



Review—Exploring Technological Innovations of Doped Rare Earth Materials

Mudasir Farooq,¹ Irfan Nazir,² Haqnawaz Rafiq,¹ and Mir Hashim Rasool^{1,z}

¹Department of Physics, Islamic University of Science and Technology, Awantipora, Kashmir—192122, India ²Department of Chemistry, University of Kashmir, Srinagar—190006, India

The manuscript reflects the implications of rare-Earth elements, which comprise an important class of material and are essential for numerous technological improvements. Their research has gradually advanced due to their peculiar chemical and physical characteristics. The implications of their versatility will encourage the development of energy-efficient technological innovations. Interestingly, materials based on rare-Earth elements have been closely studied in conjunction with several contemporary biologically based technological advances and targeted therapies, to adequately overcome neurological problems. The manuscript provides a thorough overview of the multiple effects of materials made of rare Earth's, especially within the field of neuroscience research.

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Lieutenant Karl Axel Arrhenius of the Swedish Army discovered the existence of rare Earth's (REs) in 1787 while gathering ytterbite a dark mineral (later renamed gadolinite).¹ REs mainly includes 14 lanthanides or 4 f elements from the periodic table paired with three additional components that operate similarly to RE substances: lanthanum (La), scandium (Sc) and yttrium (Y). There are 15 elements throughout the lanthanide family, containing atomic numbers spanning from 57 to 71 which include, Lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), vtterbium (Yb) and lutetium (Lu). Although promethium (Pm) emanates via radioactive decay, every element may be discovered in nature.¹ Typically, RE- ions are found in the form of trivalent elements including Eu^{3+} , Dy^{3+} , Ce^{3+} , Gd^{3+} , etc., although some RE- ions were discovered in the form of divalent elements.² Trivalent RE-ions (Ln³⁺) have distinctive electronic configurations $[Xe]4f^{n}$ (n = 0–14).³ Additional elements possessing valences of +2 involve Eu, Sm, and Yb whereas +4 elements encompass Ce, Tb, and Pr.⁴ The [Xe]4fⁿ⁻¹5d¹6s² configurations are shared by La, Ce, and Gd for 15 lanthanides, whereas the other lanthanides share $[Xe]4f^{n}6s^{2}$ configurations. Despite having less energy than those in the 4 f orbitals, the lanthanide electrons in the 5 s and 5p orbitals are much more dispersive.⁵ Depending on their atomic weight, rare Earth elements (REEs) can be divided into two classes: light rare Earth elements (LREEs) and heavy rare Earth elements (HREEs). Sc however, is not thought of as an LREE or HREE because it is not derived from the same sources as those used to make other REEs. Moreover, Pr is a radioactive element that does not exist in nature. Table I below depicts the noteworthy usage of REEs and their classifications according to their atomic weights.⁶

Owing to the extremely plentiful emission color based on the $4 f \rightarrow 4 f$ or $5d \rightarrow 4 f$ transformations, RE-ions as normally employed activators have been acting in significant positions in current lighting and display applications.^{7,8} Over a long period researchers have noticed that materials doped with RE-ions show a significant increase in their spectral characteristics compared to other ions. Therefore RE- ions develop stronger, narrow-band and sharp lines of unique emissions that extend from the UV to NIR regions.^{9,10} Er is the most often utilized activator although the two Eu³⁺ and Eu²⁺ ions may contribute as emission centers in the host lattices.¹¹ Figure 1 below depicts four different types of electronic transitions that can be detected in compounds triggered by lanthanides.¹² Throughout the band gap, an electron comes out from the upper

portion of the valence band and is triggered, establishing an exciton state with energy Ex. Such transitions reveal the location of the mobility edge or bottom of the conduction band together with the fundamental absorption threshold.¹³ Consequently, one also differentiates between the two different forms of the intra-lanthanide electronic transitions the intra-configuration $4f^n \rightarrow 4f^n$ and the interconfigurational $4f^n \rightarrow 4f^{n-1}5d^1$ transitions. Electrons can shift between different energy levels inside a single lanthanide element during intra-lanthanide transitions. Upon absorbing an energetic photon during such a transition, an inner shell electron raises to a higher level. Conversely, inter-lanthanide transitions involve the passage of electrons between energy levels within different lanthanide elements. A photon's energy is transferred to an electron in a neighboring lanthanide element when it excites an electron in one lanthanide element, causing it to move to a higher energy state. In the field of optoelectronic devices, both of those transitions are pivotal. Both of the different lanthanides endure valence alterations throughout the transition as one lanthanide operates as a donor while the other is an acceptor.¹² Thus, it is possible to conclude that lanthanides ion comprises three distinct forms of optical transitions: intra-configurational $4f \rightarrow 4f$ transition, inter-configurational $5d \rightarrow -4f$ transition and charge transfer transition (ligand to metal or metal to ligand).¹⁴ Moreover, the Laporte selection rule permits the charge transport transition $(4f \rightarrow 4f)$ in lanthanide ions. In contrast, it precludes the transition of an electric dipole with the same parity.¹⁵ When identical ions are implanted in a suitable host material, non-centrosymmetric interactions result from the ligandinfluence fields on the wavefunctions of the opposing parity states which drastically merge with 4f-wavefunctions. This makes it possible to significantly ease the parity selection criteria and allows for considerable flexibility in the use of 4 f \rightarrow 4 f transitions.¹⁶ The 5 s and 5p orbitals of lanthanide ions shield the 4 f orbital therefore the binding pattern is not significantly altered when an electron is promoted to a higher energy 4 f sub-orbital. Consequently, the internuclear separation in the higher energy state remains unaltered thus yielding narrow emission lines. The prolonged lifespan is a consequence of the 4f-4f transitions in the lanthanide ions being parity-restricted.¹⁶ Accordingly, it can be concluded that the main cause of luminescence in REEs is a parity-forbidden electronic transition within the 4 f shell.¹

General Properties of Rare-Earth Materials/ions

Energy transfer with radiation and without radiation.—It refers to an excitation (stimulation) energy exchange mechanism where the donor ion (D) is radiatively deactivated and the nearby acceptor ion (A) reabsorbs the donor ion's emitted radiation. The energy-donating ion absorbs the excitation energy effectively through this