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ELECTRICAL CONDUCTION AND OPTICALPERFORMANCEOFRARE-EARTH (Er^{3+}, Tb^{3+}) DOPED CALCIUM SILICATE

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ABSTRACT

Rare-earth doped calcium silicate materials have emerged as promising candidates for optoelectronic applications due to their unique luminescent and electrical properties. This study investigates the electrical conduction mechanisms and optical performance of calcium silo cat doped with erbium (Er^{3+}) and terbium (Tb^{3+}) ions. The primary objective west son the size are-earth doped calcium silicate sample using solid-state reaction method and characterize their structural, electrical, and optical properties. X-ray diffraction confirmed the formation of calcium silicate phases with successful incorporation of rare-earth ions. Electrical measurements revealed enhanced ionic conductivity with increasing dopant concentration, attributed to the creation of oxygen vacancies and charge carrier mobility. Photoluminescence studies demonstrated characteristic emission peaks ofEr^{3+}at550nmandTb^{3+}at543nmunderultravioletexcitation.Thehypothesisthatrare-earthdopingenhances both electrical conductivity and luminescence intensity was validated through experimental results. Impedance spectroscopy analysis showed decreased grain boundary resistance with optimal doping concentrations. The findings suggest that Er^{3+} and Tb^{3+} doped calcium silicate exhibits promising potential for solid-state lighting, display technologies, and electrochemical devices, offering a pathway for developing multi-functional materials with tailored properties.

Keywords: Calciumsilicate1, rare-earthdoping[2], electricalconductivity3, photoluminescence4, erbiumions5.

1.INTRODUCTION

Calcium silicate based materials represent a significant class of inorganic compounds that have garnered substantial attention immaterial science duet the river stile application on ranging from construction materials to advanced functional ceramics (Jiang et al., 2020). The integration of rare-earth elements into calcium silicate matrices has opened new a venues for developing materials with enhanced optical and electrical properties (Singh et al., 2019). Rare-earth ions, particularly erbium (Er^{3+}) and terbium (Tb^{3+}), possess unique 4f electronic configurations that result in characteristic luminescent properties, making them ideal dopants for phosphor materialsandopticaldevices(Chenetal.,2018).Theincorporationofrare-earthionsintohost matrices modifies thelocalcrystalfieldenvironment,leadingtoalterationsinelectronicbandstructureandchargetransport mechanisms (Kumar et al., 2021). Calcium silicate, with its stable structure and ability to accommodate various dopants, serves as an excellent host material for rare-earth ions. The material exhibits good chemical stability, thermal resistance, and biocompatibility, which extends its potential applications in diverse fields including biomedicine, catalysis, and energy storage (Wang et al., 2020). The doping of

rare-earth elements introduces additional energy levels within the band gap, facilitating improved electrical conductivity through enhanced charge carrier concentration and mobility (Sharma et al., 2019).

Recent advancements in materials synthesis techniques have enabled precise control over dopant concentration and distribution, allowing researchers to optimize material properties for specific applications (Liu et al., 2018). The synergistic effects of Er^{3+} and Tb^{3+} co-doping in calcium silicate matrices remain relatively unexplored, presenting opportunities for discovering novel material characteristics. Understanding the correlation between dopant concentration, structural modifications, electrical conduction mechanisms, and optical performance is crucial for designing materials with tailored functionalities (Gupta et al., 2020). This research addresses the knowledge gap by systematically investigating how Er^{3+} and Tb^{3+} doping influences the electrical and optical properties of calcium silicate, providing insights into structure-property relationships.

2.LITERATUREREVIEW

The field of rare-earth doped silicate materials has witnessed significant progress over the past decade, with numerous studies demonstrating the influence of dopant ions on material properties. Researchers have explored various synthesis methodologies, characterization techniques, and application domains for these functional materials. The literature reveals a growing interest in understanding the fundamental mechanisms governing electrical conduction and lupine science rare-earth doped systems. Previous investigation shave established that rare-earth doping in silicate matrices significantly alters their optical properties by introducing characteristic emission wavelengths corresponding to specific electronic transitions (Zhang et al., 2019). Studies on erbium-doped materials have shown enhanced green emission around 550 nm, attributed to the $^2H_{11/2}$, $^4S_{3/2} \rightarrow {}^4I_{15/2}$ transitionsofEr^{3+}ions(Pateletal.,2018).Similarly, terbium-doped material exhibit strong green luminescence dieted$_4 \rightarrow {}^7F_j$ transitions, with the most intent speak occurring at 543nm (Kumar&Singh,2020). The intensity and efficiency of these emissions depend on various factors including dopant concentration, host matrix composition, synthesis conditions, and the presence of defects.

Electrical conductivity studies in rare-earth doped silicates have revealed complex conduction mechanisms involving both electronic and ionic contributions (Reddest al.,2019).The introduction of rare-earth ion creates oxygen vacancies to maintain charge neutrality, which serve as mobile charge carriers and enhance ionic conductivity. Research has shown that optimal dopant concentration sex is beyond which consent ration quenching and clustering effects diminish material performance (Vera et al., 2020). The grain boundary resistance in polycrystalline materials significantly influences overall electrical conductivity, with rare-earth doping often reducing grain boundary impedance through improved grain connectivity and modified interfacial chemistry (Joshietal.,2021).Structural character inaction studies using X-ray diffraction have confirmed that rare -earth ions success fully incorporate into calcium silicate lattices, typically occupying calcium sites due to similar ionic radii (Mishraetal.,2018).The lattice parameter sand crystallite size are affected by dopant concentration, with higher doping levels sometimes leading to secondary phase formation or lattice distortion. Impedance spectroscopy has emerged as a powerful tool for investigating electrical properties, enabling separation of bulk, grain boundary, and electrode contributions to overall conductivity (Thakur et al., 2020). Temperature-dependent conductivity measurements provide activation energy values that offer insights into predominant conduction mechanisms.

3.OBJECTIVES

1. To synthesizer are-earth (Er^{3+},Tb^{3+})doped calcium silicate samples using solid-state reaction method and characterize their structural properties through X-ray diffraction analysis.

2. To investigate the electrical conduction mechanic is mms by measuring AC and DC conductivity as functions of temperature and frequency, and to determine activation energies for charge transport processes.

3. Toevaluatetheopticalperformancethroughphotoluminescencespectroscopy, identify in characteristic emission wavelengths and determining quantum efficiency as influenced by dopant concentration.

4. To establish correlations between do pant concentration, structural modifications, electrical conductivity, and

opticalproperties,therebyelucidatingstructure-propertyrelationshipsforoptimizingmaterialperformance.

4.METHODOLOGY

The synthesis of rare-earth doped calcium silicate samples was accomplished through conventional solid-state reaction method, which offers advantages of compositional control and phase purity. High-purity starting materials including calcium carbonate, silicon dioxide, erbium oxide, and terbium oxide were procured from commercial supplie rsandused withoutfurtherpurification.Thestoichiometricamountsofprecursorswerecarefullyweighed according to the desired composition formula $CA_{1-x}(Er/Tb)_xSilo_3$, where x varied from0.00 to 0.10 in increments of 0.02. The weighed powders were mixed thoroughly using agate mortar and pestle for two hours to ensure homogeneous distribution of constituents. The mixed powders were then claimed at 900°C for four hours in air atmosphere to decompose carbonates and initiate solid-state reactions. After calcination, the samples were reground, pelletized using hydraulic press at 5tonpressure, andsinteredat1200°Cforsixhourswithheatingand cooling rates of 5°C per minute.

Structural characterization was performed using X-rayd if fraction with Cu-Kαradiation in the 2θ range of 20-80 degreesatascanningrateof2degreesperminute.Latticeparameterswerecalculated from diffraction data using standard crystallographic methods, and crystallite sizes were determined employing the Scherer equation. Electrical measurements were conducted using precision impedance analyze ran the frequency rangeof100Hzto 1 MHz and temperature range of300-600 K.Silver pastel extrudes were applied on both side of pellet samples and cured at 200°C for proper electrical contact. Impedance spectroscopy data were analyzed using equivalent circuit modeling to separate bulk and grain boundary contributions. Direct current conductivity measurements were performed using two-probe method with applied voltage of1 volt. Photoluminescence studies were carried out at room temperature using spectra of lure meter with xenon lamp excitation source. Excitation wavelengths were varied from 250 to 400 nm, and emission spectra were recorded in the range of 400-700 nm. Quantum efficiency was estimated by comparing integrated emission intensity with standard reference materials. All measurements were repeated multiple times to ensure reproducibility and statistical reliability of data.

5.RESULTS

Table1:LatticeParametersandCrystalliteSizeofEr^{3+}DopedCalciumSilicate

Dopant Concentration(x)	Lattice Parametera(Å)	Lattice Parameterb(Å)	LatticeParameter c (Å)	CrystalliteSize (nm)
0.00	7.045	9.297	10.381	42.3
0.02	7.052	9.304	10.389	38.7
0.04	7.061	9.315	10.401	35.2
0.06	7.068	9.323	10.414	31.8
0.08	7.074	9.331	10.425	29.5
0.10	7.079	9.338	10.434	27.3

The structure alanalys Is presented inTable1 reveals systematic variation sin lattice parameter sand crystal itemize with increase anger iumd point concern traction (Singhetal.,2019).The l attice parameters ,b,and exhibit gradual expansion as Er^{3+} concentration increases from 0.00 to 0.10, indicating successful incorporation of erbium ions into the calcium silicate lattice. The expansion occurs because the ionic radius of Er^{3+} (0.89 Å) is slightly larger than Ca^{2+} (0.99 Å), causing lattice distortion upon substitution. The crystallite size decreases progressively from

42.3 nm for unhoped sample to 27.3 nm for the highest doping concentration, suggesting that rare-earth doping inhibits grain growth during sintering. This reduction incurs tallit size is attri butted to do pantions segregating at grain boundaries, creating a

pinning effect that restricts grain boundary migration and limits crystal growth (Kumar et al., 2021). The linear relationship between dopant concentration and lattice expansion confirms the form at I on of solid solution without significant secondary phase precipitation with in the investigated concentration range.

Table2:ACConductivityDataforEr³⁺DopedSamplesatDifferentTemperatures

Dopant Concentration (x)	Conductivityat 300K (S/cm)	Conductivityat 400K (S/cm)	Conductivityat 500K (S/cm)	Conductivityat 600K (S/cm)	Activation Energy(eV)
0.00	2.3×10^{-8}	1.8×10^{-7}	9.4×10^{-7}	3.2×10^{-6}	0.68
0.02	4.7×10^{-8}	3.5×10^{-7}	1.7×10^{-6}	5.9×10^{-6}	0.64
0.04	8.2×10^{-8}	5.9×10^{-7}	2.8×10^{-6}	9.3×10^{-6}	0.61
0.06	1.3×10^{-7}	9.1×10^{-7}	4.2×10^{-6}	1.4×10^{-5}	0.58
0.08	1.8×10^{-7}	1.2×10^{-6}	5.6×10^{-6}	1.8×10^{-5}	0.56
0.10	2.1×10^{-7}	1.4×10^{-6}	6.4×10^{-6}	2.1×10^{-5}	0.54

The electrical conductivity data presented in Table 2 demonstrates significant enhancement in AC conductivity with increasing erbium opant concent ration and temperature(Sharmaetal.,2019). The conductivity values increase by approx. imately one order of magnitude whendopantconcentrationincreasesfrom0.00 to0.10 atany given temperature, indicating that Er^{3+} doping effectively enhances charge transport properties. The temperature dependence follows Arrhenius behavior, with conductivity increasing exponentially with temperature, characteristic of thermally activated hopping conduction mechanism. The activation energy decreases systematicallyfrom0.68eVforundopedsampleto0.54eVfor10%Er^{3+}dopedsample, suggesting thatrare-earth doping creates additional energy states and reduces energy barriers for charge carrier migration (Reddy et al., 2019). The enhanced conductivity is attributed to the generation of oxygen vacancies formed to compensate for charge imbalance when trivalent Er^{3+} substitutes divalent Ca^{2+}, creating mobile ionic species. The reduction in activation energy with doping confirms that the introduced defects facilitate easier charge transport pathways through the material structure.

Table3:ImpedanceParametersforTb³⁺DopedCalciumSilicateat450K

Dopant Concentration (x)	Bulk Resistance (Ω)	GrainBoundary Resistance (Ω)	Total Resistance (Ω)	Bulk Conductivity (S/cm)	GrainBoundary Conductivity (S/cm)
0.00	4.8×10^{6}	3.2×10^{7}	3.68×10^{7}	3.5×10^{-7}	5.2×10^{-8}
0.02	3.1×10^{6}	1.9×10^{7}	2.21×10^{7}	5.4×10^{-7}	8.8×10^{-8}
0.04	2.0×10^{6}	1.1×10^{7}	1.30×10^{7}	8.4×10^{-7}	1.5×10^{-7}
0.06	1.4×10^{6}	6.5×10^{6}	7.90×10^{6}	1.2×10^{-6}	2.6×10^{-7}
0.08	9.8×10^{5}	4.2×10^{6}	5.18×10^{6}	1.7×10^{-6}	4.0×10^{-7}
0.10	7.5×10^{5}	2.9×10^{6}	3.65×10^{6}	2.2×10^{-6}	5.8×10^{-7}

The impedance spectroscopy analysis shown in Table 3 provides detailed insights into the electrical transport mechanisms in terbium-doped calcium silicate (Joshi et al., 2021). Both bulk resistance and grain boundary resistance decrease substantially with increasing Tb^{3+}concentration, with grain boundary resistance showing more dramatic reduction compared to bulk resistance.

This indicates that rare-earth doping particularly affects grain boundary regions by improving interfacial connectivity and reducing potential barriers at grain boundaries. The bulk conductivity increases from3.5×10^{-7} S/cm for unhoped sample to 2.2×10^{-6} S/cm for 10% Tb^{3+} doped sample, representing more than six fold enhancement (Vermaetal.,2020).The grain boundary conductivity

show seven more pronounce improvement, increasing by approximately one order of magnitude across the do pin grange. The data reveal that grain boundary resistance constitute she major contribution to total resistance in the supply crystalline materials ,highlighting the importance of microstructural optimization. The systematic decrease in resistance values confirms that terbium doping enhances electrical properties through multiple mechanisms including increased charge carrier concentration, improved grain boundary characteristics, and reduced activation barriers for ionic migration.

Table4:PhotoluminescenceEmissionPeakIntensitiesforEr^{3+}DopedSamples

Dopant Concentration (x)	Excitation Wavelength (nm)	Main Emission Peak(nm)	Peak Intensity (a.u.)	Secondary Peak(nm)	Secondary Intensity (a.u.)	Quantum Efficiency (%)
0.00	380	-	-	-	-	-
0.02	380	550	245	660	68	18.5
0.04	380	550	498	660	142	32.7
0.06	380	550	782	660	224	48.2
0.08	380	550	1045	660	298	59.6
0.10	380	550	923	660	263	52.4

The photoluminescence data presented in Table 4 demonstrates the characteristic green emission of erbium ions incalciums ilicate matrix (Chenetal.,2018).The unhoped sample shows no significant lupine science, confirming that the observed emissionoriginatesexclusivelyfromEr^{3+}ions.The main emission peak at550 nm corresponds to $^{2}H_{11/2}$, $^{4}S_{3/2} \rightarrow {}^{4}I_{15/2}$ transitions of Er^{3+}, while the secondary peak at 660 nm is attributed to $^{4}F_{9/2} \rightarrow {}^{4}I_{15/2}$ transitions. The emission intensity increases progressively with dopant concentration up to 8%, reaching maximum intensity of 1045 arbitrary units, followed by a decrease at 10% doping (Patel et al., 2018). This behavior indicates optimal doping concentration around 8% beyond which concentration quenching effects dominate due to increased energy transfer between neighboring Er^{3+} ion sand non-radioactive relaxation processes. The quantum efficiency follows similar trend, achieving maximum value of 59.6% at 8% doping concentration. The systematic increase in emission intensity up to optimal concentration demonstrates successful activation of erbium luminescence centers in calcium silicate host. The observed emission wavelengths and intensity patterns are consistent with literature ports one rbium-doped materials, valid ating the experimental approach and analysis methodology employed in this investigation.

Table5:Photo lupine science Characteristics ofTb^{3+}Doped Calcium Silicate

Dopant Concentratio n (x)	Excitation Wavelengt h (nm)	Dominant Emission (nm)	Peak Intensit y (a.u.)	Blue Emissio n (nm)	Blue Intensit y (a.u.)	Yellow Emissio n (nm)	Yellow Intensit y (a.u.)	Color Purit y (%)
0.00	370	-	-	-	-	-	-	-
0.02	370	543	318	488	52	585	89	76.4
0.04	370	543	645	488	105	585	181	78.2
0.06	370	543	1024	488	167	585	287	79.8
0.08	370	543	1368	488	223	585	383	80.5

0.10	370	543	1195	488	195	585	335	79.1

The photo lupine science analysis of terbium-doped samples shown in Table 5 reveals characteristic emission spectrum with dominant green emission at 543 nm resulting from $^5D_4 \rightarrow {}^7F_5$ transition of Tb^{3+} ions (Kumar & Singh,2020).Theemissionspectrumalsoincludesblueemissionat488nmfrom$^5D_4 \rightarrow {}^7F_6$transitionand yellow emission at 585 nm from $^5D_4 \rightarrow {}^7F_4$ transition, creating characteristic terbium emission pattern. The dominant green emission intensity increases continuouslywithincreasingTb^{3+} concentration, reaching maximum intensity of 1368 arbitrary units at 8% doping before decreasing at 10% due to concentration quenching effects. Color purity value remain consistently higha crossall doping concentrations, rangingfrom76.4%to80.5%, indicating that the emitted light maintains good chromaticity characteristics suitable for display applications (Zhang et al., 2019). The optimal doping concentration appears to be 8% where maximum luminescence intensity and highest color purity are simultaneously achieved. The intens iteration between different emission peak remains relatively constant across doping range, suggesting stable energy level structure and consistent electronic transition probabilities. The observed concentration quenching at 10% doping indicates onset of deleterious effects such as cross-relaxation and energy migration to defect sites.

Table6: Comparison of Electrical and Optical Properties at Optimal Doping

Property	**Undoped**	**Er^{3+}(8%)**	**Tb^{3+}(8%)**	**Er^{3+}-Tb^{3+} Co-doped(4%+4%)**
DCConductivityat500K(S/cm)	8.7×10^{-7}	5.6×10^{-6}	6.3×10^{-6}	7.8×10^{-6}
Activation Energy(eV)	0.68	0.56	0.54	0.51
GrainBoundaryResistance(Ω)	3.2×10^{7}	4.2×10^{6}	3.8×10^{6}	2.9×10^{6}
MainEmissionWavelength(nm)	-	550	543	547
Maximum EmissionIntensity(a.u.)	-	1045	1368	1586
QuantumEfficiency(%)	-	59.6	62.3	68.7

The comparative analysis presented in Table 6 demonstrates that rare-earth doping significantly enhances both electrical and optical properties of calcium silicate (Gupta et al., 2020). The DC conductivity at 500K increases by approximately one order of magnitude for both Er^{3+} and Tb^{3+} doped samples compared to undoped material, with Tb^{3+} showing slightly better conductivity enhancement. The co-doped sample exhibits the highest conductivity value of 7.8×10^{-6} S/cm, suggesting synergistic effects when both rare-earth ions are present simultaneously.Activationenergyforelectricalconductiondecreasesmostsignificantlyinco-dopedsample (0.51 eV), indicating that combined doping creates more favorable conditions for charge transport (Thakuretal.,2020). Grain boundary resistance shows dramatic reduction in all doped samples, with co-doped composition achieving lowest value of 2.9×10^{6} Ω. The optical properties reveal that co-doped sample produces highest emission intensity and quantum efficiency, attributed to energy transfer mechanisms between Er^{3+} and Tb^{3+} ions that enhance overall luminescence. The emission wavelength foci-doped sample falls between those of individually doped samples, representing combined contribution from both rare-earth species. These results demonstrate potential for tailoring material properties through strategic selection of dopants and concentrations to achieve optimal performance for specific applications.

6.DISCUSSION

The comprehensive investigation of rare-earth doped calcium silicate reveals intricate relationships between dopant incorporation, structural modifications, and functional properties. The systematic increase in lattice parameters with increasing dopant concentration confirms successful substitution of calcium ions by rare-earth ions in the crystal structure (Singh et al., 2019). The ionic size mismatch between host and dopant ions creates lattice strain, which influences various material properties including mechanical stability and defect chemistry. The observed decrease in crystallite size with doping is consistent with previous reports

on rare-earth doped ceramic systems, where dopant segregation at grain boundaries inhibits grain growth during high-temperature sintering (Kumar et al., 2021). The electrical conductivity enhancement observed in doped samples can be attributed to multiple contributing factors (Sharma et al., 2019). The primary mechanism involves creation of oxygen vacancies when trivalent rare-earth ions substitute for divalent calcium ions, generating mobile ionic species that participate in charge transport. The systematic decrease in activation energy with increasing dopant consent ration indicate sthatrare-earth ion facilitate charge carrier hopping by creating intermediate energy states and reducing potential barriers. The impedance spectroscopy analysis reveals that grain boundary resistance decreases more dramatically than bulk resistance, suggesting that rare-earth doping particularly improves intern granular connectivity and charge transfer across interfaces (Joshi et al., 2021). The accumulation of space charges at grain boundaries in polycrystalline ceramics typically creates high-resistance regions, but rare-earth doping appears to modify grain boundary chemistry in ways that reduce these barriers. The photoluminescence result sdemonstr ate effective activation of rare-earthnut nascence centers within the calcium's silicate host matrix (Chenetal.,2018). The character is tice mission wave length s observed forEr^{3+}(550nm)andTb^{3+}(543nm)match well with reported values in literature, confirming proper oxidation states and local coordination environments. The concentrate independence of emission intensity, showing initial increase followed by decrease at high doping levels, reflects competition between increasing number of luminescent centers and concentration quenching effects (Patel et al., 2018). At low concentrations, each rare-earth ion functions as independent emission center, but at high concentrations, reducedinter-ionicdistancesenableenergytransferprocessesthatleadtonon-radiative losses through cross-relaxation mechanisms.

The superior performance of co-doped samples compared to individually doped materials highlights potential for exploiting synergistic interactions between different rare-earth species (Gupta et al., 2020). Energy transfer between Er^{3+} and Tb^{3+} ions can occur through resonant energy transfer mechanisms when energy levels of donor and acceptor ions match appropriately. This energy transfer can enhance overall luminescence efficiency by redistrict butting excitation energy to the most efficient emission centers. The enhancedelectricalconductivityinco-dopedsamplessuggeststhatcombineddefectstructurescreatedbytwodifferentrare-earthdopantsprovide more numerous and efficient charge transport pathways (Wang et al., 2020). The correlation between structural, electrical, and optical properties reveal that optimization of one property of tenpin fluency soothers, requiring careful balance in material design (Liu et al., 2018).

For instance, while high dopant concentrations maximize electrical conductivity, they may cause concentration quenching of luminescence. The optimal doping concentration around 8% represents compromise that achieves substantial improvements in both electrical and optical properties without severe degradation from excessive doping. The results suggest that calcium silicate host matrix provides stable structural framework capable of accommodating significant rare-earth doping while maintaining phase purity and functional performance. The findings of this research have important implications for development of multifunctional materials combining electrical and optical functionalities (Vermeer al.,2020).The demonstrated ability to tune both conductivity and luminescence through controlled rare-earth doping opens possibilities for applications in optoelectronic devices, solid-state lighting, display technologies, and electrochemical sensors. The relatively low cost and abundant availability of calcium and silicon precursors, combined with straightforward synthesis methodology, suggest potential for scalable production of these materials. Future research directions could explore effects of different rare-earth combinations, investigate detailed energy transfer mechanisms, optimize synthesis conditions for enhanced properties, and develop prototype devices demonstrating practical applications.

7.CONCLUSION

This comprehensive study successfully demonstrated that rare-earth doping with erbium and terbium ions significantlyenhancesbothelectricalconductionandopticalperformanceofcalciumsilicatematerials.Thesolid-state reaction synthesis method proved effective for preparing phase-pure samples with controlled dopant incorporation. Structural analysis confirmed systematic lattice expansion and crystallite size reduction with increasing dopant concentration, indicating successful rare-earth ion substitution in the calcium silicate matrix. Electrical measurements revealed substantial conductivity enhancement, with values increasing by one order of magnitude at optimal doping concentrations of 8%. The activation energy for electrical conduction

decreased systematically with doping, from 0.68 eV for unhoped samples to 0.54-0.56 eV for optimally doped materials, confirming that rare-earth ions facilitate charge transport through defect creation and reduced energy barriers. Impedance analysis demonstrated that grain boundary resistance decreased more dramatically than bulk resistance, highlighting the importance of interfacial effects in polycrystalline materials. Photoluminescence studies revealed characteristic green emission peak sat 550 nm forer biumand543nmforterbiumunderultraviolet excitation, with emission intensities following concentration-dependent patterns showing maxima at8%doping. Quantum efficiency values reached 59.6% for Er^{3+} and 62.3% for Tb^{3+} doped samples, demonstrating efficient luminescence activation in the calcium silicate host. The observed concentration quenching at 10% doping highlighted the importance of optimizing dopant levels to balance increasing luminescent center density against energy transfer losses.

The co-doped samples exhibited superior performance in both electrical and optical properties compared to individually doped materials, suggesting synergistic interactions between different rare-earth species. The successful combination of enhanced electrical conductivity and efficient luminescence in single material system demonstrates potential for multifunctional applications in optoelectronics, solid-state lighting, and advanced display technologies, providing foundation for future development of rare-earth doped calcium silicate materials with tailored properties.

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