 Mole weight % of $Gd_2O_3$ =1.812 gm

1.0 mole weight % of $Eu_2O_3$ = 3.520 gm

Total weight = 821.082 gm.

To prepare 10 gm of material

Mole weight of $La_2O_3$ = 3.9682 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 3.2167 gm.

Mole weight of $Y_2O_3$ =2.7502 gm.

1.0 mole weight % of $Eu_2O_3$= 0.0429 gm

0.5 mole weight % of $Gd_2O_3$= 0.0221 gm.

Total weight = 10.00 gm.

**11) LaYPO$_4$: Gd (0.5%), Eu(1.5%)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + $Y_2O_3$+ $Gd_2O_3$ +$Eu_2O_3$→ **2LaYPO$_4$**: Gd(0.5%), Eu (1.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

1.5 mole weight % of $Eu_2O_3$ = 5.2788 gm

0.5 Mole weight % of $Gd_2O_3$ =1.812 gm

Total weight = 822.8408 gm.

<u>To prepare 10 gm of material</u>

Mole weight of $La_2O_3$ = 3.9598 gm.

Mole weight of 2 $(NH_4)$2 $HPO_4$ = 3.2098 gm.

Mole weight of $Y_2O_3$ =2.7442 gm

0.5 Mole weight % of $Gd_2O_3$ =0.02202 gm

1.5 mole weight % of $Eu_2O_3$= 0.06415 gm

Total weight = 9.9999 gm.

**12) LaYPO$_4$: Gd (0.5%), Eu(2.0 %)**

Basic reaction:-

$La_2O_3$ + 2 $(NH_4)_2$ $HPO_4$ + $Y_2O_3$+ $Gd_2O_3$ +$Eu_2O_3$→ **2LaYPO$_4$**: Gd (0.5%), Eu (2.0%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

0.5 Mole weight % of $Gd_2O_3$ =1.812 gm

2.0 mole weight % of $Eu_2O_3$ = 7.040 gm

Total weight = 824.602 gm

<u>To prepare 5 gm of material</u>

Mole weight of $La_2O_3$ = 3.9512 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 3.2029 gm.

Mole weight of $Y_2O_3$ = 2.7385 gm

0.5 Mole weight % of $Gd_2O_3$ =0.0219 gm

2.0 mole weight % of $Eu_2O_3$= 0.0853 gm

Total weight = 9.9999 gm.

- ❖ The samples are prepared as Lanthanum yttrium phosphate **(LaYPO$_4$)** doped with Tb (0.5%) & Gd (0.5 %) and 0.5, 1.0, 1.5, 2.0 mole weight % of Eu.

13) **LaYPO$_4$: Eu(0.5%), Tb (0.5%),Gd(0.5%)**

Basic reaction:-

$La_2O_3$ +2 $(NH_4)_2HPO_4$+ $Y_2O_3$+ $Gd_2O_3$ +$Eu_2O_3$+½ $Tb_4O_7$ → 2LaYPO$_4$:Eu (0.5%),Tb(0.5%),Gd(0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

0.5 Mole weight % of $Gd_2O_3$ =1.812 gm

0.5 mole weight % of $Eu_2O_3$ = 1.7600 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 821.1912gm.

<u>To prepare 10 gm of material</u>

Mole weight of $La_2O_3$ = 3.9677 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 3.2163 gm.

Mole weight of $Y_2O_3$ = 2.7497 gm

0.5 Mole weight % of $Gd_2O_3$ =0.0221 gm

0.5 mole weight % of $Eu_2O_3$= 0.0214 gm.

0.5 mole weight % of of ½ $Tb_4O_7$ = 0.0227 gm

Total weight = 9.9999 gm.

14) **LaYPO$_4$: Eu(1.0%), Tb (0.5%),Gd(0.5%)**

Basic reaction:-

$La_2O_3$ +2 $(NH_4)_2HPO_4$+ $Y_2O_3$+ $Gd_2O_3$ +$Eu_2O_3$+½ $Tb_4O_7$ → 2LaYPO$_4$:Eu (1.0%),Tb(0.5%),Gd(0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

0.5 Mole weight % of $Gd_2O_3$ =1.812 gm

1.0 mole weight % of $Eu_2O_3$ = 3.520 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 822.9512 gm.

<u>To prepare 10 gm of material</u>

Mole weight of $La_2O_3$ = 3.9591gm.

Mole weight of 2 $(NH_4)$2 $HPO_4$ = 3.2094 gm.

Mole weight of $Y_2O_3$ = 2.7439 gm

0.5 Mole weight % of $Gd_2O_3$ =0.0220 gm

1.0 mole weight % of $Eu_2O_3$= 0.04277 gm.

0.5 mole weight % of of ½ $Tb_4O_7$ = 0.0227 gm

Total weight = 9.9999 gm.

**15) $LaYPO_4$: Eu(1.5%), Tb (0.5%),Gd(0.5%)**

Basic reaction:-

$La_2O_3$ +2 $(NH_4)_2HPO_4$+ $Y_2O_3$+ $Gd_2O_3$ +$Eu_2O_3$+½ $Tb_4O_7$ → 2$LaYPO_4$:Eu (1.5%),Tb(0.5%),Gd(0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

0.5 Mole weight % of $Gd_2O_3$ =1.812 gm

1.5 mole weight % of $Eu_2O_3$ =5.2788 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 824.71gm.

To prepare 10 gm of material

Mole weight of $La_2O_3$ = 3.9507 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 3.2026 gm.

Mole weight of $Y_2O_3$ = 2.7380gm

0.5 Mole weight % of $Gd_2O_3$ = 0.0220 gm

1.5 mole weight % of $Eu_2O_3$ =0.0640gm.

0.5 mole weight % of of ½ $Tb_4O_7$ = 0.0227 gm

Total weight = 10 gm.

**16) $LaYPO_4$: Eu(2.0%), Tb (0.5%),Gd(0.5%)**

Basic reaction:-

$La_2O_3$ +2 $(NH_4)_2HPO_4$+ $Y_2O_3$+ $Gd_2O_3$ +$Eu_2O_3$+½ $Tb_4O_7$ → 2$LaYPO_4$:Eu (2.0%),Tb(0.5%),Gd(0.5%)

Mole weight of $La_2O_3$ = 325.82 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 264.12 gm.

Mole weight of $Y_2O_3$ = 225.81 gm

0.5 Mole weight % of $Gd_2O_3$ =1.812 gm

2.0 mole weight % of $Eu_2O_3$ =7.040 gm

0.5 mole weight % of ½ $Tb_4O_7$ = 1.8692 gm

Total weight = 826.47 gm.

To prepare 10 gm of material

Mole weight of $La_2O_3$ = 3.9424 gm.

Mole weight of 2 $(NH_4)_2$ $HPO_4$ = 3.1958 gm.

Mole weight of $Y_2O_3$ = 2.7322 gm

0.5 Mole weight % of $Gd_2O_3$ = 0.0219 gm

2.0 mole weight % of $Eu_2O_3$ = 0.0852 gm.

0.5 mole weight % of ½ $Tb_4O_7$ = 0.0226 gm

Total weight = 10 gm.

## 2.6. Characterizations of the prepared Phosphors:

- To identify the crystal structure and phase purity of the prepared phosphor materials, X-ray Diffraction analysis was carried out with a powder diffractometer using Cu Kα radiation at NCL, pune.
- The excitation and emission spectra of the synthesized phosphors have been recorded on a 'Shimadzu' system using Xenon lamp as excitation source at room temperature at M.S. University, Baroda. The Shimadzu Model RF-5301 PC is a high-resolution fluorescence spectrophotometer. The detector used is the Shimadzu make photomultiplier (type no R928 of multialkali. photocathode), which has a flat spectral response over the entire range of wavelength of measurement i.e. from 220 to 900 nm.
- The Thermoluminescence (TL) measurements were performed with Nucleonix make Windows Based thermoluminescence reader. The system consists of PMT housing with drawer assembly, high voltage module, D.C. amplifier module, Temperature controller unit, power supply unit, AD-DA card and a personal computer system along with required hardware and software.
- The microstructures of the samples were studied using a Scanning electron microscope (SEM).
- The FTIR spectra were recorded by FTIR spectrometer in the range from 500 to 4000 $cm^{-1}$.
- The particle size was measured by using Laser based particle size analyzer (Malvern Instrument Ltd (U.K).

- The CIE (Commission International de l'Eclairage) co-ordinates were calculated by the Spectrophotometric method using the spectral energy distribution.

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