ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)

Volume 11 Issue 7 July 2024

Plasma Energy Technologies: Recent Developments, Diverse Applications Challenges and Future Aspects

[1] Ravish Sharma, [2] Khushvant Singh, [3] Rudraksh Tiwari, [4] Kash Dev Sharma

[1] Babu Shivnath Agrawal PG College Mathura, Uttar Pradesh
[2] [3] [4] BSA PG College, Mathura, Uttar Pradesh
Corresponding Author Email: [1] ravishsharma18jan1983@gmail.com, [2] khushvants@gmail.com,
[3] drtiwarirudraksh@gmail.com1, [4] sharma.kashdev@gmail.com

Abstract— - Plasma energy technologies present a myriad of challenges as they continue to garner significant interest in scientific and industrial domains. The pursuit of a burning plasma [1], where fusion reactions serve as the primary source of heating in the plasma, represents a critical milestone in the development of self- sustaining fusion energy [2,3]. However, achieving this goal poses significant engineering, technological, and scientific challenges. These challenges include the need to create and sustain the extreme conditions required for fusion reactions, such as high temperatures and pressures, as well as the development of materials capable of withstanding these. conditions for extended periods. In addition to the challenges related to fusion energy, the diverse applications of plasma technology across various industries, including electrical, mechanical, chemical, and medical sectors, bring about a new set of hurdles. These challenges encompass scalability, efficiency, and safety. For instance, while plasma technology shows promise in areas such as hydrogen production, semiconductor processing, plasma polymerization, coatings, plasma display panels, nanotechnology, medical treatments, and pollution control, there is a need to address issues related to process control, energy efficiency, and environmental impact to realize the full potential of these applications. Furthermore, the increasing worth of plasma technology. underscores the need to overcome challenges in commercialization, regulation, and public acceptance. Bringing plasma energy technologies to market requires addressing issues related to cost, reliability, and integration with existing infrastructure. Additionally, navigating regulatory frameworks and ensuring public acceptance of new plasma-based technologies present significant hurdles that must be addressed to facilitate widespread adoption. Looking to the future, the development of plasma energy technologies will require continued innovation, investment, and interdisciplinary collaboration. to overcome these. challenges. This includes advancing fundamental understanding of plasma physics, materials science, and engineering, as well as. fostering. Collaboration between industry, academia, and government entities to drive progress in this field. Addressing these challenges will be essential to realizing the full potential of plasma energy technologies in addressing global energy and societal challenges.

Keywords: Plasma, Fusion Energy, Applications, Technology, Future Prospects.

I. INTRODUCTION

Plasma energy technology, a field that spans from the fundamental understanding of astrophysical phenomena to practical applications in daily life, stands as a testament to the progress of human inquiry and invention. Since its initial observation in nature and subsequent identification as the fourth state of matter, plasma has been an object of fascination and study. The history of plasma research, marked by milestones set by scientists like William Crooks and Irving Langmuir, has evolved to encompass a wide array of applications that leverage the unique properties of this ionized state of matter. Langmuir's development of the plasma sheath theory and the discovery of Langmuir waves were instrumental in establishing the foundations of what we now understand as plasma physics.

The significance of plasma extends well beyond its prevalence in the universe, as it has become a versatile and powerful tool in both industry and medicine. Within the industrial domain, plasma enables the modification of surface properties, enhancing the functionality and resilience of materials such as ceramics, alloys, and glass. The application of plasma in organic chemistry has facilitated the fabrication and control of synthetic materials, highlighting its role in the advancement of material sciences.

Medical advancements have also been propelled by plasma technology, showcasing its versatility from sterilization processes to therapeutic applications like the innovative Plasma needle [4]. This breakthrough has paved the way for less invasive treatments and has become an invaluable asset in the fields of diagnostics and disease monitoring.

Looking towards the future, plasma technology is poised to play a pivotal role in addressing the global challenge of sustainable energy. The pursuit of controlled nuclear fusion [5] stands at the forefront of this endeavor, with scientists and engineers working to replicate the self-sustaining reactions of stars here on Earth. The goal is to create a system where the reaction is not only self-heating but also produces more energy than is required to initiate and maintain it.

This ambitious quest for fusion energy has led to the development of two primary approaches: inertial confinement fusion (ICF)[6,7,8,9] and magnetic confinement fusion (MCF). ICF involves the rapid compression of fuel pellets to induce fusion, while MCF relies on magnetic fields to contain and control the high-temperature plasma over longer periods. Both methods seek to achieve the 'burning' state of plasma—where the reaction becomes thermally unstable and self-sustaining, opening the door to a potential revolution in energy production.One of the challenges of MCF research is the development and extrapolation of plasma scenarios to power plant conditions, where good fusion performance and energy confinement must be maintained.

However, the path to realizing the full potential of plasma energy technologies is laden with formidable challenges. Understanding and controlling the complex behavior of plasma, developing materials capable of withstanding the harsh conditions of fusion reactors, and overcoming the economic and technical barriers to scale these technologies for widespread use are ongoing areas of research and development.Despite these obstacles, the promise of plasma energy technologies remains a beacon of hope for a future powered by clean and abundant energy. The advancements in this field could lead to a paradigm shift in how we generate and consume energy, driving innovation across various sectors. From revolutionizing manufacturing processes to enabling new medical treatments, and potentially providing a solution to the looming energy crisis, plasma energy technology holds the key to a multitude of possibilities that could reshape our world.

As research continues to advance, the intricate dance of ions and electrons that characterizes plasma might one day power our cities, heal our bodies, and unlock secrets of the universe that we have yet to imagine. The journey of plasma, from the flickering lights of auroras to the core of stars, and into the heart of our technological endeavors, is a narrative of human curiosity**.**

II. RESEACH METHODOLOGY

Research methodology in plasma energy technology encompasses a multifaceted approach integrating theoretical frameworks and experimental investigations. Plasma, is a highly energized state of matter composed of charged particles. In the context of energy production, the focus lies on understanding and harnessing the immense potential of burning plasma, where fusion reactions play a central role in generating energy.

A. Theoretical Understanding:

Plasma physics forms the foundation of research methodology in plasma energy technology. Key theoretical concepts include:

- Burning Plasma: A state where most heating arises from fusion reactions within thermal plasma ions. Understanding the dynamics of burning plasma is crucial for replicating fusion processes observed in stars like the Sun.

- Ignited Plasma: Another related concept where all heating originates from fusion reactions. The study of ignited plasma sheds light on self-sustaining fusion reactions.

- Modeling Hot-spot Conditions: Mathematical models are utilized to infer hot-spot conditions such as temperature, pressure, and energy, based on measured quantities.

B. Experimental Endeavors:

Experimental formations are essential for validating theoretical predictions and exploring novel phenomena. Major experimental facilities and projects include:

-National Ignition Facility (NIF)[3]: A large-scale laser-based inertial confinement fusion research device where burning plasma[5] has been achieved.

- Tokamaks: Magnetic confinement devices like ITER and SPARC are under construction to study and achieve magnetically confined burning plasma.

-Reproducibility Studies: Experiments aimed at reproducing burning plasma states to validate findings and refine methodologies.

C. Symbolic Implications:

Beyond scientific advancements, the quest for achieving controlled fusion reactions carries significant symbolic implications:

- Milestones such as the NIF burning plasma [6] achievement signify progress towards sustainable nuclear fusion power, potentially revolutionizing energy production.

- Fusion power has implications for global energy security, climate change mitigation, and even potential applications in directed-energy weapons.

Research methodology in plasma energy technology is a dynamic interplay between theoretical insights and experimental validations. By leveraging cutting-edge facilities and collaborative efforts, researchers aim to overcome technical challenges and unlock the transformative potential of fusion energy for a sustainable future plasma research, reproducibility is a critical aspect to validate experimental findings. Research methodologies in plasma studies often involve conducting experiments to confirm the reproducibility of plasma states under different conditions. Advanced modeling techniques are used to infer hot-spot conditions and other plasma parameters based on measured quantities. These models consider factors such as temperature profiles, pressure, energy, and density distributions to provide insights.

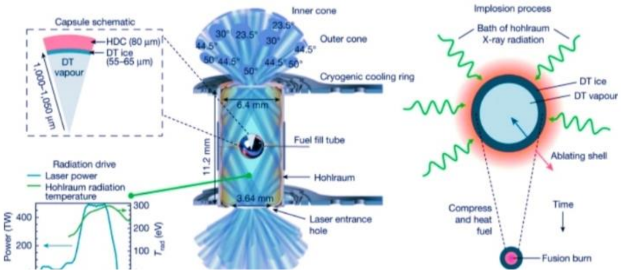

Fig. 1. ICF (Burning Plasma).

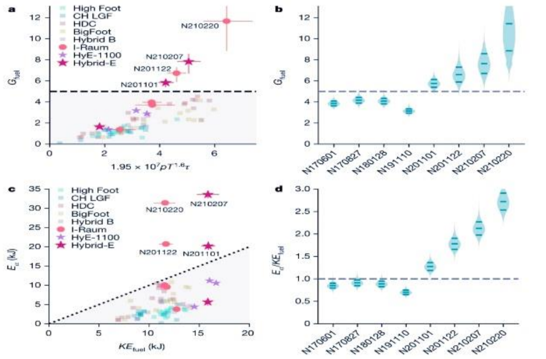

Fig. 2. Parameters for evaluating a Burning Plasma

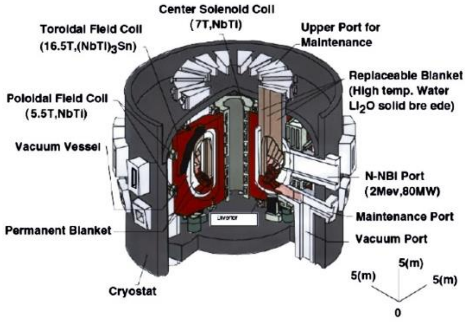

Fig. 3. (MCF)Tokamak reactor.

Fig. 4. Tokamak reactor plant layout

III. RESULTS AND DISCUSSION ON PLASMA ENERGY TECHNOLOGY FORMATION/GENERATION

Plasma lies at the heart of numerous natural phenomena and cutting-edge technologies. The generation of plasma involves the application of energy to a gas, which leads to ionization—the process where electrons are separated from their parent atoms, creating a soup of charged particles [10]. This ionized state of matter is unique for its wide range of temperatures and characteristics, which allows it to be classified into two primary groups: non-thermal (cold) plasma and thermal (hot) plasma. These classifications are defined by their degree of ionization, atmospheric pressure, and the temperature conditions under which they exist [11-17].

Thermal plasma, or hot plasma, consists of negative ions and heavy charged particles that are in thermal equilibrium with each other, meaning they share the same temperature. This state is thermodynamically stable and widely abundant throughout the universe [18]. Hot plasma can be created through electrothermal and electromagnetic launchers, with potential applications ranging from space exploration, where the study of micrometeoroid and space debris impacts are crucial, to industrial processes, such as surface treatments for material coatings [19]. Plasma antennas, which utilize plasma for beamforming, have demonstrated high efficiency in beam radiation, forming, and scanning due to their interaction with electromagnetic waves [20]. Moreover, plasma-based ion implantation offers advanced techniques for depositing thin films and modifying surfaces critical to various manufacturing processes.

On the other hand, non-thermal plasmas, or cold plasmas, display electrons at temperatures significantly higher than those of heavy charged particles and exist outside of thermodynamic equilibrium [21]. Ion sources for these plasmas include plasma generators that utilize methods such as electron cyclotron resonance and microwave frequency ionization to create discharges [22]. The ability to produce high-temperature plasma without the need for gaseous collisions has sparked interest due to its applications in space physics and both inertial and magnetic fusion [23]. Advanced technologies, such as vacuum microwave oscillators, enable the modification of the frequency and power of radiation emitted by artificial plasma, providing versatility for different applications [24].

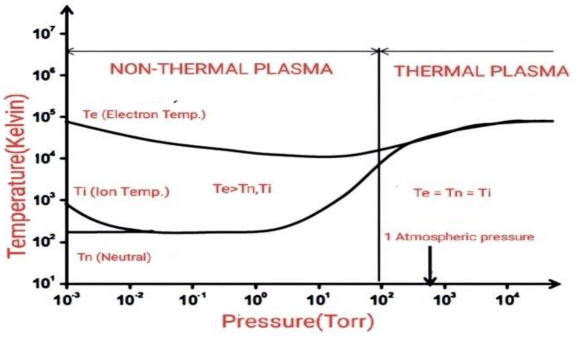

Fig. 5. Graphical representation of non-thermal and thermal plasma.

At the core of plasma physics is the concept of a burning plasma, a self-sustaining state where the majority of the heating is derived from fusion reactions involving thermal plasma ions [1][2]. The Sun serves as a natural example of a burning plasma, where fusion reactions involving hydrogen ions are the source of its immense energy. Similarly, this principle is mirrored in human-made applications such as thermonuclear weapons and research facilities like the National Ignition Facility (NIF), where significant milestones have been achieved in creating and sustaining burning plasma [3].

The development and study of plasma technology have profound implications across a spectrum of fields. From metallurgy and nanotechnology to semiconductor processing and medical applications, plasma plays a pivotal role. In medicine, plasma lenses are crafted to be biocompatible with human tissues, aiding in the treatment of living cell tissues [25]. In surface treatments, floating potential electrodes are preferred for applications targeting blood coagulation or wound healing, due to their ability to avoid electrocution [21][16]. Plasma technology also enhances reactor efficiency with corona discharges and has revolutionized display technology, surpassing the performance of conventional flat-screen televisions [26].

As we advance, the use of plasma in semiconductor processing has gained significant traction compared to its application in fusion research [23]. Plasma, plays a crucial role in various scientific and industrial applications due to its unique properties. In this discussion, we delve into two prominent plasma generation techniques – DC Glow Discharge and Radio Frequency Discharge and explore their applications.

A. DC Glow Discharge:

DC Glow Discharge is a non-thermal plasma generation technique [27] that involves the application of a direct current (DC) electric field between cathode and anode plates in the presence of a plasma gas. This technique relies on accelerating electrons near the cathode through the applied electric field, leading to inelastic collisions between electrons and atoms. These collisions result in ionization and excitation processes, generating ions and free electrons. The buildup of ions and electrons at the cathode creates a self-sustaining plasma glow. DC Glow Discharge finds wide applications in material processing, light sources, etching, ion deposition, and surface modification due to its ability to sustain plasma efficiently [28].

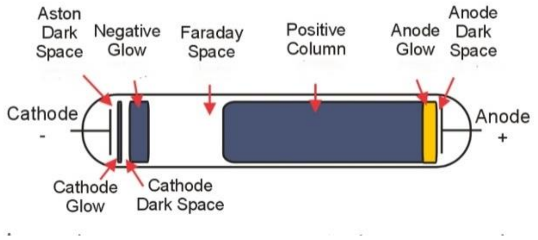

Fig. 6. Glow discharge tube.

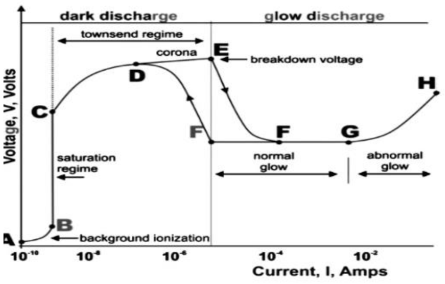

Fig. 7. Typical V/I plot of glow discharge tube

B. Radio Frequency Discharge:

Radio Frequency Discharge is another effective method for plasma generation that operates at radio frequency ranges (typically between 1 kHz to 103 MHz) [29]. This technique involves inductive or capacitive coupling of energy to create plasma. Capacitively Coupled Discharge (CCD) utilizes an alternating current (AC) voltage applied to power electrodes through a capacitor, while Inductively Coupled Discharge (ICD) employs a cylindrical helical coil to induce an electric current. RF Discharge is preferred for applications requiring lower temperature plasma, such as in aerospace and microelectronics industries.

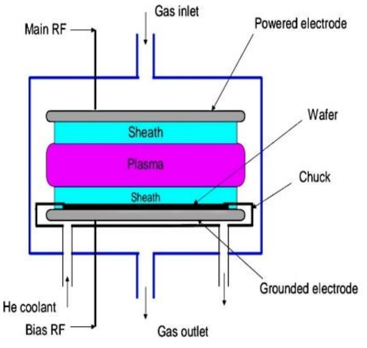

Fig. 8. CCD.

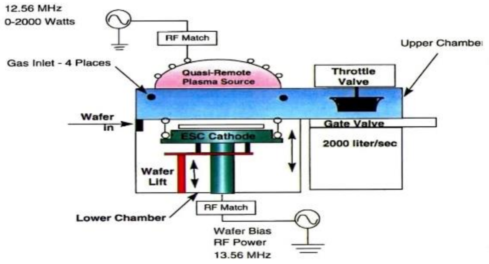

Fig. 9. ICD

C. Hydrogen Production from Alcohols:

Non-thermal plasma techniques have significant applications in hydrogen production from alcohols like methanol. Various plasma methods, including Dielectric Barrier Discharge (DBD) Plasma, corona discharge Plasma, surface-wave discharge Plasma, and Microwave Plasma[30], are employed for converting methanol to hydrogen efficiently. DBD Plasma, also known as silent plasma, features electrodes separated by a dielectric barrier, making it suitable for generating plasma for hydrogen production processes.

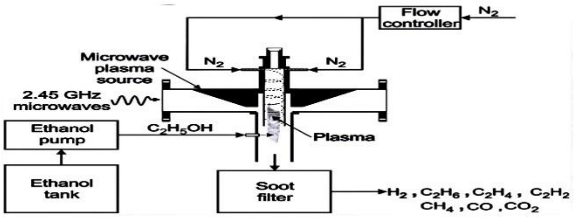

Fig. 10. Hydrogen production by Ethanol

IV. APPLICATIONS OF PLASMA ENERGY TECHNOLOGY

Pollution Treatment -

Non-thermal Plasma technology is utilized for NOX removal from diesel engines, aiding in reducing emissions [31].

Liquid Radioactive Waste Utilization

Plasma technology neutralizes liquid radioactive waste, addressing a challenging aspect of the nuclear fuel cycle [32-34].

Semiconductor Processing -

Plasma facilitates precise semiconductor manufacturing through etching processes, ensuring high-resolution chip production [23].

Ion Implantation -

Utilized in modern integrated circuit manufacturing by modifying semiconductor substrates through ion beam implantation [35].

Living Tissues Treatment -

Cold Plasma treatment [21] expands to biomedical applications, offering selective treatment for afflicted cells with minimal invasiveness.

High Energy Density Pinch Plasma -

Enables the synthesis of nanoscale materials, leveraging low-temperature Plasmas for various nanotechnology applications [36-40].

Plasma Pencil -

Low-pressure Plasma application for medical purposes like wound healing and bacterial eradication, offering precise treatment without damaging surrounding tissues [41-42].

Low Current Non-Thermal Plasmatron -

Efficiently produces hydrogen gas, offering an alternative to conventional methods with higher conversion efficiency and less heat generation [43-44].

Treatment of Prostate Cancer -

Low-temperature Atmospheric Plasma effectively targets and breaks down DNA double strands within prostate cancer cells, offering a less invasive treatment option [45-47].

Cutting by Plasma -

Plasma cutting systems have evolved to offer cost-effective solutions for cutting various materials with high precision and improved quality [48-49].

Plasma Etching -

Used in semiconductor manufacturing for precise etching processes, offering superior results in creating memory devices and chemical etches [50-51].

Surface Treatment -

Plasma-based techniques like Glow Discharge Cleaning and Plasma Immersion Ion Implantation enhance material surfaces for improved wear resistance and corrosion protection [52].

Plasma Antenna of Beam Forming -

Widely employed in communication and target directing, utilizing Plasma elements for effective radiation and electromagnetic wave manipulation [53-58].

Atmospheric Pressure Plasma Jet -

Overcomes the limitations of low-pressure plasma processes, providing efficient material processing without the need for costly vacuum systems [59-60].

Plasma Gun Techniques for Fusion at MegaGauss Energy Densities

Advanced techniques like Plasma Flow Switch enable the generation of fusion temperature Plasma for controlled fusion research [62-63].

Plasma Ion Implantation and Deposition -

Utilized for surface treatment and coating applications, offering tribological benefits and advancements in biomaterials and nanostructured thin films [64-67].

Electrothermal and Electromagnetic Plasma for Surface Treatment -

Launchers produce Plasma for direct coating purposes, enhancing material properties and resistance to corrosion and friction [68-74].

These applications demonstrate the versatility and importance of plasma technology in various industries and fields, including environmental protection, semiconductor manufacturing, and biomedical treatments

Future Aspects of Plasma Energy Technology

The trajectory of plasma energy technology is set towards a future where a profound understanding of plasma behavior under a variety of conditions takes precedence. The path to unlocking the full potential of this technology lies in rigorous fundamental studies conducted in carefully controlled environments, where the most significant progress is expected. Looking ahead, it is challenging to sketch a detailed picture of the long-term future, yet the anticipation is that plasma physics will not only expand in its criticality but also in the breadth of its applications. Despite the daunting nature of the problems faced today, the expected scientific and technological benefits justify the intense focus and resources being poured into this field.

Plasma's ubiquitous presence, from the vast expanse of the cosmos to the vital fluids of human life, underscores its significance across multiple disciplines. Its applications have already permeated various sectors, including medicine, energy, environmental science, and physics, revealing its versatility and importance. Whether it's being harnessed in medical therapies, contributing to sustainable energy solutions, or purifying our water through ozone production, plasma's role is indisputably vital.As we continue to explore and innovate, the engineering and medical fields have only begun to tap into the potential uses of plasma. The near future may see advancements in plasma particle accelerators, ion propulsion systems for spacecraft, plasma spray coatings, and more efficient methods for isotope separation, to name a few. Each development will not only elevate the importance of plasma physics but will also pave the way for new practical applications. The symbiotic relationship between engineering and plasma technology will grow stronger, with engineers playing a crucial role in translating the theoretical and experimental insights into real-world applications. The relentless pursuit of knowledge and the continuous evolution of technology together forecast a future where plasma technology becomes an integral part of our everyday lives, shaping the way we interact with the world and beyond.

V. CONCLUSION

The multifaceted and intricate field of plasma technology stands as one of the most formidable areas of modern research, holding the keys to a plethora of revolutionary applications. Despite its vast potential, the field is not without its challenges, many of which persist as open questions within the scientific community. Nevertheless, the ongoing research, fueled by a deepening understanding across disciplines such as particle and radiation physics, electronics, electromagnetic wave theory, thermodynamics, and quantum mechanics, promises to unlock these mysteries. The pursuit of plasma technology is more than a scientific endeavor; it is a quest for a deeper comprehension of the universe's origins and the fundamental forces that govern it. The potential benefits are staggering—an inexhaustible supply of energy through thermonuclear fusion, enhanced communication with spacefaring vehicles, novel propulsion systems for interplanetary journeys, high-frequency radio energy devices, mechanically-free electrical generators, and advanced semiconductor technologies.

The recent conference has spotlighted significant strides in controlled nuclear plasma fusion research, evidenced by the presentation of 150 papers that delve into magnetic and inertial confinement systems, plasma theory, and fusion reactor designs. The highlight of these findings is the experimental progress achieved with large tokamaks such as T-10 and PLT, wherein increased plasma parameters and energy confinement times align with theoretical expectations and scaling laws. The Alcator and Pulsator groups have also made considerable headway, achieving high plasma densities that have, in turn, improved the crucial product of density and confinement time (nr). The notable success of neutral injection heating in tokamaks stands as an affirmation of its efficacy.

Beyond the realm of tokamaks, the conference has brought to light the advancements in other magnetic confinement devices. Notably, devices such as the 2XII B mirror machine and various stellarator configurations have demonstrated high plasma conditions and confinement times that surpass previous limits, offering a renewed optimism for their future contributions. Theoretical support from the conference corroborates the positive experimental outcomes, with no unforeseen instabilities emerging to dampen the progress made. On the contrary, strategies to mitigate instabilities, enhance plasma performance, and manage impurities have been proposed. In this computational era, the increasing reliance on sophisticated modeling to capture non-linear effects unattainable by analytical methods underscores the pivotal role of computer simulations in advancing plasma theory.

In conclusion, the field of plasma energy technology is navigating through its complexities toward a future replete with opportunities. Through interdisciplinary collaboration and the application of both experimental and computational prowess, the path ahead is charted with promise. The research community remains optimistic, with the expectation that the continued evolution of plasma technology will not only address the current issues but also fulfill its potential as a transformative force across a wide array of scientific and technological landscapes.

REFERENCES

[1] National Academies of Sciences, Engineering, and Medicine. Final Report of the Committeeon a Strategic Plan for U.S. Burning Plasma Research (National Academies Press, 2019).

[2] Hurricane, O. A. et al. Beyond alpha-heating: driving inertially confined fusion implosions toward a burning-plasma state on the National Ignition Facility. Plasma Phys. Control. Fusion.

[3] Hurricane, O. A. et al. Approaching a burning plasma on the NIF. Phys. Plasmas 26, 052704 (2019).

[4] E. Stoffels, Y. Aranda, T. Whitmore, D. Seymour and J. Rees, "A Plasma needle generates nitric oxide," Plasma Sources Sci. Technol., 15 (2006), 501–506. DOI: 10.1088/ 0963-0252/15/3/028.

[5] Green, B. & ITER International Team and Participant Teams ITER: burning plasma physics experiment. Plasma Phys. Control. Fusion 45, 687–706 (2003).

[6] Zylstra, A. B. et al. Record energetics for an inertial fusion implosion at NIF. Phys. Rev. Lett.126, 025001 (2021) www

[7] Robey, H. F., Berzak Hopkins, L., Milovich, J. L. & Meezan, N. B. The I-Raum: a new shaped hohlraum for improved inner beam propagation in indirectly-driven ICF implosions on the National Ignition Facility. Phys. Plasmas 25, 012711 (2018).

[8] Kritcher, A. et al. Design of inertial fusion implosions reaching the burning plasma regime.Nat. Phys. (in the press).

[9] Betti, R. et al. Alpha heating and burning plasmas in inertial confinement fusion. Phys. Rev.Lett. 114, 255003 (2015)

[10] F. Chen, X. Huang, D.G Cheng, X. Zhan "Hydrogen production from alcohols and ethers via cold Plasma: A review" IJHE 39 (2014), 9036-9046

[11] H. Conrads and M. Schmidt "Plasma generation and Plasma sources". PSST 4(2000), 44-54.

[12] U Kogelschatz "Atmospheric-pressure Plasma technology" PPCF 46 (2004), 63-75.

[13] C. Tendero, C. Tixier, P. Tristant ,J. Desmaison, P. Leprince "Atmospheric-pressure Plasmas: a review" SpectrochimActa Part B Atomic Spectrosc 61(2006), 2-30.

[14] M. Laroussi, T. Akan "Arc-free atmospheric pressure cold Plasma jets: a review" Plasma Process Polymer 9 (2007), 77-88.

[15] A. Fridman, S. Nester, LA. Kennedy, A. Saveliev, O. Mutaf-Yardimci "Gliding arc gas discharge" Prog Energy Combust Sci 25(1998), 11-31.

[16] Z. Bo, JH. Yan, XD. Li, Y. Chi, KF. Cen " Scale-up analysis and development of gliding arc discharge facility for volatile

organic compounds decomposition" J Hazard Mater 155 (2008), 494-501.

[17] E. Tatarova, FM. Dias, E. Felizardo, J. Henriques, CM. Ferreira, Gordiets "Microwave Plasma torches driven by surface waves" PSST 17 (2008).

[18] Mouawad, B., Soueidan, M., Fabregue, D., Buttay, C., Allard, B., Bley, V., ... & Martin, C "Application of the spark plasma sintering technique to low-temperature copper bonding" IEEE Transactions on Components, Packaging and Manufacturing Technology, 2(2012), 553-560.

[19] E. Igenbergs. J. Sparer, M. Rott, Kh, G. Schmitt-Thomas "On the application of Plasma pulses generated by electromagnetic and electro thermal launchers for surface Treatment" Magnetics, IEEE Transactions 31(1995).

[20] X. P. Wu, J.M. Shi, Z. S. Chen, and B. Xu, "A new Plasma antenna of beam forming" Progress in Electromagnetics Research 126 (2012), 539-553.

[21] E. Hnatiuc, D. Astanei, M. Ursache, B. Hnautiuc "A Review over cold Plasma reactors and their applications" ICEPE (2012),497 – 502

[22] J. Pelletier, A. Anders, "Plasma based ion implantation and deposition: A review of physics, technology, and applications" Plasma Science, IEEE Transactions 33(2005), 1944-1959.

[23] F.F. Chen "Industrial Application of low temperature Plasma physics" AIP 6 (1995), 2164-2175

[24] O.T. Loza, A.G. Shkvarunets, and P.S. Strelkov, "Experimental Plasma relativistic microwave electronics" IEEE transactions on Plasma science, 26 (1998).

[25] Alexey A. Goncharov, Ian G. Brown "Plasma devices based on Plasma lens - A review of result and applications" IEEE 4 (2007).

[26] S. Kwak "A review of switch mode sustain drivers with resonant networks for Plasma display panels" IEEE transactions on Industrial Electronics 57(2010), 1624-1634.

[27] R.K.Y. Fu, P. K. Chu, X.B. Tian, S.Q. Yang "Ignition and dynamics of high-voltage glow discharge Plasma implantation" NIMPRB 242 (2006), 275-278

[28] L. J. Spitzer, Physics of Fully Ionized Plasmas, 2"^* ed (Wiley-Int., New York, 1962).

[29] D. Salzmann, Atomic Physics in Hot Plasma, (Oxford Univ. Press, Oxford, 1997), p 122 and F. F. Chen AVS, 2003

[30] F. Chen, X. Huang, D.G Cheng, X. Zhan "Hydrogen production from alcohols and ethers via cold Plasma: A review" IJHE 39 (2014), 9036-9046

[31] P. Talebizadeh, M. Babaie, R. Brown, H. Rahimzadeh, Z. Ristovski, M. Arai "The Role of non-thermalPlasma technique in NOX treatment: A review" RSER 40 (2014), 886-901

[32] Alex.Karengin, Olga Shakhmatov, Alek. Karengin, N. Novikov "Plasma utilization of liquid radioactive waste" IEEE (2013), 1 – 4.

[33] R. Rahman, H. Ibrahium, and Y. Hung, "Liquid radioactive wastes treatment: a review", Water, 3 (2011), 551-565.

[34] J. McLeanA, J. Becker, S. Boulyga, H. Dietze and A. Montaser, "Ultratrace and isotopic analysis of long-lived radionuclides by double-focusing sector field inductively coupled Plasma mass spectrometry using direct liquid sample introduction", International Journal of Mass Spectrometry, 208(2011), 193-204.

[35] L. Rubin, and J. Poate, "Ion implantation in silicon technology", Industrial Physicist, 9(2003), 12-15.

[36] M. C. Roco, C. A. Mirkin, and M. C. Hersam, "Nanotechnology research directions for societal needs in2020: Summary of international study" J. Nano particle Res 13, (2011), 897–919.

[37] K. Ostrikov "Plasma nanoscience: Basic concepts and applications of deterministic nano fabrication" Weinheim, Germany:Wiley-VCH (2008).

[38] K. Ostrikov, U. Cvelbar, and A. B. Murphy, "Plasma nanoscience: setting directions, tackling grand challenges" J. Phys. D, Appl. Phys. 44(2011), 174.

[39] M. Meyyappan, "Plasma nanotechnology: Past, present and future" J.Phys. D, Appl. Phys. 44 (2011), 174.

[40] M. Shiratani, K. Koga, S. Iwashita, G. Uchida, N. Itagaki, and K. Kamataki "Nano factories in Plasma: Present status and outlook" J. Phys. D, Appl. Phys. 44 (2011)

[41] M. Stein, E. Lo, D. Castner and B.Ratner, "Plasma pencil atmospheric mass spectrometry detection of positive ions from micronutrients emitted from surfaces", Analytical chemistry, 84(2012), 1572-1578.

[42] J. Janča, L/ Zajíčková, M. Klíma and P. Slavíček, "Diagnostics and application of the high frequency Plasma pencil", Plasma chemistry and Plasma processing, 21(2001), 565-579.

[43] L. Bromberg, D. Cohn, A. Rabinovich and J. Heywood, "Emissions reductions using hydrogen from Plasmatron fuel converters", International Journal of Hydrogen Energy, 26(2001), 1115-1121.

[44] D. Cohn, J. Bromberg, A. Rabinovich and N. Alexeev, "U.S. Patent No. 6,322,757. Washington, DC: U.S. Patent and Trademark Office", (2001).

[45] Giovannucci, E., Ascherio, A., Rimm, E. B., Stampfer, M. J., Colditz, G. A., & Willett, W. C. (1995). Intake of carotenoids and retino in relation to risk of prostate cancer. Journal of the national cancerinstitute, 87(23), 1767-1776.

[46] A. Roddam, M. Duffy, F. Hamdy, A. Ward, J. Patnick and C. Price, NHS Prostate Cancer Risk Management Programme, "Use of prostate-specific antigen (PSA) isoforms for the detection of prostate cancer in men with a PSA level of 2–10 ng/ml: systematic review and meta-analysis", European urology, 48(2005), 386-399.

[47] P. Gann, J. Ma, E. Giovannucci, W. Willett, F. Sacks, C. Hennekens and M. Stampfer," Lower prostate cancer risk in men with elevated Plasma lycopene levels results of a prospective analysis", Cancer research, 59(1999), 1225-1230.

[48] F. Samuel, "U.S. Patent No. 3,567,898", Washington, DC: U.S. Patent and Trademark Office, (1971).

[49] E. Couch Jr, N. Sanders, Z. Lu, L. Luo, L. and S. Stenfelt," U.S. Patent No. 5,380,976. Washington, DC: U.S. Patent and Trademark Office", (1995).

[50] U. Valbusa, C. Boragno and F. de Mongeot, "Nanostructuring surfaces by ion sputtering. Journal of Physics: Condensed Matter", 14 (2002), 8153.

[51] Elsherbeni, A. Z. and A. A. Kishk "Modeling of cylindrical objects by circular dielectric and conducting cylinders" IEEE Trans. Antennas Propag. 40 (1992), 96– 99.

[52] D. Flamm and O. Auciello, "Plasma deposition, treatment, and etching of polymers: the treatment and etching of polymers", R. d'Agostino (Ed.). Elsevier, (2012).

[53] Dwyer, T. J., J. R. Greig, D. P. Murphy, J. M. Perina, and R. E. Pechacek "On the feasibility of using an atmospheric

dischargePlasma as an RF antenna" IEEE Trans. Antennas Propag. 32(1984), 141–146.

[54] Brog, G. G., J. H. Harris, D. G. Miljak, and N. M. Martin, "Application of Plasma columns to radiofrequency antennas" Appl. Phys. Lett. 74 (1999), 3272–3274.

[55] J.Mathew, R. A. Meger, R. F. Fernsler, D. P. Murphy, R.E. Pechacek, and W. M. Manheimer, "Electronically steerable Plasma mirror based radar antenna" 10th International Conference on Antenna and Propagation, 436 (1997), 1469–1473.

[56] Cheng, Z. F., "Design and research on Plasma microwave reflector," Center for Space Science and Applied Research, (2010).

[57] Elsherbeni, A. Z. and A. A. Kishk "Modeling of cylindrical objects by circular dielectric and conducting cylinders" IEEE Trans. Antennas Propag. 40 (1992), 96– 99.

[58] P. Fauchais and A. Vardelle "Thermal Plasmas" IEEE Trans. Plasma Sci. 25 (1997), 1258–1280.

[59] M. Goldman and R. S. Sigmond "Corona and insulation" IEEE Trans. Elect. Insulation, 17 (1982),90–105.

[60] B. Eliasson and U. Kogelschatz, "Non-equilibrium volume Plasma chemical processing" IEEE Trans. Plasma Sci. 19 (1991), 1063–1077.

[61] J. Y. Jeong, S. E. Babayan, V. J. Tu, J. Park, R. F. Hicks, and G. S. Selwyn "Etching materials with an atmospheric-pressure Plasma jet" Plasma Source Sci. Technol. 7(1998), 282–285.

[62] D. R. Wells and G. Schmidt "Observation of Plasma rotation produced by an electrodeless Plasma gun" Phys. Fluids, 6 (1963), 418–421.

[63] P. J. Turchi, M. L. Alme, G. Bird, C. N. Boyer, S. K. Coffey, D. Conte, J. F. Davis, and S. W. Seiler "Review of Plasma flow switch development" IEEE Trans. Plasma S ci.15 (1987), 747–759.

[64] I. G. Brown, Ed. "The Physics and Technology of Ion Sources", (1989)

[65] B. Wolf, "Handbook of Ion Sources". Boca Raton, FL: CRC, (1995).

[66] Y. Carmel, W. R. Lou, T. M. Antonsen, J. Rodgers, B.Levush, W. W. Destler, and V. L. Granatstein "Studies of high power Plasma filled backward wave oscillators" Phys. Fluids B, 4 (1992), 2286–2292.

[67] A. G. Shkvarunets, S. Kobayashi, J. Weaver, Y. Carmel, J. Rodgers, T. M. Antonsen, Jr., V. L. Granatstein, and W.W. Destler "Electromagnetic properties of corrugated and smooth waveguides filled with radially inhomogeneous Plasma".

[68] E.B. Igenbergs, D.W. Jex, E.L. Shriver "New two stage accelerator for hypervelocity impact simulation", AIM Journal 13.

[69] 64 E.B. Igenbergs, D.W. Jex, E.L. Shriver "New two stage accelerator for hypervelocity impact simulation", AIM Journal 13.

[70] I. G. Brown, Ed."The Physics and Technology of Ion Sources". New York: Wiley (1989).

[71] B. Wolf,"Handbook of Ion Sources"Boca Raton, FL: CRC, (1995)

[72] S. Rosanvallon, C. Grisolia, G. Counsell, S. H. Hong, Onofri, J. Worms,J. Winter, B. Annaratone, G. Maddaluno, and P. Gasior, "Dust controlintokamak environment," 8th Int. Symp. Fusion Nucl.Technol (2007), 1–5.

[73] S. Benkadda and V. N. Tsytovich, "Excitation of dissipative drift turbulence in dustyPlasmas," Plasma Phys. Rep 28 (2002), 395–397.

[74] S. I. Krasheninnikov and T. K. Soboleva, "Dynamics and transport of dust particles in tokamak edge Plasmas," Plasma Phys. Control. Fusion 47(2005), 339–352. C. Y. Lin, M