© AUG 2026 | IRE Journals | Volume 10 Issue 2 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV10I2-1722418

The Interplay Between Electrical Conductivity and Electrical Thermal Conductivity in Strontium Titanate Compounds for Enhanced Thermoelectric Power Generation

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Abstract- ***The thermoelectric (TE) performance of strontium titanate (SrTiO3)-based compounds is fundamentally determined by the interplay between electrical conductivity (σ) and electronic thermal conductivity (KE), two transport parameters that collectively govern charge and heat flow during thermoelectric power generation. As a chemically stable oxide with excellent thermal stability, SrTiO3 has attracted significant attention for high-temperature thermoelectric applications. However, its intrinsically low electrical conductivity limits its practical performance. This review examines how the crystal and electronic properties of SrTiO3 influence the coupling between electrical conductivity and electronic thermal conductivity and their combined impact on the thermoelectric figure of merit (ZT). Particular emphasis is placed on the Wiedemann-Franz relationship, which establishes the inherent dependence of electronic thermal conductivity on electrical conductivity, thereby presenting a major challenge in optimizing thermoelectric efficiency. The review further discusses carrier concentration optimization as a critical strategy for balancing electrical conductivity, Seebeck coefficient, S and electronic thermal conductivity to achieve superior thermoelectric performance. The influence of rare-earth (RE) dopants such as lanthanum, La and Samarium, Sm is critically evaluated with respect to their effects on carrier concentration, electronic structure, electrical conductivity, and heat transport. These dopants enhance electron transport while modifying lattice characteristics that influence thermal conduction, enabling improved TE performance when appropriately optimized. Overall, this review demonstrates that understanding and controlling the interplay between electrical conductivity and electronic thermal conductivity through crystal chemistry, carrier concentration optimization and RE doping is fundamental to the design of high-performance SrTiO3-based thermoelectric materials for efficient and sustainable high-temperature power generation.***

Keywords: strontium titanate, electrical conductivity, electronic thermal conductivity, wiedemann-franz relationship, carrier concentration.

I. INTRODUCTION

The growing global demand for lean and sustainable energy has intensified research into technologies capable of converting waste heat into useful electrical energy. Thermoelectric power generation offers a solid state approach for directly converting heat into electricity through the Seebeck effect, making it attractive for industrial waste recovery, automotive exhaust systems, and renewable energy applications. Unlike conventional power generation technologies, thermoelectric devices are compact, reliable, environmentally friendly, and require no moving parts or working fluids (Bell, 2008; Snyder and Toberer, 2008).

The efficiency of a TE material is determined by the dimensionless figure of merit (ZT), which depends on a high Seebeck coefficient, high electrical conductivity, and low thermal conductivity. Achieving these properties simultaneously is challenging because electrical conductivity and electronic thermal conductivity are intrinsically

linked through the Wiedemann-Franz relationship. Consequently, improving electrical conductivity leads to increased electronic heat transport, thereby limiting the overall performance (Ashcroft and Mermin, 1976; Kim et al., 2015).

Among oxide thermoelectrics, SrTiO3 has attracted considerable attention because of its excellent thermal stability, chemical durability, non-toxicity, and suitability for high-temperature operation. Although pristine (pure and undoped) SrTiO3 exhibits relatively low thermoelectric performance due ti its wide band gap and high lattice thermal conductivity, its properties can be significantly improved through carrier concentration optimization, rare-earth doping, oxygen vacancy engineering and microstructural modification (Ohta, 2007; Shi et al; 2020).

This review examines the interplay between electrical conductivity and electronic thermal conductivity in SrTiO3 – based materials and discusses how carrier concentration, rare-earth doping, oxygen vacancy engineering, etc. influence thermoelectric performance.

1.1. Crystal Structure of SrTiO3

Strontium titanate (SrTiO3) is one of the most extensively studied oxide ceramics because of its exceptional electrical, optical, dielectric and thermoelectric properties. It belongs to the family of perovskite oxides with the general chemical formulaABO3, where strontium (Sr2+) occupies the A-site, titanium (Ti4+) occupies the B-site, and oxygen (O2-) forms an octahedral framework around the titanium ions (Muller and Burkard, 1979). The typical crystal structure of a cubic SrTiO3 perovskite is shown in Figure 1.

The unique crystal structure of SrTiO3 provides remarkable flexibility for chemical substitution and defect engineering, making it an ideal platform for tailoring electrical and thermal transport properties for thermoelectric applications (Ohta, 2007). At room temperature, SrTiO3 crystallizes in a highly symmetric cubic perovskite structure with the space group Pm 3m. In this structure, each Ti ion is coordinated by six oxygen atoms, forming TiO6 octahedra while each Sr2+ ion occupies a cubo-octahedral site surrounded by twelve oxygen atoms. This highly ordered arrangement promotes efficient electron transport through Ti-O-Ti network while maintaining excellent structural stability over a wide temperature range (Muller and Burkard, 1979). Below approximately 105 K, SrTiO3 undergoes a reversible cubic-to- tetragonal phase transition caused by antiferrodistortive rotation of the TiO6 octahedra. However, since most thermoelectric devices operate at temperatures far above this transition, the cubic phase is generally considered the relevant structure for thermoelectric performance.

By the introduction of dopant into the lattice, distortions from cubic to lower symmetries (size incompatibility) may occur. The measure of stability (degree of distortion) within the structure of perovskite-type ABO3 is defined by the Goldschmidt tolerance factor, t (Adams, 2010; Muller, 2007):

$$t = \frac{r_A + r_O}{\sqrt{2(r_B + r_O)}} \quad (1)$$

where rA, rB and rO are the ionic radii of atoms “A”, “B” and oxygen, respectively. For an ideal cubic perovskite such as SrTiO3, t = 1, rA = 1.44 Å, rB = 0.605 Å and rO = 1.40 Å. Lower symmetries are adopted when $t < 1$ or $t > 1$ (Adams, 2010). This deviation from t = 1 results in distortion from the ideal perovskite structure. For example, if the A ion is too small for the octahedral cage ($t < 1$) as dictated by the radius of the “B” ion, tilting occurs with the intent to fill the unused space, thereby lowering the symmetry of the crystal structure (Venkatesh and Murthy, 1999). For compounds with very low values of t, an orthorhombic perovskite structure is formed, e.g. CaZrO3 (t = 0.914). When $t > 1$, tetragonal (BaTiO3, t = 1.062) distortions occur or the ABC close packed stacking sequence is altered to create a family of hexagonal perovskite structures, such as BaMnO3 and BaNiO3 (t = 1.13). These distortions often occur due to doping or through the formation of solid solutions and can be used to tune properties of interest.

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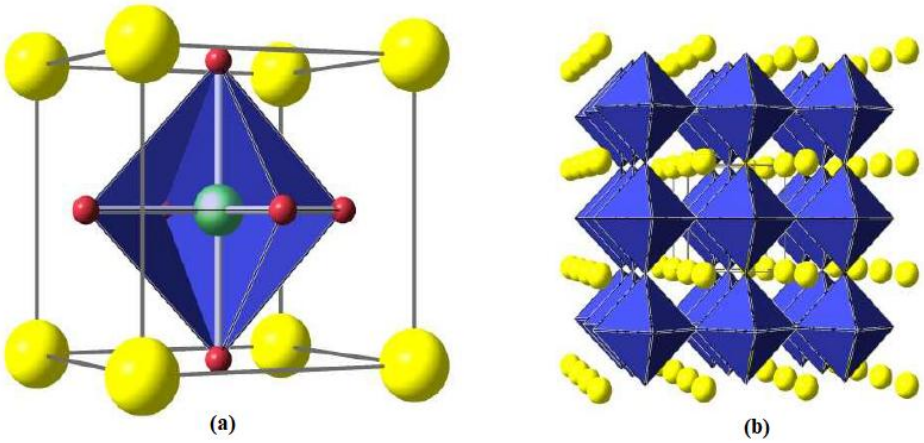

Figure 1. Crystal structure of cubic perovskite SrTiO3 at room temperature showing the (a) octahedral coordination of Ti4+ cation and (b) corner sharing array of TiO6 octahedra (Adams, 2010). Sr2+ ions are in yellow, Ti4+ ions in green and O2- ions in red.

1.2. Electronic Properties of SrTiO3

The electronic structure of SrTiO3 is characterized by a wide indirect band gap of approximately 3.2 eV, making the undoped material an electrical insulator or a very poor semiconductor at room temperature (Van-Benthem et al, 2001). The valence band is primarily composed of oxygen 2p orbitals whereas the conduction band is dominated by titanium 3d orbitals. This electronic configuration (Figure 2) provides a relatively poor electrical conductivity in stoichiometric SrTiO3 (Van-Benthem et al, 2001). Consequently, pristine SrTiO3 exhibits limited thermoelectric performance despite possessing an excellent thermal stability. The electronic structure of SrTiO3 is shown in Figure 2.

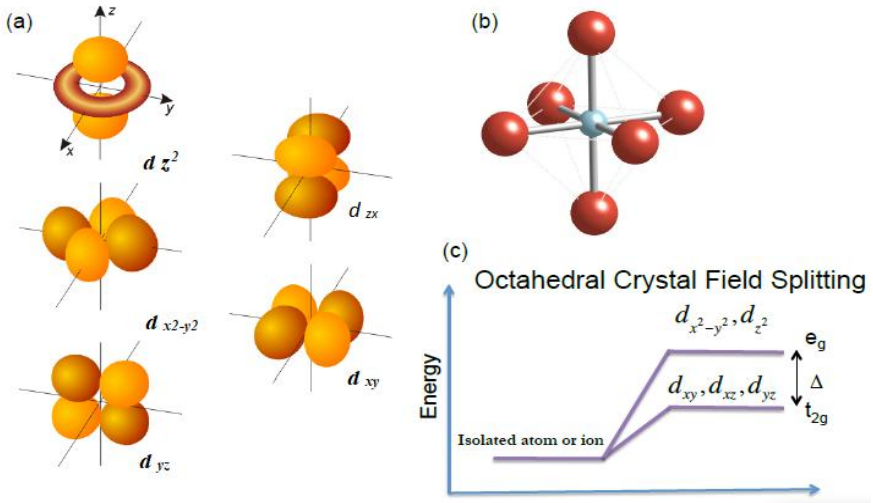

Figure 2. Diagrammatic representation of (a) spatial distribution of d-orbitals (b) oxygen octahedral cage around Ti4+ (c) d-band energy splitting due to the octahedral crystal field (Ravichandran, 2011).

Studies have shown that the large PF exhibited by SrTiO3 which is comparable to the conventional TE materials is attributed to the large orbital degeneracy of the Ti – d conduction band (Ravichandran et al, 2010). From band theory, the valence band is formed by the oxygen 2s and 2p state and it corresponds to the highest occupied molecular orbitals. The conduction band originates from the Ti – d states (mainly Ti – 3d t2g) and it corresponds to the lowest

unoccupied molecular orbitals (Ravichandran et al, 2010).

Electrical Conductivity in SrTiO3 – Based Thermoelectrics

Electrical conductivity σ is one of the most critical transport parameters governing the performance of thermoelectric materials. In SrTiO3-based thermoelectrics, σ directly influences the power factor, PF (S^2 σ) and consequently determines the efficiency of thermoelectric power generation. Since the thermoelectric figure of merit (ZT) is proportional to electrical conductivity, enhancing charge transport while preserving a sufficiently high Seebeck coefficient remains a primary objective in the design of high performance SrTiO3-based thermoelectric materials (Snyder and Toberer, 2008). However, achieving this balance is challenging because electrical conductivity is intrinsically coupled with carrier concentration, carrier mobility, and electronic thermal conductivity.

The electrical conductivity of a semiconductor is expressed as:

$$\sigma = nq\mu \tag{2}$$

where n is the carrier concentration (m-3), q is the elementary electronic charge (1.60 x 10-19 C) and μ is the carrier mobility (m2V-1S-1). This relation indicates that electrical conductivity can be enhanced either by increasing the number of charge carriers or by improving their mobility within the crystal lattice (Ioffe, 1957).

In metals, electrical conductivity results from the constant motion of the ions and decreases with increase in temperature. σ of metals is very high because they possess optimum charge carriers, about n≈10^22 Carriers/cm3. The electrical conductivity of semiconductors lies between metals and insulators. For electrical conduction to occur in semiconductors, the charge carriers must be excited across a gap and by the contributions of electrons and holes as presented equations 2 and 3:

$$\sigma \approx \sigma_0 \exp\left(+\frac{E_G}{K_B T}\right) \tag{3}$$

$$\sigma = nq\mu_e + pe\mu_h \tag{4}$$

where n, p, μe and μh are the electron concentration, hole concentration, electron mobility and hole mobility, respectively. KB is the Boltzmann constant and EG is the energy excited. Unlike metals, the electrical conductivity of semiconductors increases with increase in temperature.

Stoichiometric SrTiO3 possesses an extremely low intrinsic carrier concentration at room temperature, hence exhibits poor electrical conductivity, rendering it unsuitable for thermoelectric applications in its undoped state (Van-Benthem et al, 2001). The low σ results primarily from the absence of free electrons in the conduction band and the limited thermal excitation of charge carriers across the wide band gap. Therefore, various carrier-generation strategies have been developed to transform SrTiO3 into a highly conductive n-type thermoelectric material. These strategies include donor doping, oxygen vacancy engineering, microstructural engineering, nanostructuring and interface engineering, etc.

Electronic Thermal Conductivity and the Wiedemann-Franz Relationship

Electrical thermal conductivity (KE) is one of the fundamental transport parameters governing the thermoelectric performance of SrTiO3-based materials. It represents the portion of heat transported by free charge carriers, principally electrons in n-type SrTiO3 materials and constitutes one of the two components of total thermal conductivity, K:

$$K = K_E + K_L \tag{5}$$

where KL is the lattice (phonon) thermal conductivity (Rowe, 2018). While KL originates from phonon vibrations within the crystal lattice, KE results from the transport of thermal energy by mobile electrons. Understanding the contribution of KE is essential because it directly influences the ZT and determines the effectiveness of heat-to-electricity conversion (Snyder and Toberer, 2008).

In metallic and heavy doped semiconducting thermoelectric materials such as donor-typed SrTiO3, the same electrons responsible for electrical conduction also transport thermal energy. Consequently, improvements in σ frequently result in corresponding increase in K_E. This relationship presents one of the greatest challenges in thermoelectric materials engineering because the simultaneous enhancement of σ and suppression of K_E is necessary to maximize thermoelectric efficiency (Bell, 2008). In pristine SrTiO3 oxides, K_E is relatively small due to the extremely low intrinsic carrier concentration. The total thermal conductivity is therefore dominated by lattice vibrations (phonons) resulting in relatively high K_L but negligible electronic heat transport (Ohta, 2008).

The relationship between σ and K_E is described by the Wiedemann-Franz law, which states that the ratio of electronic thermal conductivity to electrical conductivity is proportional to the absolute temperature, T (Snyder and Toberer ,2008; Jones and Mott, 1958; Doumerc et al, 2009):

$$k_E = L\sigma T \tag{6}$$

where L is the constant of proportionality, called Lorentz number. This law demonstrates that k_E increases proportionally with both σ and T, provided that the Lorentz number remains constant (Ashcroft and Mermin, 1976). The Lorentz number, L is theoretically expressed as:

$$L = \frac{\pi^2}{3}\left(\frac{K_B}{e}\right)^2 \tag{7}$$

where e is the elementary electronic charge. For free-electron metals, L is approximately 2.45 x 10-8 WΩK-2 (Ashcroft and Mermin, 1976). For semiconductors and TE oxides such as SrTiO3, the Lorentz number often deviates from this theoretical value (2.45 x 10-8 WΩK-2) because of carrier scattering mechanisms, band structure complexity , carrier degeneracy, and energy-dependent relaxation times (Kim et al, 205).

The Wiedemann-Franz law also exposes the impediment for a TE material to achieve high temperature efficiency by simultaneously increasing σ and decreasing kE. An attempt to suppress kE affects the electrical conductivity, leading to low ZT. Therefore, TE materials with kL dominated are desirable since the σ will be preserved while k can be reduced through other techniques. Overall, kE remains one of the principal factors limiting the efficiency of SrTiO3-based TE materials. The Wiedemann-Franz law clearly demonstrates the intrinsic coupling between electrical conductivity and electronic heat transport, highlighting the fundamental challenge of simultaneously achieving high σ and low k_E.

Carrier Concentration Optimization

Carrier concentration optimization is one of the most effective strategies for improving the thermoelectric performance of SrTiO3-based compounds. This performance is fundamentally governed by the intricate interplay between σ and k_E. These two parameters are fundamentally coupled (as seen in Wiedemann-Franz law) because they originate from the same charge carrier-electrons in n-type SrTiO3. While electrical conductivity facilitates the transport of electrical charge necessary for power generation, the electronic thermal conductivity transports heat, thereby reducing the temperature gradient that drives thermoelectric conversion.

The efficiency of a thermoelectric material is determined by the dimensionless thermoelectric figure of merit (ZT):

$$ZT = \frac{S^2\sigma T}{K} \tag{8}$$

where S is the Seebeck coefficient, σ is the electrical conductivity, T is the absolute temperature at which the properties are measured and k = kL+kE (Triit and Subramanian, 2006) is the total thermal conductivity. kL and kE are the lattice thermal conductivity and electronic thermal conductivity, respectively. ZT describes the material's performance, hence is a prerequisite for a good thermoelectric material. According to Dehkordi (2014), ZT is a measure of the competition between the electronic transport and

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DOI: https://doi.org/10.64388/IREV10I2-1722418

the thermal transport in a material. The higher the ZT, the better the efficiency of the TE materials to convert heat energy into useable electricity. In equation 8.0, S^2 σ is known as the power factor (PF) and is another important TE performance factor. PF is the determination of the capacity of electronic transport in a material for thermoelectric applications. It is the electric power through which the heat flows between the hot and cold sides per unit temperature gradient (Dehkordi et al, 2015). Therefore, PF is a measure of the power anticipated from a thermoelectric power generator, TEG (Lee et al,2012).

The carrier concentration of charge carriers (i.e. electrons in the compound) directly controls the σ, S, kE and the ZT. This is because these parameters are strongly interdependent; hence identifying an optimum carrier concentration rather than maximizing the number of carriers is essential for achieving high thermoelectric efficiency (Snyder and Toberer, 2008).

Effect of Carrier Concentration on Seebeck Coefficient

The Seebeck coefficient exhibits an inverse relationship with carrier concentration. At low carrier concentrations, charge carriers possess relatively high average transport energy, resulting in a large Seebeck coefficient. As the carrier concentration increases, the Fermi level moves deeper into the conduction band, reducing the average carrier energy difference responsible for thermoelectric voltage generation.

Consequently, excessive carrier concentration leads to a significant reduction in Seebeck coefficient (Goldsmid, 2010). This reverse relationship creates a fundamental tradeoff between electrical conductivity and thermopower (Seebeck coefficient). The overall influence of carrier concentration on thermoelectric performance is summarized in Table 1.

Table 1. Effect of Carrier Concentration on Thermoelectric Performance.

Increasing Carrier Concentration	Effect
Electrical Conductivity (σ)	Increases
Seebeck Coefficient (S)	Decreases
Electronic Thermal Conductivity (K_E)	Increases
Power Factor ($S^2\sigma$)	Initially increases, then decreases
Figure of Merit (ZT)	Exhibits an optimum maximum

This behaviour demeonterates that thermeoelctric materials possess an optimum carrier concentration at which the combined effects of electrical conductivity, Seebeck coeffient, and thermal conducivity produce the highest thermeoelctric figure of merit (Snyder and Toberer,2008).

Controlling Carrier Concentration in SrTiO3-Based Thermoelectrics

In SrTiO3-baased thermoelectrics, carrier concentration is primarily controlled through the following processes:

Donor doping

Substitution of Sr2+ with La3+ introduces one additional electron into the conduction band for every dopant atom. Similarly, substitution of Ti4+ with Nb5+ or Ta5+ generates additional free electrons while maintaining overall crystal charge neutrality (Ohta, 2007). Among these dopants, lanthanum, La has been extensively investigated because of its high solubility in SrTiO3 and its ability to produce significant improvements in electrical conductivity without severe structural distortion.

Okuda et al (2001) systematically investigated La-doped Sr_(1-x) La_x TiO_3 and demonstrated that thermoelectric performance reaches a maximum at intermediate carrier concentrations. Their results showed that low doping levels produce insufficient electrical conductivity, whereas excessive doping decreases the Seebeck coefficient and increases electronic thermal conductivity. The optimum thermoelectric was therefore achieved through careful optimization of electron concentration rather than maximum donor addition.

Oxygen Vacancy engineering

During reduction under hydrogen containing atmospheres, or vacuum, oxygen vacancies are generated according to the Kroger-Vink defect reaction:

$$O_o^{\times} \rightarrow V_o^{\cdot\cdot} + \frac{1}{2}O_2 + 2e^- \quad (9)$$

where $O_o^{\times}$ represents an oxygen ion occupying its normal lattice site, $V_o^{\cdot\cdot}$ denotes a doubly positively charged ion and e^- represents conductive electrons. Each oxygen vacancy contributes two electrons to the conduction band, thereby increasing electrical conductivity (Tuller and Nowick, 1981). Although oxygen vacancies effectively improve carrier concentration, excessive reduction introduces structural disorder and increased defect scattering, which may decrease carrier mobility and degrade thermoelectric performance. Therefore, oxygen vacancy concentration must be carefully controlled to balance conductivity enhancement with structural stability.

Carrier Mobility

Carrier mobility is equally important during carrier concentration optimization. Since electrical conductivity depends on both carrier concentration and mobility, increasing mobility represents a more efficient strategy than simply increasing the number of carriers.

High carrier mobility enables excellent σ while minimizing the increase in k_E associated with excessive electron concentrations (He and Tritt, 2017). Grain refinement, improved densification through spark plasma sintering, and reduced impurity scattering have all been shown to enhance carrier mobility in $SrTiO_3$ ceramics.

Band Structure Engineering

Band structure engineering provides another powerful route for carrier concentration optimization. Chemical substitution can modify the density of electronic states near the Fermi level, thereby increasing the effective mass without excessively reducing mobility. This enables relatively high Seebeck coefficients to coexist with good electrical conductivity, improving the power factor at moderate carrier concentrations (Ohta et al, 2007). Similarly, convergence of multiple conduction bands increases the density of states while preserving carrier mobility, thereby enhancing thermoelectric performance.

Nanostructuring and Interface Engineering

Recent advances have shown that nanostructuring and interface engineering also influence the optimum carrier concentration. Nano structured SrTiO3 contains numerous grain boundaries that selectively scatter low energy carriers and phonons to contribute to electrical transport. This phenomenon is known as energy filtering, and it improves the Seebeck coefficient without causing a substantial decrease in electrical conductivity (Shi et al, 2020). Consequently, the optimum carrier concentration in nanostructured materials differs from that of coarse-grained ceramics.

Operating Temperature

The operating temperature of thermoelectric devices further influences carrier concentration optimization. At elevated temperature, intrinsic carrier excitation becomes increasingly important, and the optimum electron concentration shifts toward slightly higher values because increased phonon scattering reduces carrier mobility (Rowe, 2018). Since SrTiO3 is primarily intended for high-temperature thermoelectric applications above 700 K, optimization strategies should account for temperature-dependent transport behaviour rather

than relying solely on room temperature measurements.

Computational Materials Science

Computational materials science has recently become an independent tool for optimizing carrier concentration. Density functional theory (DFT), Boltzmann transport calculations, and machine learning techniques now enable researchers to predict optimum doping levels, carriers effective masses, and transport coefficients before experimental synthesis (Shi et al, 2020). These computational approaches significantly reduce experimental trial-and-error while accelerating the discovery of high performance SrTiO3 compositions.

Influence of Rare-Earth (RE) Doping

Rare-earth (RE) doping is among the most effective strategies for enhancing the thermoelectric Performance of SrTiO3-based Compounds. By substituting Sr2+ ions at the A-site of the perovskite lattice with trivalent RE ions such as lanthanum (La2+), samarium (Sm2+), neodymium (Nd2+), and gallium (Gd2+), researchers can precisely tailor the electrical conductivity, Seebeck coefficient, carrier concentration and thermal conductivity of SrTiO3.

RE doping introduces additional charge carriers and also modifies the electronic band structure, defect chemistry, lattice strain, phonon scattering mechanisms, thereby improving the ZT (Ohta, 2007). The substitution of trivalent rare-earth ions for divalent structure creates donor effects that release electrons into the conduction band. This substitution illustrated for La substitution using Kroger-Vink notation as:

$$La_2O_3 \rightarrow 2La_{Sr}^{\cdot} + 2e^- + 3O_o^{\times} \qquad (10)$$

where $La_{Sr}^{\cdot}$ denotes a La^{3+} ion occupying a Sr^{2+} lattice site. The additional electrons significantly increase the carrier concentration and consequently improve the electrical conductivity of SrTiO3 (Tuller and Nowick, 1981).

Lanthanum (La) Doping

Lanthanum is the most effectively investigated rare-earth dopant for SrTiO3 due to its ionic radius (1.38 Å for 12-fold coordination) closely matches that of Sr^{2+} (1.44 Å), allowing high levels of substitution with minimal lattice distortion (Shannon, 1976). La doping effectively transforms insulating SrTiO3 into a highly conductive n-type semiconductors by increasing electron concentration within the Ti 3d-derived conduction band.

According to Lu et al (2016), La-doped A-site deficient SrTiO3 ceramics exhibits significantly large Seebeck coefficient and improved ZT (0.41) at 973 K. This illustrates the importance of combining La donor doping with vacancy engineering.

Samarium (Sm) Doping

Samarium has attracted increasing attention as an alternative donor dopant because its smaller ionic radius (1.24 Å in 12-fold coordination) produces greater lattice distortion than lanthanum. This lattice distortion enhances phonon scattering and reduces lattice thermal conductivity (KL) while maintaining adequate electrical conductivity (Shi et al, 2020). Consequently, Sm-doping offers the possibility of simultaneously improving the power factor and reducing thermal conductivity.

Experimental studies have shown that samarium substitution increases electron concentration, improves σ, and suppresses KL through enhanced point-defect scattering. It further promotes local lattice disorder that disrupts phonon propagation more effectively than La, resulting in improved TE performance at elevated temperatures (Guo et al, 2021). However,, excessive Sm concentrations reduce carrier mobility due to increased impurity scattering, highlighting the importance of optimizing dopant concentration.

Co-Doping with Multiple Rare –Earth Elements

More recently, researchers have explored co-doping strategies involving two or more rare-earth elements to achieve synergistic improvements in thermoelectric performance. Co-doping combinations such as La+Sm, La+Nd, La+Gd, La+Sm, etc., enable independent control of carrier concentration, lattice

strain, and defect chemistry. These strategies often produce better thermoelectric performance than single-element doping because different dopants contribute distinct effects on carrier transport and phonon scattering (Shi et al, 2020). For example, La primarily enhances electrical conductivity through increased electron concentration, whereas Sm or Gd contributes stronger phonon scattering due to greater lattice distortion. The combined effects result in a favorable balance between electrical conductivity and thermal conductivity, leading to improved thermoelectric figure of merit (Iyasara et al, 2026). Such multi-element doping strategies have become increasingly important in the design of advanced oxide thermoelectric materials.

II. CONCLUSION

The thermoelectric performance of SrTiO3-based compounds is primarily determined by the interplay between electrical conductivity and electronic thermal conductivity. Although SrTiO3 possesses excellent thermal stability and chemical durability for high-temperature applications, its low intrinsic carrier concentration limits its enhanced conductivity and overall thermoelectric efficiency.

This review has shown that the crystal and electronic properties of SrTiO3 strongly influence charge and heat transport, making optimization of these transport parameters essential for improving the thermoelectric figure of merit. The Wiedemann-Franz relationship highlights the inherent coupling between electrical conductivity and electronic thermal conductivity, presenting a major challenge in thermoelectric material design. Therefore, optimizing carrier concentration rather than simply maximizing electrical conductivity is critical in achieving superior thermoelectric performance. Rare-earth dopants such as La and Sm effectively modify the electronic structure and carrier concentration, thereby improving electrical conductivity while maintaining thermoelectric characteristics.

In summary, enhancing the interplay between electrical conductivity and electronic thermal conductivity through carrier concentration optimization and appropriate rare-earth doping offers a practical pathway for improving the performance of SrTiO3-based thermoelectric materials. Continued research in these areas will support the development of efficient oxide thermoelectric materials for sustainable high-temperature power generation.

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