SOLID OXIDE FUEL CELLS

A DISSERTATION REPORT

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INDEX

INTRODUCTION :

Fuel cell is an energy conversion unit that converts a gaseous fuel to electrical energy and heat by electrochemical combination of a fuel with an oxidant.[1] Fuel cells are presently attracting tremendous interest because of their large potential for power generation in stationary, portable and transport applications and our increasing need for sustainable energy resources. Due to its high energy conversion efficiencies and the much lower emissions of sulphur and nitrogen oxides and hydrocarbon pollutants, and significantly reduced CO_2 emissions, they are considered as one of the most cleanest and efficient technologies for generating electricity.[2]

Solid oxide fuel cells are a class of fuel cells characterized by the use of a solid oxide material as the electrolyte. It is considered as one of the most promising fuel cell systems. SOFCs has been particularly of interest due to its high operation temperature and fuel management. SOFCs requires fuel such as hydrogen and oxidant reactants such as oxygen or air to electrochemically react at high temperature and generate electrical energy. SOFCs has emerged as a better fuel cell technology due to the following reasons:-

(i) It is most suited to applications in distributed generation (stationary power) because of high conversion efficiency.

(ii)High operating temperature of SOFCs allows internal reforming, promotes rapid electro catalysis with non-precious metals and produces high quality heat by products which can be used for cogeneration.

(iii)SOFCs have extremely low emissions.

(iv) SOFCs do not have problems with electrolyte[2–6]

WORKING PRINCIPLE:

SOFC is an electrochemical conversion device that produces electricity directly by oxidizing a fuel and is characterized by the use of solid oxide material as the electrolyte. The three main components of SOFCs are anode, electrolyte and cathode. The porous electrodes are separated by the dense ceramic electrolyte . The SOFC can either use an oxide ion or proton conduction through the electrolyte. H_2 and CO are supplied to the anode of the fuel cell and oxygen (from the air) enters the cell through the cathode. H_2 and CO gets oxidized on the anode side and emit electrons which flows through the electrical circuit and reach the cathode. After receiving electrons, O_2 undergoes a reduction reaction producing oxygen ions (O^{-2}) which are then conducted through the electrolyte and react with fuel to produce water and carbon dioxide as the reaction products and heat is generated.

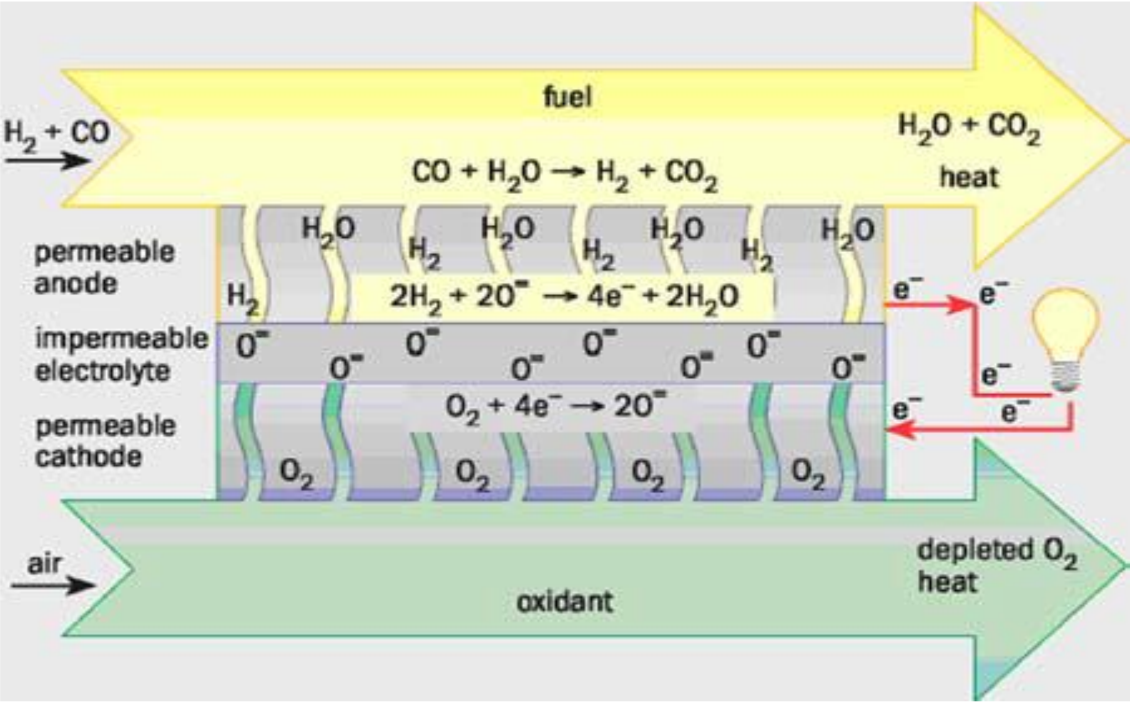

Fig: Operating principle of solid oxide fuel cells [7]

Solid Oxide Fuel Cell (SOFC) – Summary of electrode reactions and overall cell reaction

Anode:	$H_2 + O^{2-}$	$\rightarrow$	$H_2O + 2e^-$
	$CO + O^{2-}$	$\rightarrow$	$CO_2 + 2e^-$
Cathode:	$O_2 + 4e^-$	$\rightarrow$	$2O^{2-}$
Overall:	$H_2 + CO + O_2$	$\rightarrow$	$H_2O + CO_2 + \Delta E$

MATERIAL FOR SOFC COMPONENTS:

SOFC consists of three basic components: anode , cathode and electrolyte. Different inorganic materials are used as anodes, cathodes, electrolytes and interconnects in SOFCs, and the strategy behind their selection and choice is in terms of their chemical properties and the function they fulfil.

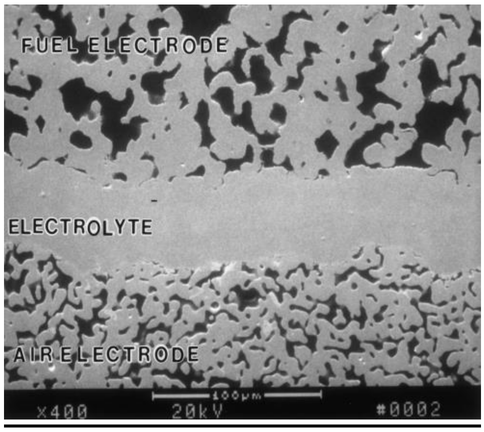

Fig: Microstructure of a cross section of a Seimens Westinghouse solid oxide fuel cell [8]

ELECTROLYTE

The electrolyte is the central part of solid oxide fuel cell lying between the cathode and the anode terminal. The main feature of it is that it should be of fully dense ceramic layer in structure and it must be fabricated into very thin layers in order to reduce internal cell resistance. An ideal electrolyte material should have high oxide ion conductivity, low electronic conductivity low cost and should be environmentally benign. It should also have thermodynamic and chemical stability over a wide range of temperatures. It should have closely matched thermal expansion coefficient with electrode materials.

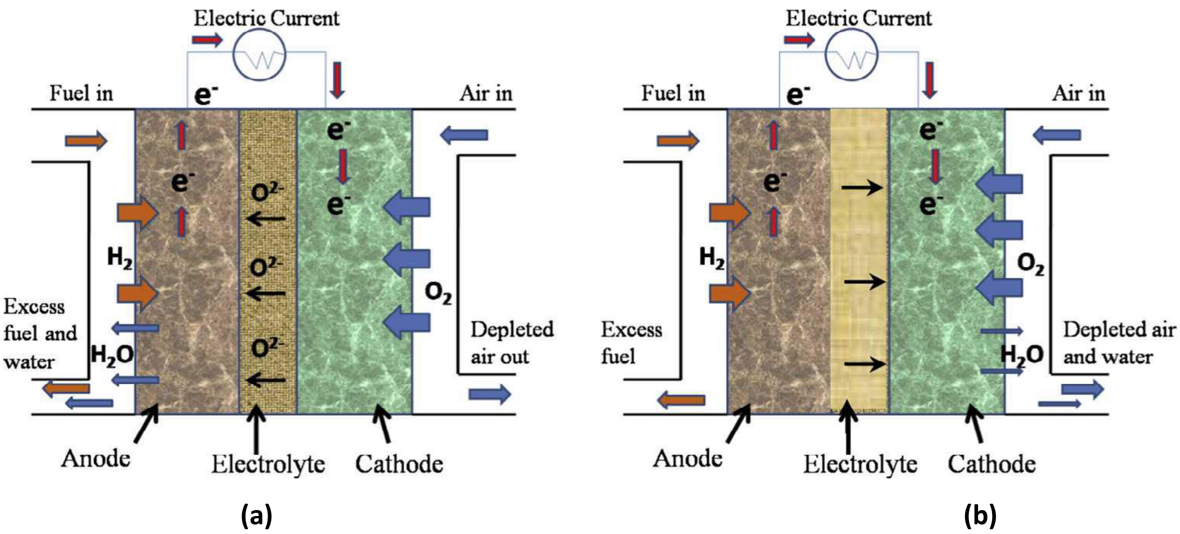

Fig: Schematic diagram of solid oxide fuel cell (SOFC) (a) oxide-ion conducting electrolyte [9] **,b) proton conducting electrolyte during its operation.** [9]

Oxide ion conducting electrolytes

Zirconia based oxide ion conductor: The solid electrolyte should possess a number of properties such as high oxide ion conductivity ,chemical stability ,good mechanical strength and low cost. These requirements are fulfilled by doped zirconia. Addition of rare earth and lanthanide oxides stabilizes monoclinic zirconia to cubic fluorite phase at room temperature and enhances ionic conductivity. The commonly used dopants for zirconia are Calcia (CaO), Magnesia (MgO), Scandia (SC_2O_3) and Yttria(Y_2O_3). Yttria is widely used as stabilizers for zirconia because of its abundance and cost effectiveness. Zirconia stabilised with 8 mol % Yttria exhibits a very consistent coefficient of thermal expansion of 10.5 x 10^6 K from 25° C to 1000° C. Scandia , stabilised zirconia (ScS_2) can be used as an alternative to YSZ for use at intermediate temperature because of its high conductivity.[2,10,11]

Ceria based electrolytes: Gd or Sm stabilized ceria electrolytes are interesting candidates for intermediate temperature SOFC (550-560°C)both because of high ionic conductivity and compatibility with high performance electrode materials such as cobalt containing perovskite oxide cathodes. However at elevated temperatures in a reducing atmosphere ,such as present at the anode, ceria undergoes partial reduction to Ce^{+3} which leads to electronic conductivity and reduces the efficiency of SOFC. This can be prevented by using an additional ultra-thin interfacial electrolyte layer which prevents electronic transport and can suppress the reduction of ceria under reducing conditions.[2,10,11]

Perovskite Related Systems: Doped Perovskite (ABO_3)material can serve as solid electrolyte materials for SOFC . Lanthanum strontium gallium magnesium oxide ($La0_{0.9}$ $Sr_{0.1}$ $Ga_{0.8}$ $Mg_{0.2}$ O_3) showed oxygen ion conductivity higher than $Zr0_2$ based and $Ce0_2$ based ion conductors. But this material does not process good mechanical strength. It showed thermal expansion coefficient of 11.5 and 10^{-6} down from the room temperature to 1000°C which is compatible with other components of SOFC.[10]

Bismuth Oxide: Among the oxide ion conductors Bi_2O_3 has the highest ionic conductivity compared to other solid electrolytes. This is due to a combination of high anion mobility and a high concentration of oxygen vacancies (around 25%) Bi_2O_3 presents polymorphism with two stable phase α and δ. High conductivity appears in the high temperature δ-phase of a fluorite type structure . The δ-phase is only stable above 730°C . The main problem with Bi_2O_3 -based electrolytes for fuel cell application is their instability is the reducing atmosphere since they decompose into bismuth metal under anode conditions. Studies on these electrolytes are reduced to low-temperature conductivity measurements.[12]

Proton Conducting Electrolyte materials for SOFC

In the proton transportation mode, the hydrogen ions resulting from the oxidation reaction of hydrogen molecules that occurred in the anode are transferred to the cathode through the interface. The proton conducting material is an essential functional material with protons as charge carriers for light weight small diameter and reasonably high mobility of the particle.

$BaCeO_3$ and $BaZrO_3$ are the widely used proton conducting materials. $BaCeO_3$ has the highest proton conductivity but its low stability in H_2 and Co_2 environments restricts its use in large in large scale applications. Another alternative as electrolyte material is $BaZrO_3$, which presents reasonably high stability in water or carbon dioxide atmosphere and improved chemical and mechanical strength. The large-scale application is restricted due to its high grain-boundary resistance and high sintering temperature.[2,10,12]

ANODE

The main purpose of the anode is the oxidation of fuel and to provide a path to the electrons produced in oxidation reaction so that they can reach at current collector. The SOFC anode should have properties like good electronic conductivity, sufficient permeability, good electro-catalytic activity, phase relevance with current collector and electrolyte, good microstructural strength to operate at SOFC working temperature and compatible thermal expansion coefficient with electrolyte. In SOFC the fuel arriving at the anode is reducing in nature. Thus metals can be used as the anode materials Also the elevated working temperatures of SOFCs limit the choice to cobalt, nickel and noble metals. Majority of the SOFC have nickel anode due to its low cost.[3]

Ni- based cermet : Nickel and YSZ ($Zr_{0.92}$, $Y_{0.08}$ O_2) cermet is the most commonly used material as anode. YSZ is added to the anode to match the thermal expansion coefficient between anode and electrolyte. At the working temperature which is 700- 1000 ºC , nickel starts sintering and the porosity decreases. This adverse effect will cause the anode to be dense and finally the fuels cannot diffuse through it. The YSZ also serves as the skeleton to prevent the sintering of Ni. The use of nickel is due to its low cost and good electrochemical properties such as the high electrical conductivity and catalytic activity under reducing conditions. The YSZ also provides an ionic pathway for O^{-2}. The key advantages of this anode are as follows. The conductivity, electrochemical performance with hydrogen fuel cell is extremely good, consistent with power densities approaching 2Wcm² at 800ºC. The processing of NiO-YSZ with YSZ electrolyte layers is straight forward allowing co sintering of anode supported structures and the NiO is easily reduced to Ni providing extra porosity. The reduction of NiO to Ni was achieved in H_2 atmosphere at 900 °C. The disadvantages of this material are its poor redox stability, low tolerance to sulphur, carbon decomposition when using hydrocarbon fuels and tendency of nickel agglomeration after prolonged operation.[5,13]

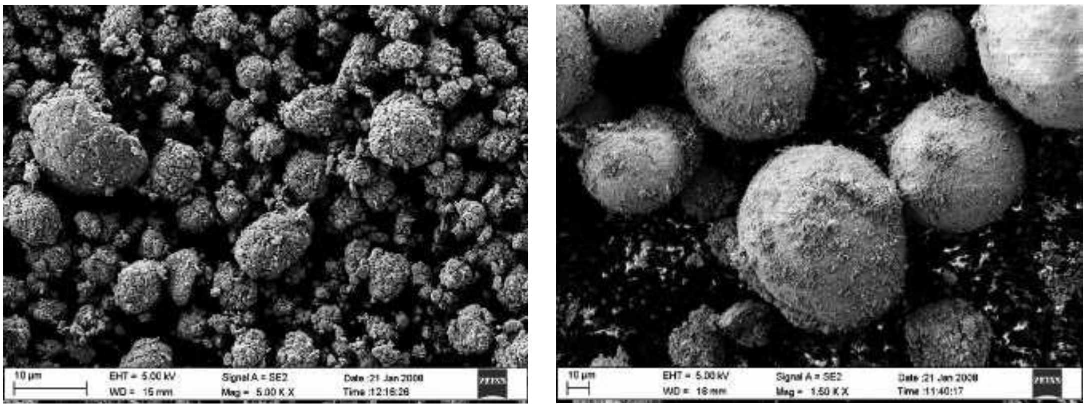

Fig: SEM micrographs of (a) NiO [14] **and (b) YSZ powders** [14]

Perovskite Oxides: Most of the functional perovskite oxides in SOFC exhibit simultaneously high oxygen ionic and electronic conductivities. This property is typical of mixed ionic electronic conducting(MIEC). These MIEC perovskites have been studied as an alternative ceramic anode materials. They present much larger areas of TPBs, leading to a better anodic performance relative to its electronic or ionic conducting perovskite counterpart. MIEC perovskite oxide is an appealing next generation SOFC anode component since it has active sites that promote the activation of C-H bonds for hydrocarbon oxidation, which can be enhanced by adjusting the concentration of oxygen vacancies and their mobility to mitigate the carbon coking. Among those, $Sr_2MgMoO_6{-}\delta$ (SMMO), $(La_{0.75}Sr_{0.25})_{0.9}Cr_{0.5}Mn_{0.5}O_3$ (LSCM), $Pr_{0.4}Sr_{0.6}Co_{0.2}Fe_{0.7}Nb_{0.1}O_3{-}\delta$ (P-PSCFN), and $PrBaMn_2O_5{+}\delta$(PBM) showed potential as anodes for SOFCs operated on hydrocarbon fuels.[10]

Chromite-based single perovskites: The strontium-doped lanthanum chromite (LSCr) single perovskites have been a focus of study and characterization as SOFC anode materials over the past decade. Cr has strong hexagonal coordination with oxygen deficiency and the introduction of cations with lower coordination numbers (e.g., Mn, Co, Fe, and Ni) can enhance the catalytic activities of LSCr. The presence of these cations in the B-site provides the possibility to create oxygen vacancies in reducing atmospheres at high temperatures, leading to improved LSCr anode electrical conductivity.

LSCrM is one of the most known perovskites that displays high-temperature stability and good resistance to carbon deposits. It also shows redox stability when fueled under oxidizing and reducing environments, which allows its application as electrodes in symmetrical SOFC (SSOFC). Though, LSCr-based perovskites have rather low electrical conductivity in reducing atmosphere, therefore showing weaker electrochemical-reaction kinetics than Ni-YSZ.

Lanthanum-doped $SrTiO_3$: Lanthanum strontium titanate (LST) has also been proposed as an alternative cathode material. It is chemically stable and shows electronic conduction upon reduction due to the presence of Ti^{+3}. Nevertheless, its relatively low catalytic activity for the fuel-oxidation reactions conducted to low maximum power densities for LST anode-based single cell, making it unsuitable for industrial applications.[10]

Double perovskites: Double perovskite anodes have been studied because of their exceptional electrochemical properties and the ability to resist carbon formation and sulfur poisoning. Sr_2MMoO_6 (M) Co, Ni)has drawn considerable interest given its MIEC properties, high power density inH_2/CH_4 fuels, and long-term stability when supplied with H_2S. However, some studies showed that SMMO displays low oxygen-vacancy concentration along with low catalytic activity and electrical conductivity and detrimental performance degradations under H_2S concentration higher than 140 ppm. The structural features of double perovskite offer flexibility via doping route to enhance the SMMO properties. Frequent doping approaches are as follows:

- Partial substitution of La, Sm, and Ba for Sr
- Mg substitution with transition metal elements, such as Mn, Fe, Co, Ni, Ti, and Cr
- Mo substitution with V and Nb.

Even though perovskite anodes seem a promising option, as they are usually stable in anode operating conditions and present high sulfur and coking tolerance under different fuels conditions, their catalytic activity, electrical conductivity, and power density are still significantly lower than those for the typical Ni-YSZ anode.[15]

Cathode

Cathodes in SOFCs have multiple roles within the cell: reduction of molecular oxygen, transport of charged species to the electrolyte, and supply of electrical current for the oxygen reduction reactions. The materials used for SOFCs should possess the following characteristics

(1) High electronic conductivity

(2) The thermal expansion coefficient values of the cathode should match with the other components of the cell

(3) Good chemical compatibility with the electrolyte and interconnect materials

(4) Sufficient porosity to allow fast diffusion of O_2 gas from cathode to cathode-electrolyte interface

(5) High oxide ion conductivity;

(6) Good stability under an oxidizing atmosphere in the course of fabrication as well as operation;

(7) High catalytic activity during oxygen reduction reaction (ORR); and cost effective.[9]

Perovskite materials are the widely used cathode materials in SOFCs. Strontium-doped lanthanum manganite (LSM), $La_{1-x}Sr_xMnO_3$, is the most commonly used cathode material for zirconia based SOFCs.LaMnO3 is a perovskite material with intrinsic p-type conductivity, the oxygen stoichiometry of which at high temperature is a function of the oxygen partial pressure, having an oxygen excess in an oxidising environment, whilst becoming oxygen deficient in a reducing environment. The p-type conductivity of $LaMnO_3$ is a consequence of the formation of cation vacancies, and hence the conductivity can be enhanced by the use of a lower valence ion as a dopant for either the A or B sites. The alkaline earth metals, magnesium, calcium, strontium and barium, have all been used as dopants, together with nickel.[12]

Another perovskite material that has been extensively studied as a cathode material for SOFCs is doped lanthanum cobaltite, $LaCoO_3$. $LaCoO_3$, like $LaMnO_3$, shows intrinsic p-type conductivity, and has a large oxygen deficiency at high temperatures. The conductivity can be increased by substituting a divalent cation on the lanthanum site. As with $LaMnO_3$, strontium is generally used. Further improvements in performance have been found by substituting iron on the cobalt site to form:

$La_{1-x}Sr_xCo_{1-y}Fe_yO_3$ (LSCF). $LaCoO_3$ has a superior electrical conductivity to $LaMnO_3$ under equivalent conditions. However, there are several disadvantages with $LaCoO_3$ which generally preclude its use as the cathode in zirconia-based SOFCs. $LaCoO_3$ shows much greater reactivity towards zirconia than

$LaMnO_3$ at high temperatures and it is also much more susceptible to reduction at high temperatures than $LaMnO_3$. In addition, the thermal expansion coefficient of $LaCoO_3$ is considerably greater than that of $LaMnO_3$, which is already higher than that of yttria-stabilised zirconia. $LaCoO_3$ has been mixed with $LaMnO_3$ in an attempt to improve the electrical conductivity of the cathode and to better match the thermal expansion coefficient to that of zirconia.[2]

Oxides with the perovskite related K_2NiF_4 structure, for example, Ln_2NiO_{4+x}, (Ln=La, Pr, Nd) are of interest for SOFC cathodes because of the high diffusivity of the interstitial oxygen ions.The structure of Ln_2NiO_{4+x} can be described as a succession of $LaNiO_3$ perovskite layers alternating with LaO rock salt layers. The oxygen excess in Ln_2NiO_{4+x} is associated with the incorporation of interstitial oxygen anions into the rock salt layers where they are tetrahedrally coordinated by La^{+3} cations. At higher temperature, the diffusivity increases though this is offset by the decrease in the concentration of oxygen interstitials. The advantages of lanthanum nickel oxide include in addition to high oxygen mobility a relatively low lattice expansion induced by variations in temperature and oxygen partial pressure. The range of thermal expansion coefficients observed for the La_2NiO_4 compounds (11 - 13 $x10^{-6}$ K^{-1}) matches reasonably well with the values for the electrolytes YSZ, CGO and LGSM.[4]

INTERCONNECT

The interconnect in a solid oxide fuel cell is a very important component and has two functions; firstly to provide the electrical contact between adjacent cells, and secondly to distribute the fuel to the anode and the air to the cathode. The SOFC interconnect material should fulfil the following requirements :

(i) high electrical conductivity with area-specific resistance (ASR) less than 0.1 X cm2

(ii) structural, micro-structural, chemical and phase-stability at operating temperature 800–1000 C in both oxidizing and reducing atmospheres during its service lifetime i.e., >40,000 h;

(iii) excellent gas tightness or do not allow the passage for oxygen and hydrogen, in order to provide a barrier for direct combustion between oxidant and fuel during operation;

(iv) matching CTE (10.5 $x10^{-6}$/K) with electrodes and electrolyte materials that minimizes the thermal stresses developed during initiation and close-down of SOFC device

(v) chemical inertness towards adjoining components;

(vi) resistance towards oxidation, sulfidation and carbon cementation;

(vii) moderate mechanical strength as well as high resistance to creep is required to avoid fracture when stresses are generated during operation since interconnect materials have to bear the load of a stack.

(viii)Also minimal PO_2 gradient is required across the interconnects in order to restrict dimensional change and minimize mechanical stress, which might cause cracking of the stack and deteriorates the overall cell functionality.

(ix) low cost and ease of fabrication. SOFC interconnect could either be ceramic or alloys materials.[9]

Ceramic interconnects: Ceramic interconnects are developed from semiconductor oxides which possess fair stability in air, and also retain good compatibility with other SOFC component materials. The conductivity of these oxides is an increasing function of temperature, which makes them suitable for high temperature applications (>800°C). The doped $LaCrO_3$ is normally used as ceramic interconnects. $LaCrO_3$ has a perovskite structure and is a p-type conductor. The dopants are typically strontium or calcium to increase the conductivity. The ceramics interconnects are generally stable with YSZ electrolyte. However, the limitations of their uses are the high cost and the decreasing of conductivity with decreasing temperature.

Metal alloys as interconnect materials: Low cost, availability, and ease of fabrication make metals more attractive than ceramic oxides as interconnect materials. The metals like Ni, Fe and Cr based oxidation resistant alloys and some precious metals like Ag have been employed as interconnect materials. However, due to their low melting point, high volatility, intrinsic instability under air-hydrogen dual exposure conditions and high cost, the use of precious metals is restricted to a very limited extent. Among metal alloys, Fe–Cr based alloys, Cr-based alloys, Ni(Fe)–Cr-based heat resistant alloys, austenitic and ferritic stain-less steels are being widely used as interconnect materials.[1,9]

SEALANTS

The sealants need to fulfil all the criteria for all of components. They must be stable in a wide range of oxygen partial pressure (air and fuel) while minimizing thermal stresses during high-temperature operation. The quality of seals must be high, since even small leaks in these seals can affect the cell potential, resulting in the reduction of performance . Sealant development is additionally complicated because the optimal sealant depends on the materials of other components.

SOFCs seals can be divided into two types; compressive seals (mica sheets or metal gaskets) and rigid seals (composites of glass/ceramic or glass). The low cost and air tight seals are usually composite glass ceramic seals such as $CaO-SiO_2$ and $BaO-Al2O_3-SiO_2$.Furthermore,these materials show chemical inertness toward components in contact with them as compared to bare borosilicate type glasses. Also, in the case of rigid seal, whole SOFC stack will also become rigid, thus if the single cell cracks, the whole stack will become useless.[2]

APPLICATIONS OF SOFC

Combined Gas Turbine (GT) Power System with SOFC: An integrated fuel cell–GT hybrid system has a higher energy conversion efficiency, low environmental pollution, and possible use of renewable energy sources as fuel. It consists of air compressor, recuperator, high temperature SOFC, combustor, gas turbine, and power turbine. There are two different ways for gas turbines to be connected with SOFCs, by indirect or direct integration.Under indirect SOFC–GT hybrid system, heat exchanger is used instead of combustor , due to which air from the compressor is heated by the fuel cell exhaust (thermal energy). In the direct SOFC–GT hybrid system, pressurized air from the compressor is preheated by the exhaust gas from the power turbine before entering the cathode side of the SOFC, while fuel flows into the anode side. This system can achieve a cycle efficiency of up to 60%. One disadvantage related to SOFC–GT system is the start-up time, which is much longer than in a GT conventional plant. Also in this system, SOFC stacks need to be pressurized in an extremely large vessel.[12]

Combined Heat and Power with SOFC: Combined heat and power (CHP) is basically a sequential generation of two different forms of useful energy, usually mechanical and thermal energy, from a single primary energy source. Solids oxide fuel cells are operated at elevated temperatures typically between 750-1000ºC which leads to the production of high temperature heat as by product in addition to electrical power. The elevated temperatures of SOFC makes them particularly suited to combined heat and power applications. The useful heat from the SOFC is usually utilized in energy-requiring units, i.e., preheaters and reformers, to preheat cooling streams or to generate steam and hot water.[12]

Trigeneration with SOFC: Trigeneration, defined as combined cooling, heating, and power (CCHP), is currently a promising technology for efficient and clean energy production. It uses in the best possible way the chemical energy of the fuel used to generate electricity and heat from the exhaust. Simultaneously, cooling can be generated from absorption or desiccant cooling, consequently reducing the use of electricity in a traditional air conditioning unit. In trigeneration efficiency increased by at least 22% compared to a power plant. It was also found that in trigeneration, CO_2 emissions were decreased by 30% at a cost growth of 70% compared with a conventional system.[12]

Power Generation Systems: SOFC technology has been developed for a broad spectrum of power generation applications. SOFC systems that have been considered ranges from portable devices (e.g., 500-W battery chargers), small power systems (e.g.,5-kW residential power or automobile auxiliary power units) to distributed generation power plants (e.g., 100–500kW systems). SOFCs can also be integrated with a gas turbine to form large (several hundred kW to multi-MW) pressurized hybrid systems.[16]

Fig: Portable SOFC system [16]

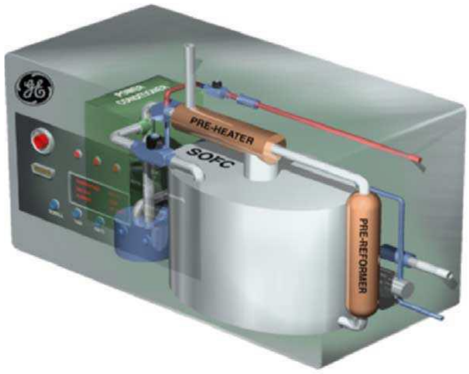

Fig: 5-kW SOFC power system concept. [16]

COMMERCIALIZATION OF SOFCS

Siemens Westinghouse Power Corporation: Westinghouse (W) has been actively involved with SOFC development for more than 3 decades. In 1998 it merged with the Germany Company which later became Siemens Westinghouse Power Corporation (SWPC). This new company concentrates on research and development (R&D) of SOFC-mGT hybrid systems for the emerging distributed power market. (damo) A full scale 100 kW plant, without integrated micro gas turbines, was tested, running more than 15,000 h. Another prototype was tested, with a total output of 200 kW composed of an output roughly 180 kW from the SOFC and roughly 40 kW from the microturbine generator. These systems continue to undergo further development at the National Fuel Cell Research Centre(NFCRC) to determine performance characteristics and operational parameters, to gain experience for the design of prototypes and commercial products.[12]

Bloom Energy : Bloom Energy products are mainly stacks of planar electrolyte-supported fuel cells fabricated with metals sprayed on ceramic supports. Their SOFC systems possess currently up to 65% (LHV) net electrical efficiencies. The company focused on improving continuously the size of their systems in the last years, presently developing the “Energy Server 5”, with an electrical power output of 200–300 kW and the possibility of being combined to form a wider system owing to its modularity.

These servers comprise 1 kW electricity stacks, coined as “Bloom Boxes”, which consist of 40 cells of 25 W electricity each, fed with natural gas or biogas. Bloom Energy had a huge impact on SOFC commercialization when it sold, in 2018, 80.9 MW of SOFC systems, which can be compared to a total market of ca. 91 MW.[12]

Mitsubishi Power : In 2016, Mitsubishi Hitachi Power Systems, Ltd. (MHPS) began testing a pressurized hybrid power-generation system integrating a SOFC stack and a micro gas turbine (MGT). The demonstration system was in the range of 250 kW and delivered a generation efficiency of 55%, with the capability of using various fuels, including natural gas, biogas, and hydrogen. In 2018, MHPS got its first request for a pressurized hybrid power-generation system to be installed in the Marunouchi Building in Tokyo, held by Mitsubishi Estate Co., Ltd. (Tokyo, Japan). This hybrid system was fueled with city gas, generating electricity with both ceramic SOFC stacks, which operated at approximately 900°C, and MGTs. Since it is used in a CHP system, exhaust heat can be recovered as steam or hot water, improving the combined efficiency. This hybrid system can decrease CO_2 emissions by nearly 47% compared to conventional power generation systems, supporting the goal of a low-carbon society.[12]

CURRENT STATUS

Solid oxide fuel cell is considered by many developed countries as an alternative solution of energy in near future. A lot of efforts have been made during last decade to make it commercial by reducing its cost and increasing its durability. Different materials, designs and fabrication technologies have been developed and tested to make it more cost effective and stable. Efforts are made to discover new compounds, nanostructured electrodes and electrolytes. Advancements are made in the field of cell and stack design are also explored along with hurdles coming in their fabrication and performance.[4]

Research is going on for lowering the temperature of SOFCs . The reduction in temperature will allow use of cheaper interconnecting and structural components. A lower temperature will also ensure a greater system efficiency and a reduction in the thermal stresses in the active ceramic structures, leading to a longer lifetime of the system. For some years, scientists and researchers throughout the world have been on a quest to drop the operating temperature of SOFCs without sacrificing their performance.[17]

The advance of SOFC in lowering its operating temperature has opened up new prospects for applications of both micro and nano-materials. Recently researchers focus on methods and materials to prepare an excellent performance of nanostructured SOFCs. Nano size of materials has unique properties for enhancing grain boundary ionic conductivity of electrolytes in SOFC devices. Nanomaterials are used in SOFCs because of their are their possibility to offer high thermal stability with accepted electrochemical conductivity values (0.25 W/cm^2 and 0.1 S/cm per single cell). Moreover, they showed ability of sulfur tolerance and lack of carbon deposition on the anode side with hydrocarbon fuel feeding . The nanostructured array can also concurrent a well-connected pores and work as contact points for triple phase boundaries isolation in electrode components. Thus, achieving all the previous aspects make the nanomaterials selection for the cell components are very compatible to each others and have the required chemical, mechanical and thermal stability as well.[17]

CONCLUSION

Solid oxide fuel cells (SOFCs) have the promise to improve energy efficiency and to provide society with a clean energy producing technology. The high temperature of operation (500-1000 C) enables the solid oxide fuel cell to operate with existing fossil fuels and to be efficiently coupled with turbines to give very high efficiency conversion of fuels to electricity. Solid oxide fuel cells are complex electrochemical devices that contain three basic components, a porous anode, an electrolyte membrane, and a porous cathode. Different innovative materials are identified and tested to make fuel cell cost effective and durable unordered to make SOFCs suitable for commercialization.

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