# DBD PLASMA TREATMENT-INDUCED OXYGEN VACANCIES FOR ENHANCED IONIC CONDUCTIVITY IN YSZ

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## ABSTRACT

Yttrium-Stabilized Zirconia (YSZ) is widely used as a Solid Oxide Fuel Cell (SOFC) electrolyte for its ionic conductivity, though it faces limitations at intermediate temperatures. This study explores the use of Dielectric Barrier Discharge (DBD) plasma treatment to increase oxygen vacancies and enhance YSZ conductivity. Four types of 8YSZ samples (Bare, YSZ-5, YSZ-10, and YSZ-15) were treated for varying durations with a bipolar pulsed DC power supply under air at 0.7 kV, 0.470 A, 10 kHz, and 1.0 µs pulse width. X-ray diffraction (XRD) analysis revealed rightward shifts in the (111), (200), and (220) planes, indicating d-spacing reduction and vacancy formation. At 800°C, YSZ-15 exhibited a conductivity of 0.0474 S/cm, confirming the DBD plasma treatment's effectiveness in enhancing YSZ for SOFCs.

## KEY WORDS

Yttrium-Stabilized Zirconia (YSZ), Dielectric Barrier Discharge (DBD) plasma, Oxygen vacancies, Ionic conductivity, Solid Oxide Fuel Cells (SOFCs)

## 1. INTRODUCTION

Yttrium-Stabilized Zirconia (YSZ) is a widely used material in Solid Oxide Fuel Cells (SOFCs) due to its excellent ionic conductivity, which is essential for efficient energy conversion. However, at intermediate temperatures (600–800°C), YSZ's ionic conductivity is limited by its oxygen vacancy concentration, which is typically constrained by the amount of yttrium doping. As the performance of SOFCs is strongly dependent on the ionic conductivity of the electrolyte material, methods to enhance oxygen vacancies in YSZ are crucial to improve its conductivity at these temperatures.

Recent advancements in surface modification techniques, particularly Dielectric Barrier Discharge (DBD) plasma treatment, have shown promise in creating additional oxygen vacancies on the surface of materials. DBD plasma treatment is an effective method for modifying the surface properties of ceramic materials without causing significant bulk changes. The treatment involves exposing the material to a non-thermal plasma, which can induce chemical reactions that increase the oxygen vacancy concentration, potentially enhancing the ionic conductivity of YSZ.

This study aims to investigate the effect of DBD plasma treatment on the ionic conductivity of 8 mol% $Y_2O_3$-doped zirconia (8YSZ) by analyzing structural changes, such as lattice expansion and oxygen vacancy formation, as well as electrical conductivity improvements. We explore the impact of varying treatment durations using a bipolar pulsed DC power supply under air atmosphere and report the resulting changes in the material's properties. The findings are expected to provide valuable insights into the potential of DBD plasma treatment for improving the performance of SOFCs and other energy applications relying on solid electrolyte materials.

## 2. EXPERIMENTAL

### *2.1 Materials preparation*

8 mol% Y2O3-doped zirconia (8YSZ) pellets were prepared using commercially available YSZ powder (Tosoh Co Ltd, Japan). The powder was pressed into pellets at 5 MPa using a hydraulic press to form dense samples. The pellets were subsequently annealed at 1500°C for 10 hours to ensure stability and crystallinity.

### *2.2 DBD Plasma treatment*

The DBD plasma treatment was conducted using a bipolar pulsed DC power supply under an air atmosphere. The parameters for plasma treatment included an output voltage of 0.7 kV, an output current of 0.470 A, a frequency of 10 kHz, and a pulse width of 1.0 µs. (Fig.1, 2) Four different samples were prepared: Bare (untreated), YSZ-5 (5 minutes treatment), YSZ-10 (10 minutes treatment), and YSZ-15 (15 minutes treatment). These varying treatment times allowed investigation into the effects of plasma exposure duration on oxygen vacancy formation and conductivity.

### *2.3 Characterization*

To analyze the crystal structure and observe any lattice changes due to plasma treatment, X-ray diffraction (XRD) was performed using a Rigaku Ultima IV X-ray diffractometer. Shifts in the diffraction patterns were monitored to determine structural modifications and potential oxygen vacancy formation. Additionally, Field-Emission Scanning Electron Microscopy (FE-SEM, JEOL, JSM-7900F, Japan) was used to observe the microstructure and assess any mechanical changes induced by DBD plasma treatment, ensuring that surface modification did not adversely affect the material's morphology.

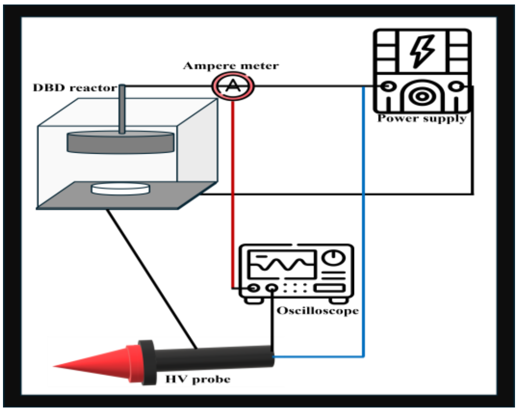


Fig.1 Circuit of DBD plasma reactor

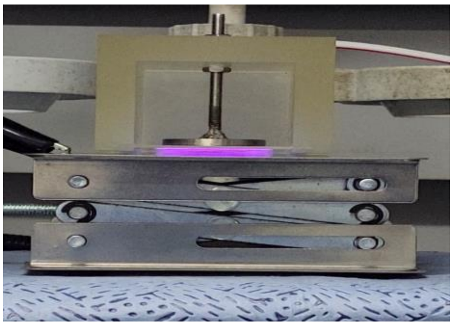

Fig.2 DBD Plasma

## 3. RESULTS AND DISCUSSION

*3.1 Phase characterization*

The X-ray diffraction (XRD) patterns show distinct shifts in the diffraction peaks for the DBD plasma-treated YSZ samples compared to the bare sample. (Fig.3) The shifts are evident in the (111), (200), and (220) planes, with a significant 1% shift observed in the (111) plane for the YSZ-15 sample, indicating reduced d-spacing and increased oxygen vacancies. These shifts suggest that DBD plasma treatment successfully alters the crystal structure of YSZ, likely due to the formation of vacancies at Zr and O sites, enhancing its ionic conductivity potential.

*3.2 Morphology analysis*

Field-emission scanning electron microscopy (FE-SEM) images reveal no substantial mechanical or morphological changes across the treated and untreated YSZ samples. This lack of structural alteration indicates the reaction exclusivity of DBD plasma treatment in YSZ, as it selectively influences the chemical and electrical properties without inducing undesired mechanical transformations. This observation supports the idea that DBD treatment enhances the material's performance through chemical and electrical pathways without compromising its mechanical integrity.

*3.3 Electrical properties characterization*

The electrochemical impedance spectroscopy (EIS) results demonstrate a remarkable improvement in the ionic conductivity of the YSZ samples at elevated temperatures. At 800°C, the YSZ-15 sample achieves an impressive conductivity of 0.0474 S/cm, indicating that prolonged DBD plasma treatment effectively enhances the electrical properties of YSZ. This significant increase in conductivity reinforces the potential of plasma treatment as a viable method to optimize YSZ for high-performance applications in solid oxide fuel cells (SOFCs).

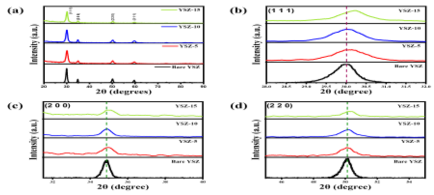

Fig.3 (a) XRD peak positions and (b), (c), (d) enlarged

XRD peak positions of Bare, YSZ-5, YSZ-10, and YSZ-15

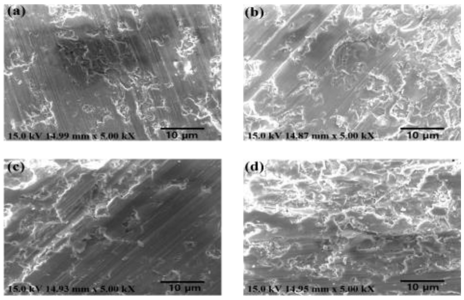

Fig.4 FE-SEM images of (a) Bare, (b) YSZ-5,

(c) YSZ-10, and (d) YSZ-15

Fig.5 Ohmic resistances of Samples

## 4. CONCLUSION

The study demonstrates that DBD plasma treatment effectively increases oxygen vacancies in YSZ, improving its electrical conductivity. Among the treated samples, YSZ-15, with the longest exposure, showed the highest conductivity (0.0474 S/cm) at 800°C, confirming the potential of this treatment to enhance YSZ performance as a SOFC electrolyte.

## REFERENCES

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