ABSTRACT
Solid oxide fuel cell (SOFC) is becoming more and more popular as a clean and high-efficiency energy conversion system due to the high-cost oil and low-efficiency traditional generation. In the last decades, much research work about SOFC were made throughout the world. According to many theoretical and computational researches, the performance of SOFC is very much dependent on anodic structure where reforming and electrochemical reactions will take place. In this paper, it is reviewed main researches about anodic performance, requirements, potential materials, microstructure and sinter processes of SOFC, some results and conclusions are summarized, finally next work is also discussed.

KEYWORDS: Solid Oxide Fuel Cell, Cermet, Three-phase Boundary, Electrochemical Reactions, Sinter, Physical and Chemical Phenomena

INTRODUCTION
Solid oxide fuel cell (SOFC) is an electrochemical device that can convert the chemical energy of fossil fuels to electricity and heat energy through electrochemical reactions. Being an electrochemical device, SOFC has unique advantages over the conventional power generation systems. The efficiency of SOFC is higher than the traditional power system because it is not limited by the Carnot cycle of a heat engine. Being a place where reforming and electrochemical reactions will take place, microstructure and long-term performance stability of Ni/YSZ cermet anode are critical issues in the development of SOFC. The anode needs high catalytic activity and electrical conductivity to keep electrochemical reactions. Because when fuel gases meet with oxygen ions from the electrolyte and are oxidized in the anode, high catalytic activity is very important. Ion-conductivity will be functional to transport oxygen ions through the interface of the anode and the electrolyte, concurrently electrons emitted by electrochemical reactions will be conducted to the external circuit. In the past time, many different materials were attempted to make the anode, mainly including precious metals and transition metals, like platinum, gold, iron, nickel, copper and so on. But platinum is easily separated from YSZ phase when SOFC is operating several hours. Nickel will be easy to aggregate at high operating temperature, and further block gas pores. Spacil found that nickel aggregation would be solved effectively by adding mass grains of yttria stabilized zirconia (YSZ) to the nickel matrix. This kind of nickel cermet anode could show some good performance under some specific conditions, but there are still some problems, like carbon deposition. However, so far the nickel cermet is still the best anodic material in the development of solid oxide fuel cell materials. In this paper, almost all requirements for anodic performance, typically including thermal expansion coefficient, chemical compatibility between the electrolyte and interconnection, the porous microstructure to penetrate gases, corrosion against fuel and impurities will be reviewed, and then the nickel cermet anode will also be discussed, especially its manufacturing process. What's more, stable anode reactions of hydrogen and carbon monoxide and anodic characteristics will be analyzed.

ANODIC REQUIREMENTS
In the anode of solid oxide fuel cell, electrochemical reactions and reforming reactions will take place. The anode microstructure will be very important to conduct
electrons and ions, and anodic materials are very much depending on its functions and operating conditions. In literature [1], it was reviewed that anodic nanostructure had an important role on the performance of SOFC, and how to optimize the nanostructure of anodes in order to maximize the electrochemical reactions sites, mainly focusing on some new materials and synthesis techniques. Obviously, the anode must work well at high temperatures and huge temperature gradient. In addition, a very low partial pressure of oxygen will be caused in the anode with electrochemical reactions going on, and the change of oxygen partial pressure will be very huge due to differences of reactants and products. However, it is very important to keep chemical and physical stabilization in the anode, because some oxidation products will corrode the anode, and electrical performance and microstructure of zirconia in the anode will change with mole fractions of components. Exactly, the anodic stabilization means microstructure of the anode will be not destroyed and no irreversible losses are given throughout the whole temperature range, and normally the temperature range includes sinter temperature, operating temperatures and even repeated circulations between ambient temperature and operating temperatures. In the whole temperature range and gas atmosphere, the anode should be compatible with the electrolyte, interconnection, and other next materials. Basically, physical compatibility means mechanical performance is consistent in different materials, like thermal expansion coefficient and thermal stress caused by the temperature change. Chemical compatibility requires no mass diffusion and contact reactions in interfaces between adjacent parts of fuel cell, even at critical temperature, because which will increase resistance loss and influence other anodic functions. Definitely all of above requirements will also be applicable in the fuel cell stack. Additionally, compatibility should also include anti-corrosion and anti-poisoning in ambient atmosphere, and corrosion and poisoning will be cause by some impurities, like sulfur, ammonia, hydrogen chloride and so on. Obviously, the anode not only has high electron-conductivity, but also has high catalytic activity so as to quickly exchange charges and further decrease resistance and overpotential losses as far as possible. However, if catalytic activity of the anode is too high, it will result in some bad side-effects, such as carbon deposition caused by hydrocarbons decomposition. In electrochemical sites, there are oxygen ions from the electrolyte, electrons produced by electrochemical reactions, and gases including fuels and water vapor. YSZ phase of the anode will be functional to conduct oxygen ions, nickel phase will conduct electrons, and pores will be used to transport fuel gases and water vapor. Sometimes, electrochemical sites will also be called triple-phase boundaries. According to the anodic performance, triple-phase boundaries should be three dimensional and porous instead of two dimensional and linear unities. In other words, porosity and tortuosity are very important to anodic performance. In literature [2], the relation between electrode microstructure and electrode performance and gas diffusion has been investigated by AC impedance techniques. According to some measurements operated at high temperature (800-1000 °C) and low oxygen partial pressure regions (P_{O2}<0.1 atm), electrochemical reaction sites should be located at the peripheral line of nickel, YSZ and nickel/YSZ interfaces where gases can easily diffuse.

**CERMET FEATURES**

Only little metals or ceramics are fit to be anodic material in order to ensure the anodic performance. Nowadays, yttria stabilized zirconia is considered the most appropriate ceramic electrolyte and anodic substrate at high operating temperatures. Iron and graphite were also used as anodic material. But because graphite was corroded easily by electrochemical oxidation, so that the graphite anode has the very short duration. Platinum was also focused on extensively owing to its stabilization and catalytic activity at high temperatures. What's more, other transition metals are also considered. Unfortunately, transition metals have limitations as well. Iron will be oxidized into red iron oxide once the oxygen partial pressure in the anode is above a critical value. To some extent, cobalt is more stable but it's very expensive. It's really hard to keep the thermal expansion coefficient of nickel consistent with the zirconia's, and nickel is easily aggregating at high temperatures, which will block pores of the anode and decrease triple-phase boundaries. Many literatures indicated that almost all of metallic anodes are not suitable for solid oxide fuel cells. A porous medium made by cermet which combines advantages of metal and ceramic is a practical option.

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present, the common anode of solid oxide fuel cell is nickel-YSZ cermet. Zirconia is used to prevent nickel from growing and aggregating, keep porosity and dispersion of nickel phase, and further ensure the duration of the anode. And YSZ which connects with the electrolyte could sustain different thermal stresses caused by thermal expansion. The higher the ceramic fraction is, the lower thermal expansion is. The second function of ceramic is to conduct oxygen ions in the electrolyte and the anode. However, nickel-YSZ cermet could not still meet all anodic requirements. The anode is sensitive with fuels as well. When hydrocarbons are supplied to fuel cell, at high temperatures, hydrocarbons will be decomposed in the nickel surface, which will make carbon deposed around nickel phase. This will destroy porosity of the anode. When syngas including rich-hydrogen and carbon monoxide is supplied to SOFC, this phenomenon will vanish. But impurities should be filtered in advance because nickel is very sensitive with sulfur, even if the sulfur concentration is low to 0.1 ppm. Natural gas also contains sulfur because thiophenol and mercaptan will be added due to some security factors. Fortunately, the nickel surface poisoned by sulfur is not irreversible, and it will be recovered when pure fuel without sulfur is feed. However, to solid oxide fuel cell, sulfur should be adsorbed by activated carbon or reacting with zinc oxide. Probably fuel gases will also contain other impurities, such as ammonia or hydrogen chloride owing to different manufacturing processes for fuel gases. Though impurities concentration is very low, the performance of fuel cell will decrease after 2000 hours revolution. In literature [3], Ni-YSZ is used as the anode of a SOFC for its excellent electrochemical performance for operation with coal-derived syngas. And Ni/Fe-based filters were used to prefilter impurities of PH3, H2S and AsH3, which would impact SOFC’s duration. And the cell performance was evaluated by current-voltage measurements and impedances. It indicated that the SOFC could work well without degradation before prefilters saturating. But fuel cell has a higher tolerance to hydrogen chloride than hydrogen sulfide. It is indicated that SOFC is not sensitive to ammonia, even if ammonia concentration is up to 5000 ppm, potential of SOFC is not changed obviously after 2500 hours revolution. If some minerals are contained in the form of dust, they will react with silicate from ceramic. Therefore, in order to make fuel cell work well, fuel gases must be preprocessed. Commonly, in spite of different defects, nickel cermet is still the popular anode in solid oxide fuel cell.

**CERMET MANUFACTURING**

In the past decades, the development of the nickel cermet anode has made the performance of SOFC increasing quickly. Although Spacil[4] had published his patent in 1964, his principles are also consistent with anodic characteristics nowadays, and many of them are still functional in SOFC presently. During the long-time revolution at high temperatures, metallic densification is a big problem, which could be solved by using of cermet materials. When the cermet is used, the anode and the electrolyte can be connected tightly, and sinter method will make them more tightly connected. In the anode, the fraction of nickel phase should be kept the minimum, and YSZ phase must be connected as much as possible. Therefore, Spacil thought that in the anode YSZ will mainly keep nickel phase dispersion and porosity. Picture 1 shows the typical microstructure of the anode.

![Pic. 1 Microstructure of the anode of SOFC](image)

According to picture 1, it’s easy to find that the anode layer could be made single or multi layers due to different functions, and different layer will display different porosity and nickel content. To anodic active layer, nickel content should be kept to the minimum for conducting electrons. Additionally, pores will become bigger and bigger away from the electrolyte, and nickel content is increasing close to interconnection. It is very advanced and complicated nowadays to manufacture the nickel-YSZ cermet anode. As we all know that the cermet anode totally includes three components, nickel/nickel oxide, yttria and zirconia. The
size of commercial nickel oxide powder is ranging from 0.1 μm to 50 μm, typically combining 1 and 10 μm powder, and the commercial YSZ size is smaller than the size of nickel oxide powder, ranging from 0.2 μm to 15 μm. Normally, the size ratio of YSZ powder to nickel oxide powder is 0.01, because it will influence significantly anodic performance. In order to decrease anodic shrinkage and sinter temperature and increase specific surface, original powder of nickel oxide and YSZ will coarsened and milled. And then nickel oxide and YSZ powder will be made into mixed slurry. Next step the mixed slurry will be sprayed over the surface of the electrolyte, and further sintered for about 10 hours at 1350 °C to 1550 °C. Finally nickel oxide will be reduced into nickel in order to conduct electrons from the anode to interconnection. Picture 2 roughly shows the sinter processes of fuel cell unit[5].

![Diagram](image)

**Pic. 2 Sinter processes of fuel cell unit**

In reduced process, the volume of nickel oxide will shrink at least 25% because metal is more dense than oxide. But shrinking of nickel oxide will be useful to increase anodic porosity. Besides, there are some other methods to manufacture the anode, like chemical deposition method (CDM), screen printing method (SPM), plasma spraying method (PSM) and so on. Nowadays, when many researchers are considering how to improve anodic performance, it is noteworthy that Spacil had reported a kind of fuel cell with power density of more than 500 mW/cm² several decades ago. In literature [6], using LSGM electrolytes and nano-scale Ni anodes in SOFCs, showed high power density with 2.2 W/cm². In the cermet anode, no matter nickel or zirconia, their own physical and chemical characteristics are very important to the compatibility and functions. In the interface, very tight connection at micro-scale level between the anode and the electrolyte is very useful to build triple-phase boundaries. Therefore, although affinity of nickel and zirconia is very weak, and their contact angle is only 120 degree, to some extent, physical or chemical interaction or wetting will be very necessary. Nowadays the main option is to prepare nickel oxide and YSZ powder with specific size so as to ensure surface activity enough. Although affinity of zirconia to nickel oxide is very limited, it is very useful to prevent from interface reactions and interdiffusion between different components and keep the cermet phase-separating in the working conditions. As we all know, in special reductive atmosphere, when dry fuels are supplied and fuel cell is working with approximated open circuit, an intermediate metal product Ni$_2$Zr will be produced possibly, but in normal revolution, nickel will aggregate again with zirconium oxidized again. It is indicated that nickel has quite low solid solubility in stabilized zirconia, about 2% at 1000 °C. In literature [7], the impurity of PH$_3$ in coal-derived syngas could cause irreversible degradation to the Ni-YSZ anode-supported SOFC. A series of tests with 10 ppm PH$_3$ in fuel were given in different operating conditions with syngas, dry or humidified hydrogen, and different operating temperatures (750, 800 and 850 °C). When impure syngas was used, higher cell working temperature, larger cell degradation rate. Meanwhile, Ni$_x$P$_y$ would be produced if syngas or dry hydrogen were used as fuel. Presently, it is possible to make nanoscale cermet with uniform solid solution of nickel, zirconium and yttrium salt. In the past years, the key point to optimize the anode is how to improve materials' performance and how to effectively control cermet microstructure. In the previous cermet, nickel content was very high, and its volume fraction would be more than 50%. Nickel would be obtained by reducing nickel oxide. The size of nickel oxide powder was around 45 μm. The size of nickel particle was smaller, and nickel phase normally contains many discontinuous zirconia with 10 μm size. Generally speaking, because nickel content was more than the minimum content to conduct electrons effectively, which would destroy the continuity of YSZ phase, so that the low oxygen ion-conductivity would be given and the
thermal expansion coefficient was very high. Additionally because original powder of nickel oxide and YSZ is very coarse, so that the sinter process of the anode will be operated at high temperature of 1550 °C. But nowadays, submicro powder can be sintered at 1400 °C or lower temperatures, and this will make the anode with more specific surface area. Thermal stresses in the manufacturing, reducing and operating processes will be decreased owing to the lower thermal expansion coefficient of cermet. The higher ceramic content is, the lower thermal expansion coefficient of the anode is. Nowadays, the typical size of nickel oxide powder is 1 μm, and YSZ powder is normally less than nickel oxide powder in order to make the anode more efficient. Slurry made by mixed nickel oxide and YSZ powder will be sprayed over the YSZ electrolyte in order to form the anode layer. Because the traditional fuel cell was supported by the electrolyte, so that its electrolyte layer was very thick, up to 150 μm or higher. Recently, the anode-supported fuel cell is mainly focused on. Comparing with the traditional electrolyte-supported fuel cell, this kind of fuel cell has lower polarization and resistance losses, and can be operated at 800 °C or lower temperatures. In this whole system, it will show better material characteristics at low temperatures and many potential metals with lower cost would be used as structural and interconnecting material of fuel cells. What's more, thermal and mechanical stresses and components' responses will be decreased, and fuel cell's lifespan will be increased significantly when fuel cell is operated at lower temperatures. But on the other hand, its power output will not be very high, because when fuel cell is working at less than 800 °C, the resistance of fuel cell will increase sharply. So that it is necessary to reduce thickness of the electrolyte to less than 10 μm for the purpose of lowering its resistance loss. Therefore, the development of solid oxide fuel cell is trending to the anode-supported type gradually. In that case, the anode is not only a functional component but also the supported structure and the stress medium. The cermet anode with up to 1 mm thickness will supply a place where hydrocarbons can be reformed. Similarly, the thicker anode will have lower thermal activity on account of higher polarization loss. Consequently this will account for why to closely follow catalytic activity of the anode. In this case, hopefully the anode should be multi-layers, typically bilayers or trilayers. In picture 3, a multi-layer anode is given[8].

![Pic. 3 The single/multi-layer anode](image)

Exactly one or two layers of the anode are substrate with coarse porosity and another layer which is close to the electrolyte will be the active, normally which has very fine porosity and tortuosity. In literature [9], a five-layered anode-supported solid oxide fuel cell was developed by low-cost tape casting, cosintering, and screen printing techniques. Finally the cell could produce 1.34 W/cm^2 power density at 700 °C, which was resulted from optimized cell structure and increased ion conductivity and TPB by nanoscale ion conductor infiltration.

Sintering of the Ni/YSZ cermet coating at high temperatures (typically 1400 °C) is essential to achieve high electrode performance and low electrode ohmic resistance. Porous structure also has significant effect on the electrical conductivity of the Ni/YSZ cermet anodes in addition to the porosity. Conductivity of the Ni/YSZ cermet anode coatings in fuel cells is also affected by the heat treatment and sintering temperatures of the anodes. The effect of sintering temperature of Ni/YSZ cermet on the electrical conductivity behavior was also studied by Pratihar et al. [10]. Sintering at temperatures of 1300 to 1400 °C significantly reduced the mechanical strength of YSZ electrolyte cell. Optimized processing technique during electroless deposition of Ni generates YSZ core and Ni shell microstructure. This unique microstructure enables the interconnection among Ni, YSZ and pores throughout the matrix and thereby ensures easy transportation of electrons (through Ni-Ni continuity), oxygen ions (throughout YSZ-YSZ continuity) and gases (throughout interconnected pores) respectively. The conventional anode exhibits multimodal pore-size

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distribution with peak pore diameters varying in the range of rough 1.5-8.4 μm. Such wider pore distribution helps in easy gas diffusion through the anode thereby accelerating the fuel percolation and is subsequently followed by the catalytic oxidation. The combined effect of these larger and smaller pores is therefore expected to perform the dual function of fuel transportation and electrochemical anodic reactions.

**CERMET-ANODIC CHARACTERISTICS**

When the anode has been finished in the form of covering the electrolyte, some essential tests will be carried out, basically including electrochemical performance, interconnecting with next components, resistance contribution and so on. And it should be done in the whole fuel cell system by using of experimental or numerical methods, like the comparing electrode method. For example, the open-circuit potential is up to the partial pressure of oxygen in side of the anode, because the cathode is exposed into oxygen, and it hasn't the certain potential. So the whole potential of fuel cell can be measured by referencing with the potential in side of the cathode. The direct current method by using of three electrodes method is still good enough to evaluate the anode despite some problems.

Typical current and potential properties of the cermet anode of solid oxide fuel cell can be researched through analyzing fuel gases, hydrogen and carbon monoxide with different proportion and responding products of water and carbon dioxide. In low temperature fuel cells, the main method to promote charge transportation is to improve electrocatalytic activity as high as possible. However, in high temperature fuel cells, thermal activation has an important role in the anodic performance.

The perturbation technique exactly means the stable property will be compensated by the continuous current method, such as transient-state in time domain caused by current or potential jumping, or electrochemical impedance spectroscopy analysis in frequency domain, which can expose the mechanism of overpotential loss based on responding time and distinguish it with pure resistance effect. Other system parameters, like potential, temperature or gas environment change, all of them will influence features tested by EIS in some specific physical and chemical processes. The real system can be analyzed by the equivalent circuit, and the frequency responding can be obtained by electronic simulation too. Electricity is not essential to the impedance spectroscopy, but any storing and consumptive process related to total polarization loss will be corresponded with an analog electronic component in the equivalent circuit.

Actually, in the anode of solid oxide fuel cell, the mechanism of polarization loss observed by impedance spectroscopy is not consistent in quantity and significance. According to microstructure and experimental conditions of single anode, at least three features could be distinguished. It is indicated that the anodic impedance spectroscopy is changing by comparing cermet anodes with different microstructure and the same working condition. Presently, the discussed impedance spectroscopy is mainly about the equilibrium state, that means current is alternate. It shows that overpotential is a variable through analyzing anodic impedance spectroscopy with load. The responding impedance spectroscopy and interface polarization will reduce quickly with overpotential increasing. Besides, over the past few years, it was found that the partial pressure ratio of reactant to product not only improved the partial pressure of oxygen in the anodic side and Nernst equilibrium potential but also reduced polarization concurrently. Mizusaki et al. [11] discussed oxygen adsorption by nickel phase of the cermet anode, which could adjust hydrogen movement in surface of the cermet anode. And it supported that anodic reactions would take place in functional bodies instead of linear triple-phase boundaries. It was also proposed the principle of effective thickness in the electrochemical active area of the anode. Literature [12] showed that polarization has no relationship with anodic thickness when anodic thickness is reduced to 10 μm. In literature [13], an effective three-phase boundary (TPB) width of about 1.0-1.5 μm was determined by current-driven 18O tracer incorporation in SOFCs. In literature [14], the relation between TPBs and EAZs was studied on LSV-YSZ composite anodes in SOFCs. The length specific TPB length was 1.8 × 10^9 cm/cm, the cross-section area of EAZs was about 6-8 times of the geometric area, and the active electrode thickness and in-depth penetration of electrocatalysts were ranging from 5-20 μm and 2-8 μm, respectively. Nowadays it's getting clear that the supported anode not only has mechanical and structural functions but also has thermal and chemical functions, and it is really dependent on reaction mechanism in the
anode to optimize the anode. In actual applications, hydrocarbons, like natural gas are more common than hydrogen. Unfortunately, the anode is easily aggregated by carbon when it is directly exposed into hydrocarbons. In order to avoid this phenomenon, fuels will be reformed in advance, which exactly means hydrocarbons will react with water vapor and then produce hydrogen and carbon monoxide. Hydrogen and carbon monoxide will be real fuels. Therefore, the cermet anode being a place with electrochemical reactions of carbon monoxide taking place is important to kinetic processes of carbon monoxide. Carbon dioxide's function is similar with water in fuel cell with hydrogen supplied, and when 55% carbon dioxide and 45% carbon monoxide are supplied as fuels, there is minimum interface polarization. In addition, nowadays it is evidenced that polarization will decrease with the partial pressure of carbon dioxide increasing when the partial pressure of carbon monoxide is reducing to 1 atm and the reaction order is 0.5 [15]. Because the partial pressure of oxygen is not independent, and it will be defined by carbon oxide. Consequently, the reaction order of oxygen will be 0.25 when carbon dioxide's is 0.5. According to reversible Boudouard reaction, when carbon occupies the adsorption site of carbon monoxide and is deposited, it could be removed through reacting with carbon dioxide or being oxidized electrochemically. When reforming reactions of hydrocarbons are taking place in ancillary facilities of the whole system, it will significantly affect maintenance and efficiency of the system, therefore, the new system where oxidation will take place directly and new materials are developing continuously. With high current density, methane can be oxidized into water vapor and carbon dioxide, and when the partial pressure of oxygen in the anode is high enough, methane will be oxidized directly in the anode without serious carbon deposition. If oxidation products of fuel cell are reformed into incoming fuel, although maintaining the constant current, it's impossible to output the power density more than a critical value in commercial applications. Distributed reforming will probably be implemented by adding much water vapor into incoming fuel or autothermal reforming, especially by a co-catalytic method [16]. Nevertheless, it is required to improve anodic materials in order to directly oxidizing without reforming reactions. Transition metals of iron and cobalt are suggested to produce the cermet anode because nickel is easily corroded in high water vapor environment, although transition metals have low pyrolysis activity to hydrocarbons. Copper oxide and silver oxide will be melted during the sinter process. Fortunately the composite of copper and cerium oxide has many advantages for being the anode. It is practical to sinter copper composite by firstly sintering porous and structural zirconia over dense zirconia substrate, secondly adding copper and cerium in the form of nitrate solutions and lastly drying and pyrolysis. It is very possible to add two kinds of cation and keep them separating concurrently as what the anode requires because copper can’t dissolve into cerium oxide in the form of solid phase. It is indicated that the catalytic activity of the anode with copper, cerium oxide and YSZ is obviously higher than the anode's with copper and YSZ or cerium oxide and YSZ. Additionally, the power density with methane supplied is lower than the power density with hydrogen supplied. Comparing with fuel cell with the nickel-YSZ anode which will permanently expire after 30 min revolution, fuel cell with the copper-cerium oxide-YSZ anode has longer duration and is developing deeply in order to make high hydrocarbons oxidized directly.

High-temperature electron-conductive ceramic will also be potential materials for the anode with direct oxidation. At present, titanate, cerium salts and solid solutions of cerium oxide and other rare earth elements like Picture 4 are being researched.

![Pic. 4 Potential materials for the anode of SOFC][17] And they must be concurrently used with other metals because their electron-conductivity is varying with gas atmosphere. In literature [18], ceramic composites were
made by infiltration of La$_{0.7}$Sr$_{0.3}$VO$_3$ (LSV) into porous scaffolds of YSZ and used as SOFCs’ anodes. A 10 vol% LSV-YSZ composite formed an effective three-phase boundary structure and exhibited high electronic conductivity of 2 S/cm at 700 °C. Its electrode impedance was about 0.1 Ω cm$^2$ in humidified hydrogen with additional 0.5 vol% Pd and 2.8 vol% ceria but it could be found that Pd was poisoned by V following high-temperature oxidation. The mixed composites of LSCM (La$_{0.75}$Sr$_{0.25}$Cr$_{0.5}$Mn$_{0.5}$O$_{3-δ}$)-(YSZ-CGO) were both used as anode and cathode, consequently, it could offer better performances, like 0.4 W/cm$^2$ power density at 950 °C fed with humidified hydrogen, and lower than 850 °C operating temperatures. In solid oxide fuel cells, lower nickel content will avoid carbon deposition, simultaneously more selecting sites will be supplied for fuels activating. In literature [19], Ni-SeYSZ symmetric SOFCs showed that isothermal redox cycling at 850 °C didn’t obviously change the electrode performance, but redox cycled at 650 °C showed a 60% reduction in the polarization resistance, which was attributed to smaller Ni grains and an undamaged ceramic structure due to the redox cycle.

RESULTS AND CONCLUSION

After decades of development, the nickel-YSZ anode is dominant in solid oxide fuel cell applications because of its longer duration and higher performance, but to internal reforming reactions, it is also required to supply practical hydrocarbons in commerce. Microstructure is definitely essential to performance of the cermet anode, because reforming and electrochemical reactions mainly take place in triple-phase boundaries of the anode. Consequently, it is very crucial to prepare fine powder of original materials and sinter anodic layers over the electrolyte substrate for anodes with high performance. Recently, anode-supported fuel cell with thin electrolyte and lower operating temperatures is being focused on by more and more researchers. It is very possible to evaluate anodic performance by the direct current method in the stable state or the impedance spectroscopy method in the transient state. Experimental and numerical methods are also used to evaluate anodic performance at microscale or nanoscale levels. In the high-load cases, the thickness of anodic active layer is about 10 μm. In fact, it is necessary to make the anode thicker in order to better conduct electrons from the anode to the interconnect.

Commercially non-hydrogen fuels are more competitive, and also more challenging for carbon deposition. Normally speaking, fuels supplied must be pre-reformed before supplied into the anode. Although fuels could be reformed directly in fuel cells with the nickel cermet anodes, carbon deposition should be paid attention to in the long-time revolution. The copper cermet anode could probably prevent carbon from deposing, but its performance is really disappointed. Nowadays, the mainstream is to develop the new anode with direct oxidation, like the improved anode make by copper, cerium oxide and YSZ. Finally it is really noteworthy to develop another anode made by hydrocarbon composites, actually which is very practical.

REFERENCE

[9] Pratihar S.K., et al., Electrical behavior of nickel coated YSZ cermet prepared by electroless coating