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ESTIMATION OF ELECTRON DENSITY, TEMPERATURE AND ELECTRICAL CHARACTERIZATION OF SILICA SEEDED ARC PLASMA AT ATMOSPHERIC PRESSURE

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Plasma technology stands at the forefront of numerous industrial applications, offering versatile solutions from materials processing to aerospace engineering. This study employs a single Langmuir probe technique operating at atmospheric pressure to scrutinize the transformative impact of silica seeding on low-temperature arc plasma. The investigation unveils a dynamic interplay of electrons and ions within the plasma, unveiling key electrical properties. The I–V electrical properties of the arcs plasma before seeding, having a floating voltage of –39 V, demonstrate electron and ion currents for varied probe voltages. The electrons' density is calculated to be 2.11×10^{13} m^{-3}, and the electrons' temperature is at 6.25 eV. The I–V characteristics show a floating potential of about –35 V and –37 V after seeding an arc plasma using silica in the presence of aluminum oxide (2 % by weight) powder and grain, respectively. After seeding, it is discovered that the electron temperature falls to 1.18 eV for powder while 1.16 eV for grain and electron density rises to 2×10^{16} m^{-3} for powder and 1.84×10^{16} m^{-3} for grain. In addition, a notable fall in electron temperature and a discernible rise in electron density are seen. This non-equilibrium behavior is related to silica's catalytic function, which is enhanced by the presence of aluminum oxide. Additionally, increased ionizing activity brought on by inelastic electron collisions causes the electron temperatures in the silica-seeded arcs plasma to rise with discharge voltage. These findings can be essential for enhancing plasma-based technologies in a variety of industrial applications because they provide insightful information on how silica seeding affects arc plasma properties

Keywords: arc discharge, silica seeding, electron density, electron temperature, Langmuir probes

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1. Introduction

In the realm of plasma physics and materials science, the study of seeded arc plasma has garnered increasing attention for its pivotal role in a spectrum of industrial applications. Among the myriad materials employed in this context, silica emerges as a paramount contender, offering unique catalytic properties that have the potential to revolutionize plasma-based technologies. This, in turn, has profound implications for fields as diverse as materials processing, surface modification, and advanced manufacturing technologies. The utilization of a single Langmuir probe technique enables us to elucidate the intricate interplay of electrons and ions within the plasma, offering invaluable insights into its behavior before and after silica seeding. The I–V electrical properties, and comprehensive understanding of the plasma's response to varying probe voltages, elucidating the dynamic nature of the system [1]. This is important to study with silica-seeded arc plasma because of cost-effective, industries ranging from semiconductor fabrication to aerospace engineering.

Increasing electron density in a plasma is essential for various applications. It leads to more efficient energy transfer, stabilizes the plasma, and raises temperatures, critical for tasks like welding or material processing [2]. Therefore, this study helps to control the electron density and temperature. Additionally, higher electron density in plasma confinement is crucial for nuclear fusion research and can enhance radiation characteristics for applications like spectroscopy. In fields like astrophysics, achieving a high degree of ionization is vital. Furthermore, in scenarios where plasma acts as an electrical conductor, such as in spacecraft propulsion, elevated electron density ensures efficient current conduction [3]. Achieving higher electron density involves adjusting factors like gas composition, temperature, and pressure, and applying external energy sources. The specific techniques employed depend on the application's requirements and desired plasma characteristics [4]. Furthermore, employing local and natural materials aligns with sustainability goals, as it minimizes the environmental footprint associated with transporting and processing exotic materials [5]. The research work in this area involves experimental studies, laboratory tests, and computational simulations to understand how different seeding materials affect electron density and overall plasma behavior.

The provided passage illustrates the significant role of plasma processing in assessing plasma properties through experimental measurements [6]. It emphasizes the burgeoning interest in the potential anti-cancer properties of Cold Atmosphere Pressure Plasma (CAPP), which has led to its increasing popularity in research [7]. Moreover, the integration of heterogeneous catalysts with plasma has become standard practice in various applications, such as waste treatment [8, 9] and methane conversion [10], as well as in diverse uses of plasma technology [11, 12]. But these technologies don't used catalytic function to study electron density and temperature. The patterns of interphase interaction, as well as the characteristics involved in the development of intermetallic phases (IMPs) and defects during the process of surfacing steel onto titanium using four distinct methods: P-MAG, CMT, plasma surfacing via an indirect arc with conductive wire, and PAW [13]. Applying a silica film onto a ceramic plate surface doesn't significantly alter the filamentary discharge pattern. However, the presence of silica leads to a notable rise in both ozone concentration and ozone yield, attributed to its catalytic effect [14]. but they don't study the electron density and temperature effect.

The Langmuir Probe method is highlighted as a prevalent technique for measuring critical plasma parameters, including electron temperature (T_e), electron density (n_e), ion density (n_i), and floating voltage (V_f) [15]. Despite the wealth of research in these areas, it is noteworthy that there appears to be a gap in the literature regarding the study of silica-Al_2O_3 as a means to increase electron density within plasma. This indicates an unexplored avenue in the field, suggesting that the potential of using silica-Al_2O_3 as a seeding material for electron density enhancement remains untapped. This study also helps to search different materials for searching electron density of desirable study in plasma-based processes.

In this study, let's use the pressure of the atmosphere plasma arc discharges to measure the electron temperatures while taking a heterogeneous catalyst into consideration. Our work provides direct experimental evidence for the amplification of non-equilibrium states in low-temperature plasmas caused by catalysts, especially when silica is found in the form of aluminum oxide (2 % of the weight), which is present in our research. Plasma studies have a distinct section known as arc plasma research [16], which has a diverse range of uses.

High-density, low-temperature plasma is referred to as arc plasma. However, if the probe is left within it for a while, its inside temperature is sufficient to melt it. The solution to this issue is to use a moving probe that can stay in the arc, namely in the highest temperature zone, for a brief period of time.

In modern conditions, scientific research on plasma technology, particularly the impact of silica seeding on low-temperature arc plasma, is crucial due to its pivotal role in various industrial applications. Understanding the dynamic interplay of electrons and ions within the plasma and uncovering key electrical properties enables the refinement and optimization of plasma-based technologies. Such studies provide valuable insights into enhancing processes ranging from materials processing to aerospace engineering. The results of such studies offer practical benefits by offering precise control and manipulation of plasma properties. Silica seeding, especially in conjunction with aluminum oxide, demonstrates potential for improving electron density and temperature, crucial factors in plasma-based applications. This knowledge empowers industries to develop more efficient and effective techniques, thus enhancing the performance and capabilities of plasma technology across a wide range of industrial sectors.

2. Literature Review and Problem Statement

The paper's findings demonstrate that electromagnetic radiation, spanning various frequencies such as UV, visible light, and near-infrared, is emitted by electric arcs. Comparative analyses of spectra were conducted across different current frequencies, including DC. This research highlights the significance of optical techniques in detecting electrical discharges [17]. A study commissioned by the Nuclear Regulatory Commission (NRC) and carried out at Sandia National Laboratories (SNL) focused on localized particle dispersion resulting from electrical arcing faults. The experiments involved the application of four voltage levels (480 V, 4160 V, 6900 V, and 10 kV) mirroring those encountered in High-Energy Arc Fault (HEAF) events at nuclear power plants [18]. Notably, the investigation did not delve into the utilization of Al_2O_3 for cost-effective electron generation in arc plasma.

The analysis presented underscores the significant influence of quenching on the growth of silicon nanoparticles within a thermal plasma tail, with a specific focus on varying cooling rates. It is observed that higher cooling rates lead to increased nanoparticle density, smaller particle size, and reduced standard deviation. While quenching proves to be effective in promoting certain desirable characteristics, it also poses a limitation by constraining precise control over nanoparticle properties [19]. Recent numerical studies have applied a tailored method for simulating the dynamic interactions between thermal plasma and non-ionized gas coexisting flows [20] but authors don't mention catalytic functions such as aluminum oxide. These studies have identified robust cross-correlations between the temperature at an upstream plasma fringe [21] and the concentration of nanoparticles in a downstream region [22]. This examination shows that catalytic function as nanoparticles has an impact on temperature.

The various configurations, including transferred arc plasma systems and non-transferred arc plasma jets, encompass both two-dimensional and three-dimensional fields [23] but they don't study the catalytic function to study the electron density and temperature. It is worth noting, however, that the analysis provided in the paper does not delve into the discussion of utilizing Al_2O_3 for cost-effective electron generation in arc plasma. This represents a potential avenue for further research and exploration in the field.

The study in question primarily focuses on the environmentally friendly surface modification of mesoporous silica nanoparticles using dielectric barrier discharge (DBD) plasma. These silica nanoparticles are sourced from rice husk, which is known for being both cost-effective and biocompatible. The study goes on to showcase advanced cellular experiments that demonstrate an increased level of apoptosis in MCF-7 cells when treated with Dox-loaded mesoporous silica nanoparticles that have been directly hybrid-modified (RMSN-D) using this DBD plasma technique [24]. The research underscores the significance of atmospheric pressure plasma (APP) deposition, particularly in the context of oxide film growth. It offers an overview of non-thermal APP techniques applied to TiO_2 thin films, presenting a historical perspective alongside recent developments. Furthermore, the review discusses ongoing research concerning the effects of deposition parameters and highlights the challenges associated with APP deposition in this dynamic field [25]. However, it's crucial to note that the paper doesn't delve into the use of Al_2O_3 for cost-effective electron generation in arc plasma. This topic represents a separate area of interest and research within the broader field of plasma science and materials modification. Future studies could explore the potential application of Al_2O_3 for electron generation in arc plasma, but this is not addressed in the context of the research presented in the paper.

The seed layer, housing nanobots, underwent a plasma cleaning process at 0.517 bar atmospheric pressure for 15 minutes to remove surface impurities. Post-cleaning, it was immersed in an organic solution at 120 °C overnight [26]. Argon forms the plasma, while ammonia serves as the reactive gas. Experiments vary plasma input powers (1.5, 3.0, and 4.5 kW) for optimization [27]. In Alternating Current Powder Pool Coupled Activating TIG welding for aluminum alloy, activating flux powders enhance weld penetration. The dissociation of SiO_2 enhances ionization in the plasma. The flux transition leads to a constricted, higher-temperature arc, elevating voltage and substantially augmenting weld penetration in comparison to traditional TIG welding [28]. The study shows not mention of any involvement or experimentation with seeded Al_2O_3. It predominantly focuses on the plasma cleaning process, the use of argon and ammonia gases, variations in plasma input powers, and the application of flux powders in welding processes. As a result, there is no information available in this passage regarding the interaction or performance of seeded Al_2O_3 in the described procedures.

The literature review reveals a gap in research pertaining to the estimation of electron density, temperature, and electrical characterization specifically for silica seeded arc plasma at atmospheric pressure. Previous studies primarily focus on different aspects of plasma behavior, including electromagnetic radiation, particle dispersion, nanoparticle growth, and surface modification. However, there is an absence of investigations specifically targeting the mentioned parameters in the context of silica seeding at atmospheric pressure. This necessitates the current study to contribute valuable insights in this unexplored area.

3. The aim and objectives of the study

The aim of this study is to identify the impact of silica seeding on low-temperature arc plasma using a single Langmuir probe technique at atmospheric pressure. By employing the single Langmuir probe technique at atmospheric pressure, the investigation seeks to elucidate the dynamic interplay of electrons and ions, and to uncover key electrical properties of the plasma system. This scientific knowledge contributes to the broader body of research in plasma physics and can serve as a basis for further theoretical advancements and experimental studies in the field.

To achieve this aim, the following objectives are accomplished:

– investigate the current and voltage without catalytic function (absence of silica seeded) and electron density and temperature using arc plasma;

– analyze the impact of current and voltage with silica-seeded arc plasma with aluminum oxide including inelastic collision;

– comparison of electron density and temperature with discharge voltage in the silica-seeded arc plasma with aluminum oxide.

4. Materials and methods of research

4. 1. Experimental Setup

Fig. 1 displays a schematic representation of the experimental configuration. When DC voltage (0–600 V) is given to the electrodes, an arc plasma sparks across the copper electrodes. The tungsten wire-based movable cylindrical probe is kept moving back and forth between the electrodes. Insulating fiber covers a large section of the probe. The probe's biasing DC voltage (0–60 V) is utilized to drag both ions and electrons for I–V characteristics. A deflection measurement on a ballistic galvanometer is used to measure the electron as well as ion current. Table 1 displays the probe and electrode's specifications. Fig. 1 shows the experimental setup that was employed in this investigation. Arc plasma is sparked by a pair of electrodes made of copper that make up the setup. In order to promote plasma production, a direct current (DC) supply of 0 to 600 V is placed across the electrodes. Between the electrodes is a moveable cylindrical probe composed of tungsten wire. In order to avoid unintended interactions with the plasma, the probe is partially coated by an insulating fiber. By applying a biasing DC voltage between 0 and 60 V to the probe, electron as well as ion currents can be collected in order to examine the I–V characteristics.

A ballistic galvanometer is used to measure the current measurements, which enables accurate determination of the electron as well as ion currents. Table 1 provides specific information about the probe as well as the electrodes utilized in the tests. The wire made of a tungsten probe has particular dimensions and characteristics that are pertinent to its function in gathering plasma data. The copper-based electrodes have particular geometries and material properties that guarantee stable plasma production throughout the studies.

The direct current (DC) power across the electrodes made of copper is gradually increased within the predetermined range (0–600 V) in order to start the arc plasma. Once the supplied voltage crosses the breakdown threshold, a plasma discharge is seen. The tungsten-based probe is then carefully moved around the electrodes to collect data at various spatial locations within the plasma zone. Effective collection of the two types of electrons and ions is accomplished by delivering a biasing direct current voltage (ranging between 0 to 60 V) through the probe, and their associated currents are measured using a ballistic galvanometer. Insights into the dynamics of electron and ion currents in the arc plasma environment can be gained from the data gathered on the I–V characteristics, as obtained from the ballistic galvanometer. The laboratory formation arc plasma is shown in Fig. 2 (a photo from our laboratory at the Central Department of Physics of Tribhuvan University, Kathmandu). Using this information, it is possible to compare the plasma's floating potential, electron density, and electron temperature before and after adding silica to the arc plasma. The effects of silica seeding upon low temperatures arc plasma are then investigated through comparison and analysis of the results.

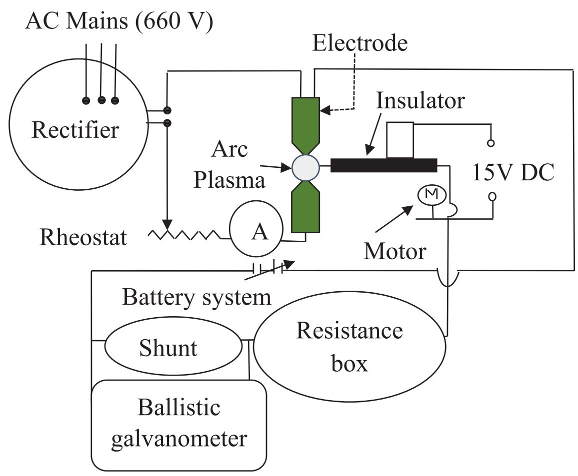

Fig. 1. Basic Circuit for Single Probe Method

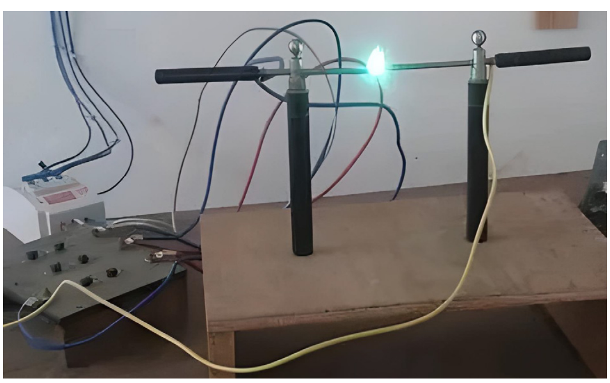

Fig. 2. Arc Discharge in the Plasma Laboratory

Table 1

Specifications of the Probe and Electrodes

Probe material: Tungsten
Length of the probe=1.60 mm
Average radius of the probe=0.45 mm
Diameter of the electrode=6.2 mm
Surface area of the probe (A)=5.16×10^{-6} m^2
Average diameter of the arc=8.23×10^{-3}m
Average velocity of the probe=20.07 mms^{-1}
Passage time of the probe through the arc=0.41 s
Maximum probe current=0.52 mA
Electrode material: Copper

The choice of materials for the probe and electrodes in the experimental setup is specified in Table 1 and these instrumentals and materials are crucial to ensure accurate measurements and reliable data collection. Tungsten was selected for the probe due to its high melting point, excellent thermal conductivity, and resistance to arc erosion. These properties are essential for maintaining the structural integrity of the probe when subjected to high temperatures and intense electrical discharges within the plasma. The probe's specific dimensions, including length and radius, were carefully determined to allow for precise positioning and interaction within the plasma. The choice of tungsten also contributes to the probe's durability, ensuring it can withstand the harsh conditions of the plasma environment. Copper was chosen as the material for the electrodes due to its high electrical conductivity. This property is crucial for efficiently transmitting electrical current to generate the plasma. Additionally, copper's good thermal conductivity helps in dissipating the heat generated during the experimental process, preventing overheating and potential damage to the electrodes.

4. 2. Theory regarding to experiment

The Single Probe Method (SPM) of the cylindrical Langmuir probe is a widely employed technique for characterizing plasma parameters. The fundamental principle underlying SPM lies in the collection of current-voltage (I–V) characteristics. By systematically varying the applied voltage and recording the corresponding current, a set of I–V characteristics is obtained. Additionally, the method enables the determination of the plasma potential, which is the voltage at which the current collected by the probe approaches zero. This approach is highly valuable for extracting essential information about plasma behavior, particularly in situations where a multi-probe setup may not be practical, such as in high-temperature or high-pressure environments. Following are the fundamental equations of the cylindrical Langmuir probe for SPM experiments [29]:

$$I_e = \frac{n_e eA}{2}\left(\frac{2kT_e}{\pi m_e}\right)^{\frac{1}{2}} \exp\left(-\frac{eV}{kT_e}\right), \tag{1}$$

when $V=0$, $I_e=(I_e)_r$ and so, it is possible to write:

$$n_e = \frac{(I_e)_r}{eA}\left(\frac{2\pi m_e}{kT_e}\right)^{\frac{1}{2}}, \tag{2}$$

where I_e is the probe's current owing to an electron, I_i is the probe's current due to an ion, n_e is electron density in the system, and e is the charge on an electron. A stands for the probe's surface area, k for Boltzmann's constant, T_e for electron temperature, m_e for electron mass, m_i for ion mass, and V for probe potential. By drawing a tangent to the probe's ln(I_e) vs V curve, equation (1) is utilized to calculate the electron temperature (T_e). Equation (2) can be used to get the electron density once the temperature of the electrons has been determined. There is a point where the electron current drawn simply cancels the ion current with a sufficiently negative probe potential. When V equals V_s, something happens. Here, V_s stands for the possibilities of space. The Langmuir probe method is excellent for studying moderately dense plasmas.

5. Results of electrical characterization, electron density and electron temperature with catalytic function power and grain

5. 1. Impact of current and voltage without Silica Seeded Aluminum Oxide and determination of electron density and temperature

Before being seeded with silica, the arc plasma's I–V characteristics are shown in Fig. 3. The curve's positive portion reflects the electron current, and its negative portion is the ion current. Electrons are drawn to the positive-biased probe as the probe voltage rises, increasing the electron current. In contrast, with larger negative potentials, ions that are positive are attracted to the probe, and the ion current increases. The floating potential, which is determined to be –39 V, is the junction of these two zones. When the amount of net current received by the probe is zero, this potential indicates the plasma potential relating to the probe.

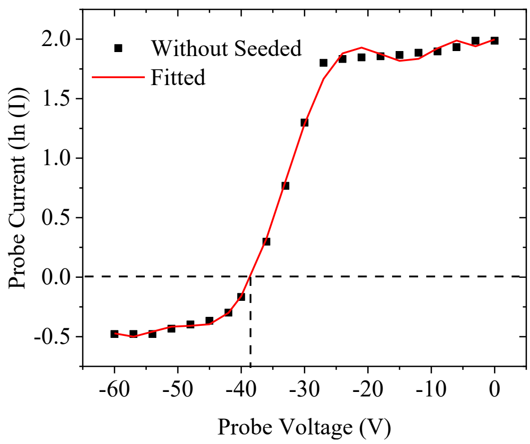

Fig. 3. I–V Characteristics for single probe method before seeding

The linear fit used to calculate the electron temperature prior to seeding is displayed in Fig. 4. The relationship $\ln(I)=0.16V+6.23$ provides the equation that fits this line the best.

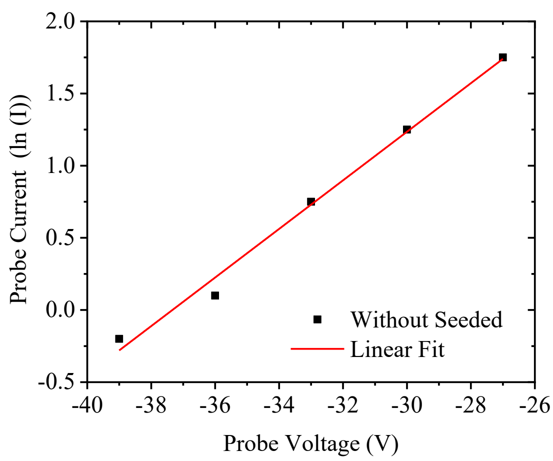

Fig. 4. Linear fit for the determination of electron temperature before seeding

The electron's temperature, which is determined to be 6.25 eV, is calculated using this line's slope. The electron density within the arc plasma is also calculated to be 2.11×10^{13} m^{-3} based on the I–V curve. In an argon environment, observed single cylindrical probe I–V characteristic curves and derived an electron density that was of order 10^{14} m^{-3} [30]. However, the nature of the issue is the same in the negative zone and different in the positive region.

5. 2. Impact of current and voltage with Silica Seeded Aluminum Oxide and determination of electron density and temperature

The I–V parameters for the silica-seeded arc plasma in the presence of aluminum oxide powder and grain (2 % by weight) as determined by the single probe approach are shown in Fig. 5. For various probe voltages, the graph shows discrete zones that correspond to the electron current as well as the ion current. After seeding the arc, it is noticed that the floating potential is roughly –35 V for powder and –37 V for grain. This potential represents the probe's plasma potential following the addition of silica as well as aluminum oxide powder and grain seeds.

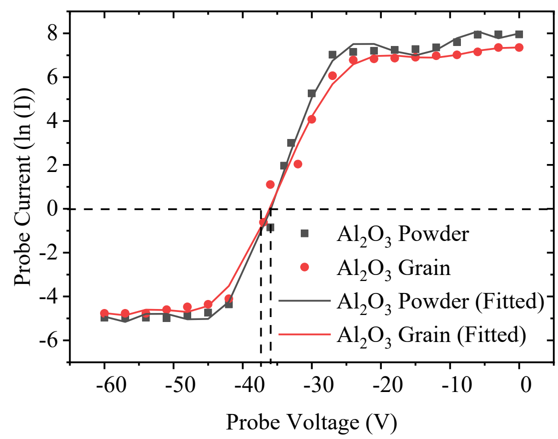

Fig. 5. I–V Characteristics for single probe method seeding

After seeding the arc plasma with silica, the linear fit used to calculate the electron temperature is shown in Fig. 6. This line is best matched by the equation $\ln(I)=0.85V+29.13$. This line's slope represents the new electron temperature that resulted from the addition of silica as well as aluminum oxide (powder and grain) seeds.

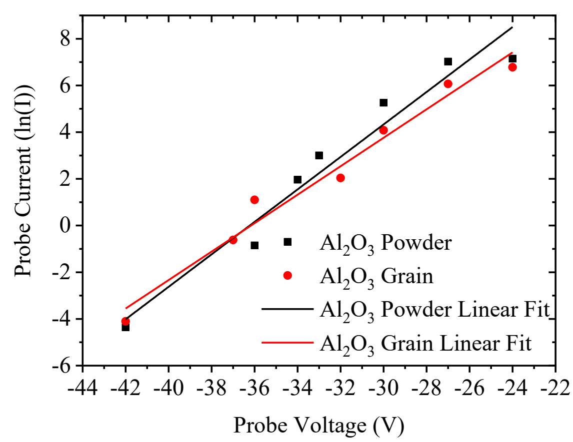

Fig. 6. Linear fit for the determination of electron temperature after seeding

It is noted that the electron temperatures dramatically drop to 1.18 eV for powder and 1.16 eV for grain after seeding the arc plasma. Additionally, a considerable increase in electron density occurs, rising to a value of 2×10^{16} m^{-3} for powder and 1.84×10^{16} m^{-3} for grain.

5. 3. Nature of electron density and temperature with discharge voltage in silica-seeded aluminum oxide

The fluctuation of electron temperatures with discharging voltage in silica-seeded arc plasma is seen in Fig. 7. The electron temperatures of the silica-seeded arc plasma exhibit a distinct rising trend as the discharge voltage rises. According to this discovery, the electron temperature fluctuates depending on the operating conditions and is affected by the discharge voltage. There is a significant association between these two parameters, as evidenced by the finding that in silica seeded arc plasma, the electron temperature rises with the discharge voltage. The plasma is driven by the discharge voltage, which also affects how energetically distributed the electrons are in the plasma.

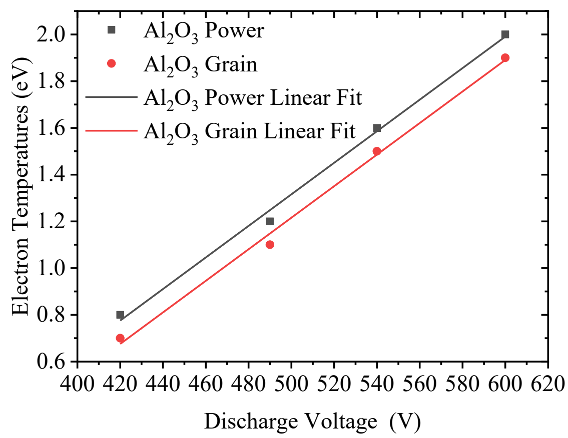

Fig. 7. Variation in Electron Temperature with Discharge Voltage

The higher kinetic energy that electrons acquire from an electric field as the discharging voltage rises can be used to explain the rise in electron temperature. Because electrons gain more energy at greater discharge voltages, the average electron temperature rises. This behavior is in line with the fundamental ideas of plasma physics, according to which higher voltages result in more energetic electrons.

The Fig. 8 depicts the typical progression of variations in electron density in respect to discharge voltage.

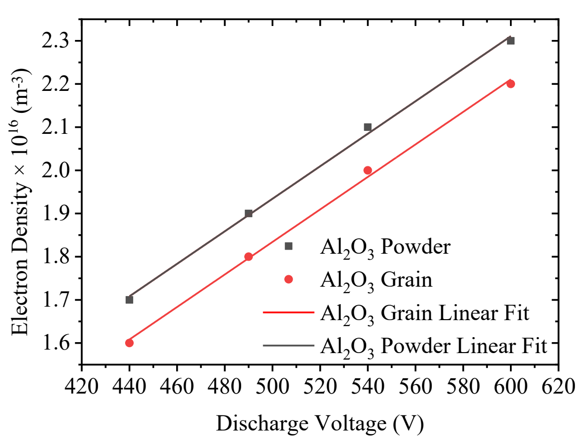

Fig. 8. Variation in Electron Density with Discharge Voltage

The system's internal electron flow accelerates as the discharge voltage rises. The electron density rises as a result of this acceleration. In essence, the discharge voltage, electrons velocity, and electron density are all directly correlated.

The electron density increases with discharge voltage, demonstrating higher values in the case of powder-seeded silica-aluminum oxide compared to grain-seeded silica-aluminum oxide. This discrepancy arises from the larger surface area provided by powdered silica-seeded aluminum oxide, even at an equivalent weight concentration, in comparison to its granular counterpart.

6. Discussion of the results of the study of electron density and temperature without and with silica-seeded arc plasma with aluminum oxide

The data acquired offer insightful knowledge of the properties of the arc plasma prior to silica seeding. The presence of separate electron as well as ion current zones in the I–V diagram indicates that electrons and ions behave differently in plasma. The electron saturation zone, which can be seen in the positive half of the curve shown in Fig. 3, implies that the majority of the available electrons are gathered by the instrument's probe at high positive voltage, causing an electron current plateau. Similar to this, the ion saturation area in the negative half of the curve shows that the probe gathers the majority of the positive ions that are accessible at high negative potentials, which causes the ion current to become saturated. The plasma's potential with regard to the probe is represented by the observed floating voltage of –39 V, making it a crucial parameter. This potential can also be utilized to evaluate the plasma potential in relation to the environment, which will help us better understand how plasma interacts with electrodes.

The plasma's electron energy distribution can be inferred from the calculated electron temperature of 6.25 eV. Understanding diverse plasma processes as well as reactions requires knowledge about the mean energy generated by electrons, which is provided by this information. Research shows that observed electron temperature varies in the 2 eV to 8 eV range [30]. Additionally, the calculated electron concentration of 2.11×10^{13} m^{-3} provides important information about the particle concentration in the arc plasma. For defining the entire state and behavior of the plasma, the density value is crucial. The findings from the I–V properties of the single Langmuir probe offer crucial information for describing the arc plasma and comprehending its basic characteristics. The results of this study's measurements of electron temperature as well as electron density can be utilized as a guide for future research on low temperatures arc plasmas and as a contribution to the area of plasma physics as a whole. Additionally, these results establish the framework for examining how silica seeding affects plasma properties, which is essential for improving plasma-based technologies in numerous industrial applications.

The electron current is shown by the positive portion of the curve. Electrons are drawn to the biased probe as the probe voltage rises, increasing the electron current. For a variety of probe potentials, this section within the curve is often linear (–40 V to –32 V). Ion current is represented by the curve's negative portion. Ions are attracted to the probe at larger negative potentials, which increases ion current. Depending on the range of probe potentials, this portion of the path may also be linear (–40 V to –32 V). The «floating potential» is the location of the intersection of the electron as well as ion currents. This refers to the potential level where the probe draws no net current. A key metric, the floating potential sheds light on the plasma potential in relation to the probe. The region of 32 V to 0 V and –60 to –40 V, there is a continuous range known as the electron-saturated region and the ion saturation region. The Langmuir probe's electron current reaches its maximum value and ceases to be reliant on the probe potential in the area of electron saturation. This happens because the probe attracts the majority of the electrons that are freely present in the nearby plasma at high positive potentials. The number of electrons the probe is able to capture plateaus as the probe voltage is raised and reaches a saturation point. Since the majority of the accessible electrons are already pulled to the probe, further raising the probe voltage has little impact on the electron current. The ion current that the Langmuir probe collects achieves its maximum value and ceases to be reliant on the probe potential at the ion saturation area. The probe draws positive ions that exist in the plasma at strong negative potentials. The number of ions the probe collects rises as the probe voltage becomes more negative until it reaches the point of saturation. Beyond that point, further lowering the negative probe voltage has little effect on the ion current since the majority of the available ions have already been gathered by the probe.

The I–V parameters of the silica and aluminum oxide powder and grain-seeded arc plasma offer critical insights into how seeding affects plasma behavior. When contrasted with the value of –35 V for powder and –37 V for grain obtained prior to seeding, the floating voltage of –35 V for powder and –37 V for grain observed after seeding shows a shift within the plasma potential as shown in Fig. 5. Foreign particles may have caused this change by altering the charge distribution of the plasma and changing its potential in relation to the probe. After seeding (both powder and grain), the floating potential changed, indicating changes to the plasma-electrode interactions as well as plasma's overall condition. The electron as well as ion densities, the distribution of energy, as well as charge neutrality of the plasma can be affected by the presence with silica as well as aluminum oxide (powder and grain) seeds. For plasma-based operations involving silica seeding, including processing of materials as well as surface modification, optimization of these changes is crucial.

After seeding the arc plasma, the findings of the linear fit of the I–V property yielded significant insights into the impacts of silica as well as aluminum dioxide (powder and grain) seeding on plasma variables as shown Fig. 5. The measured drop in electron temperatures between 6.25 eV to 1.18 eV for powder and 6.25 eV to 1.16 eV for grains suggests that the plasma's electrons have significantly cooled, as shown in Fig. 6. The energy transfer pathways involving silica as well as aluminum oxide (powder and grain) seeds may be responsible for this cooling. These new particles may cause collisions that exchange energy, lowering the temperature of the electrons as a result.

After seeding, there was a noticeable rise in electron density, reaching 2×10^{16} m^{-3} for powder while for grain 1.84×10^{16} m^{-3}, which points to an improvement in plasma particle concentration. Different causes, such as greater ionization brought on by the seeds' presence, changed recombination rates, or modifications to the plasma's general charge balance, could be to blame for the rise in electron density. Using a single Langmuir probe, the investigation shows the effects of deposit conditions on plasma parameters. They discovered that the electron temperatures ranged from 0.8 to 2.2 eV, or 5.5 to 1.2×10^{18} m^{-3} of plasma density. The study demonstrated the importance of the relationship between probe location and deposition circumstances and plasma parameter values. As a result, the incorporation of seeding was recognized as a key element in generating high electron densities [31].

Silica's catalytic role in regulating plasma behavior is highlighted by the discovery that it increases the non-equilibrium with cold plasmas, particularly those loaded with aluminum oxide powders as well as grain. The non-equilibrium condition of the plasma appears to be significantly shaped by the promoter impact of aluminum oxide upon the silica seeds. For situations where plasma with particular energy distributions as well as particle concentrations is sought, knowing that non-equilibrium behavior is essential. The results of the study suggest that silica seeding has the ability to customize plasma characteristics as well as non-equilibrium effects for particular purposes. Plasma-based processes can be improved in areas including materials synthesis, modification of surfaces, and plasma-assisted technologies by carefully controlling electron temperature as well as electron density. The results collected help to clarify how plasma interacts with seeds and how silica as well as aluminum oxide seeding affect plasma characteristics. The alterations in electron temperature as well as density that were seen shed light on the complex structure of plasma-seed interactions also provided useful information on the possible uses of seeded plasmas. A deeper comprehension of the reported effects can be achieved through further research into the fundamental mechanisms as well as thorough examination of the plasma-seed interactions, which can also result in more effective and specialized plasma-based technologies.

The rise in ionization activity throughout the plasma can also be connected to the increase in electron temperature. The electric field in the plasma gets stronger as the discharge voltage rises, which causes electron collisions to happen more frequently and energetically. The rate at which neutral molecules or atoms are ionized to form ions and extra free electrons is increased as a result of these predominately inelastic collisions between electrons. The greater ionization results in more energetic electrons, which raises the temperature of the electrons. The discovery that higher discharge voltages are associated with higher electron energies further supports this idea by showing an increase in the average energy of electrons in the arc plasma. The observed correlation further supports the effect of the discharging voltage on the distribution of electron energy in the plasma. The average energy of electron is closely connected to their temperature.

Controlling and improving plasma processes requires an understanding of the relationship between electron temperature and discharge voltage. It is possible to modify the plasma's properties as well as energy distributions to suit a variety of applications by adjusting the discharge voltage. Controlling the electron temperature, for instance, might affect the reactions as well as interactions between the plasma as well as the target materials in applications involving the processing of materials or surface modification.

This research investigates the I–V characteristics of arc plasma, both before and after seeding with silica-seeded aluminum oxide. Prior to seeding, the study reveals a clear distinction between electron and ion currents in the I–V curve, with a calculated electron temperature of 6.25 eV and an electron density of 2.11×10^{13} m^{-3}. Following seeding, there is a notable shift in floating potentials, a significant drop in electron temperature, and a substantial increase in electron density. Additionally, the study demonstrates a direct relationship between electron temperature and discharge voltage, highlighting the influence of voltage on plasma behavior. While this research provides valuable insights into plasma-seed interactions, it may have limitations in terms of generalizability to other conditions or materials. Future studies could delve deeper into the underlying mechanisms and challenges associated with modeling and validating such complex interactions, offering potential advancements in plasma-based technologies.

7.Conclusions

1. The study observed significant differences in the I–V characteristics between grain and powder forms of silica-seeded arc plasma with aluminum oxide. Notably, the electron density in the powder form silica-seeded arc plasma with aluminum oxide was higher compared to the grain form silica-seeded arc plasma with aluminum oxide.

2. The research identified silica's catalytic function in both grain form silica-seeded aluminum oxide and powder form silica-seeded arc plasma with aluminum oxide states within seeded arcs plasma. Interestingly, the catalytic activity was found to be more dynamic in the grain form silica-seeded arc plasma with aluminum oxide.

3. The study also assessed the influence of inelastic electron collisions on ionization activity, which led to variations in electron temperature with discharge voltage. This resulted in higher electron density in the powder form silica-seeded arc plasma with aluminum oxide and a higher electron temperature in silica-seeded arc plasmas.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data cannot be made available for reasons disclosed in the data availability statement.

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