Review

State of the Art Synthesis of Ag-ZnO-Based Nanomaterials by Novel Atmospheric Pressure Microplasma Techniques

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Posted Date: 29 July 2024

doi: 10.20944/preprints202407.2283.v1

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State of the Art Synthesis of Ag-ZnO-Based Nanomaterials by Novel Atmospheric Pressure Microplasma Techniques

Ayesha Khalid [1], M. Naeem [1,*], Omar Atrooz [2], M. R. Mozafari [3,*], Fatemeh Anari [3], Elham Taghavi [4], Umair Rashid [5] and Bushra Aziz [1]

[1] Department of Physics, Women University of Azad Jammu and Kashmir Bagh, Pakistan; mnaeem@wuajk.edu.pk
[2] Department of Medical Laboratory Sciences, Faculty of Applied Medical Sciences, Al-Ahliyya Amman University, Amman 19328, Jordan; and: Department of Biological Sciences, Mutah University. Mutah, Jordan.
[3] Australasian Nanoscience and Nanotechnology Initiative (ANNI), Monash University LPO, Clayton, Victoria3800, Australia. dr.m.r.mozafari@gmail.com
[4] Faculty of Fisheries and Food Science, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.
[5] Department of Materials Science and Engineering, Beijing Institute of Technology, China.
* Correspondence: dr.m.r.mozafari@gmail.com (M.R.M.); mnaeem@wuajk.edu.pk (M.N.).

Abstract: Atmospheric pressure Microplasma is a simple, cost-effective, efficient, and eco-friendly procedure, which is superior to the traditional nanomaterials synthesis techniques. It generates high yields and allows for a controlled growth rate and morphology of nanomaterials. The silver (Ag) nanomaterials, with their unique physical and chemical properties, exhibit outstanding antibacterial and anti-fungal properties. Similarly, zinc oxide (ZnO) nanomaterials, known for their low toxicity and relatively lower cost, find wide applications in wound repair, bone healing, and antibacterial and anticancer applications. The use of core-shell nanomaterials in certain situations where some nanoparticles can cause serious harm to host tissues or organs is a testament to their potential. A benign material is coated over the core to reduce toxicity in these cases. This review compares the numerous configurations of microplasma systems used for synthesizing nanomaterials and their use in producing Ag, ZnO, and their core-shell (Ag-ZnO) nanomaterials for biomedical applications. The summary also includes the effect of control parameters, including cathode diameter, gas flow rate, precursor concentration, voltage, and current, on the nanomaterial's characteristics and applications. In addition, it provides a research gap in the synthesis of Ag, ZnO, and core shall nanomaterials by this technique, as well as the development and limitations of this technique and the use of these nanoparticles for biomedical applications.

Keywords: Atmospheric microplasma technique; core shall nanoparticles; antibacterial activity; antifungal activity; silver nanoparticles

1. Introduction

Nanotechnology, one of the most promising technologies of the 21st century, can potentially convert nanoscience theory into beneficial applications. It enables us to observe, compute, handle, collect, monitor, and develop matter at the nanometer scales [1–3]. It is an emerging technology in many fields, such as electronics, gas sensors, catalyst, and biomedical applications. Nanomaterials, with their widespread applications in biomedical fields such as drug delivery, cancer treatment, immunotherapy, etc., are revolutionizing healthcare [4–6]. Nanoparticles are also applied to diagnostic instruments, pharmaceutical products, targeted medicinal products, and imagery and methodologies. Their high surface-area-to-volume ratio allows for maximum absorbance of medicine and quick movement in the bloodstream [7]. Owing to their excellent biocompatibility and

 doi:10.20944/preprints202407.2283.v1

biodegradability, nanoparticles can accumulate in defective organs with the most minor side effects. Furthermore, nanoparticles can be slowly released, reducing drug concentration and toxic side effects [8]. Diseases like cancer can be cured if they are detected at an early stage. Still, traditional diagnostic techniques cannot detect these tumors and cancers, and they cannot differentiate between malignant and benign lesions [9]. On the other hand, nanoparticle imaging can yield more appropriate and selective imaging of damaged and diseased tissues [10]. The nanoparticles are extensively applied to deliver chemotherapy drugs to the tumor cells, which reduces the toxicity of healthy tissues [11].

Zinc oxide (ZnO) nanoparticles are among the most common metal oxide nanoparticles, having distinctive chemical and physical properties that make them suitable for use in many fields as summarized in Figure 1 [12]. They are widely used in self-care products such as skincare, sunscreen, and cosmetics due to their beneficial properties against UV absorption [11,13]. They are also used in the textile industry; they are added to the fabric and have attractive features of visible light resistance and deodorant [14,15]. ZnO nanoparticles reveal brilliant biomedical applications such as wound healing, drug delivery, diabetes treatment, bio-imaging, anti-bacterial, anti-inflammation, and anticancer. They are less toxic and relatively cheaper than metal oxide nanoparticles [12,16]. In modern eras, immunotherapy is another approach to combat various diseases by providing immune molecules (antibodies and antigens) [17]. ZnO nanoparticles have received the utmost consideration owing to their high biocompatibility with human cells [18–20]. ZnO nanoparticles can hinder viral entrance, reproduction, and spreading all over the organ, which causes viral death because of stimulating reactive oxygen species, which results in oxidative stress [18,21].

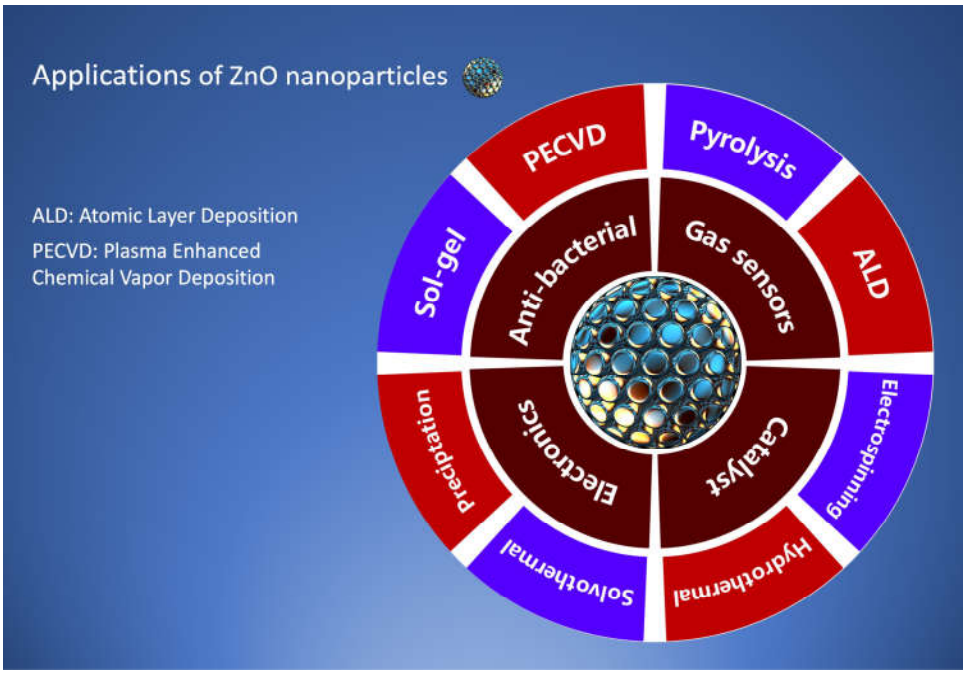

Figure 1. Applications of Zinc Oxide nanoparticles in diverse fields and conventional synthesis techniques.

Over the years, silver (Ag) nanoparticles have earned significant attention because of their exceptional electrical, optical, and antimicrobial properties [22]. It is commonly known that silver nanoparticles have remarkable antibacterial ability and admirable physical properties, which make them useful for applications in water purificants and disinfection of medical devices [23,24]. Due to their tiny size, they acquire a large surface area, providing a high surface energy and further probable reactive locations [25]. They have low volatility and high thermal stability and are less toxic to human cells [26,27]. They are used in medicine for treating burns, dental tools, and coated stainless steel materials [28,29]. In addition, they are utilized in various applications in textile fabrics, water treatment, and sunscreen lotion [30–32]. More importantly, Ag nanoparticles have the potential to be

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used for treating diseases that demand the maintained concentration of circulating drugs or the targeting of particular cells or organs [33,34].

Furthermore, the core-shell nanoparticles also earned much importance because of their great biological stability and good performance [9,35–38]. Core-shell nanoparticles, including noble metal semiconductors, are the most interesting materials for biomedical applications [38–41]. Ag-ZnO core-shell nanoparticles have strong anti-bacterial and antifungal properties [42,43]. Core-shell nanoparticles consist of a material core covered in a layer of another material [44]. Compared to simple nanoparticles, core shells offer significant advantages in biological applications, including improved properties like reduced cytotoxicity, increased dispersibility, biocompatibility, improved conjugation with other bioactive molecules, and enhanced thermal and chemical stability [44]. More specifically, if the desired nanoparticles are toxic, they can cause serious harm to the host tissues and organs. Then, the benign material can be coated over the core to reduce its toxicity. Sometimes, the shell layer enhances core materials' properties and is non-toxic [45]. There are two main approaches for nano-synthesis: bottom-up and top-down [46]. The Microplasma technique is a bottom-up technique with advantages over other techniques, such as its short processing time, environment-friendly nature, and low cost. It also has more benefits like small size, non-toxicity, control of growth, and flexibility, making it suitable for nanosynthesis [47–49].

2. Atmospheric Pressure Microplasma for Nanosynthesis

2.1. Background

In the past few years, research about nano-size particles has earned great attention because nanoparticles have distinct and unique properties compared to bulk materials due to their high surface-to-volume ratio [50]. The main task during nanoparticle synthesis is to control the shape, size, and stability of nanoparticles because these characteristics greatly influence their properties [51]. This control can be attained by varying the conditions of reactions, such as the concentration of precursors, the stabilizer, and the reducing agents [50]. Various synthesis techniques have been investigated for the synthesis of nanoparticles, such as laser ablation [52], electrochemical [53], microwave-assisted synthesis [54], and chemical reduction [50]. These processes require several hours for nanomaterials synthesis, so these techniques are time-consuming and expensive [55]. Plasma discharges with diverse arrangements are among the leading and eco-friendly techniques for nanoparticle synthesis. In particular, atmospheric pressure plasma systems are an essential technique, as they are cheap and simple and require no costly vacuum pumps and systems.

2.2. Synthesis of Nanomaterials

In recent years, various Microplasma systems have been used for nanosynthesis, as shown in Figure 2. These systems illustrate the versatility and flexibility of Microplasma's processing conditions. Here, we classify the system into four categories based on electrode geometry, way of injecting precursors, power coupling method, and plasma power source, as described in the following sub-sections [49–51].

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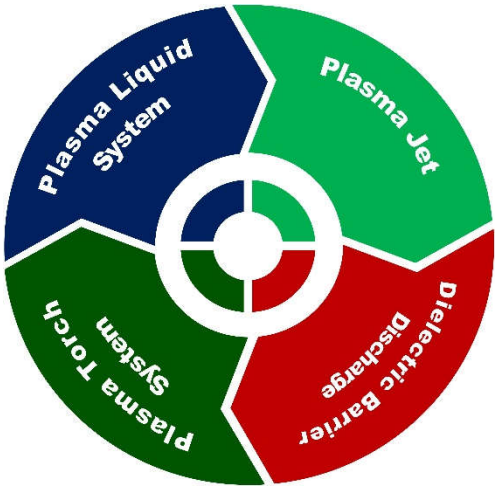

Figure 2. Atmospheric pressure plasma-based approaches for nano synthesis.

2.2.1. Plasma Jet System

The atmospheric pressure plasma jet system synthesizes nanoparticles by generating inert gas plasma. Habib et al. [55] demonstrated the synthesis of silver nanoparticles by atmospheric pressure plasma jet using silver nitrate as a precursor and trisodium citrate dihydrate. The Microplasma jet system is shown in Figure 3, which consists of a gas flow system and power supply. A high-voltage electrode was coiled around the asymmetric source and was composed of a tube with 3.77 mm. This system has a large reservoir with a diameter of 38.2 mm, connected to a ground electrode. The support was connected to another ground electrode. The discharge was generated by high voltage. The working gas used in this system was helium, and 8A current and 25kHz frequency were applied. The surface of the liquid and plasma jet was kept at a distance of 7 mm. The samples were exposed to plasma for 5 minutes.

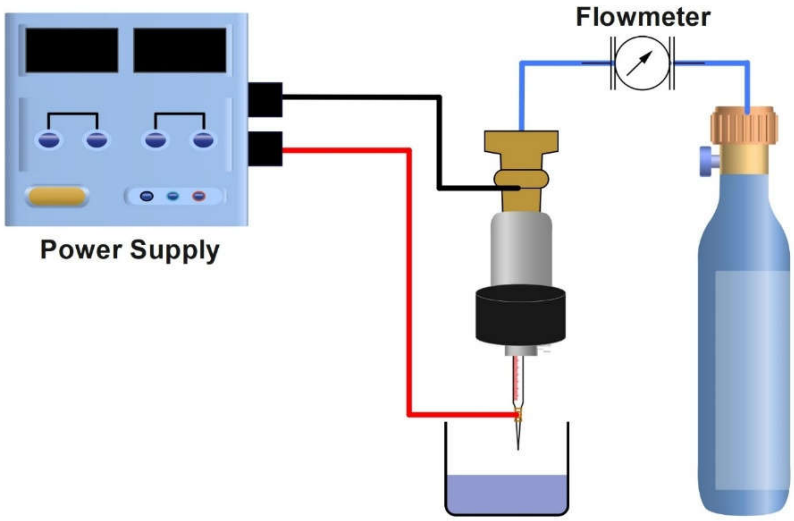

Figure 3. Schematic diagram of atmospheric pressure plasma jet system for nanomaterials synthesis (redrawn from Reference [55]).

In addition, plasma jets have various configurations, such as hollow electrode micro discharge [56], Microplasma jets with external electrodes [57], and Microplasma jets having consumable electrodes [58].

2.2.2. Dielectric Barrier Discharge

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The synthesis of silver nanoparticles by atmospheric pressure dielectric barrier discharge was demonstrated by Janith and co-workers [59], and the schematic diagram of the process is shown in Figure 4. The reactor is a quartz-based cylindrical structure. The sodium citrate solution (34 mM) and aqueous silver nitrate were mixed to prepare a solution of silver precursor. The precursor solution could be injected into the hollow central part of the plasma reactor, which could be sealed by a quartz lid. The central part was linked with the outlet and gas feeding line. The chamber has a total volume of 25 mL; the precursor solution used in this experiment was 4 mL. The bottom and lid of the quartz chamber acted as a dielectric barrier. The dielectric barriers were at a distance of 8 mm from each other. The power supply of 2000 K was used to apply high voltage to the stainless-steel electrodes. The frequency and power supply were 9.1 kHz and 39 kV respectively [59].

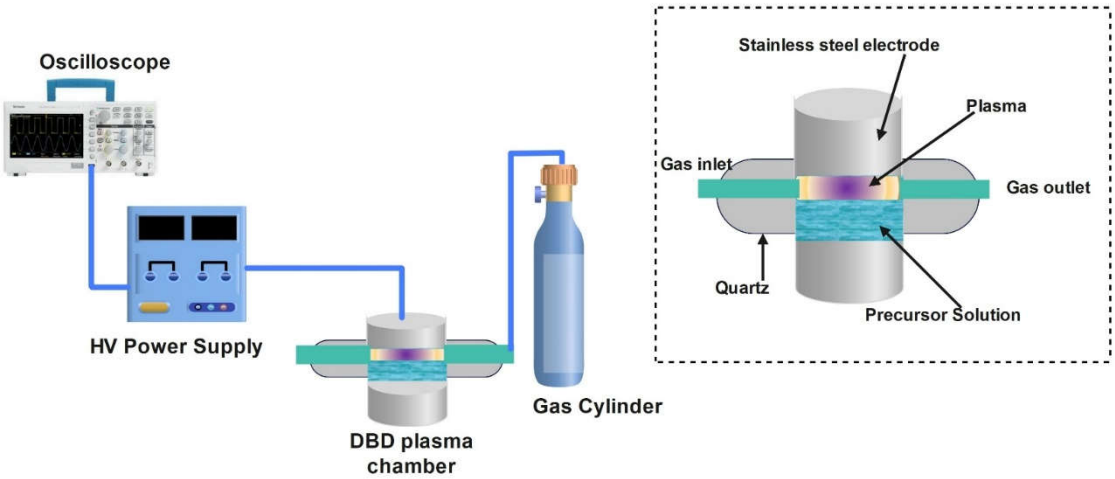

Figure 4. Schematic diagram of atmospheric dielectric barrier discharge for nanomaterials synthesis (redrawn from Reference [59]).

2.2.3. Plasma Torch Method

Another technique for nanomaterials synthesis is the atmospheric plasma torch method. Bjelajac et al. [60] reported the synthesis of Au nanomaterials by the atmospheric pressure plasma torch method. Tetra chloroauric acid trihydrate dissolved in ethanol or water was used as a precursor. The atmospheric pressure plasma torch consists of two hollow quartz tubes. The plasma was generated between the outer plasma tube (7mm inner diameter and 9mm outer diameter) and the inner tube (4mm inner diameter and 6mm outer diameter). The inner tube was grounded, and its outer surface was coated with a thick Pt film of 300 nm. Physical vapor deposition was used to deposit Pt film. The aluminum foil 5cm long covered the external quartz tube, and the aluminum foil was connected to the high voltage (H.V) generator. The plasma was produced in the space between the two tubes by applying sinusoidal high voltage to the external electrodes. The internal hollow electrode carried the nebulized gold precursor solution close to the discharge. The schematic diagram of the plasma torch setup is given in Figure 5.

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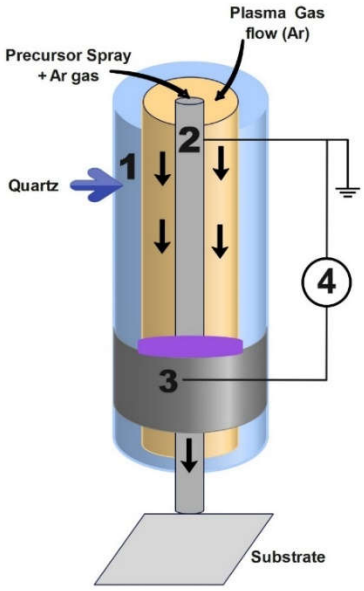

Figure 5. Schematic diagram of atmospheric pressure plasma torch method for nanomaterials synthesis (redrawn from Reference [60]).

2.2.4. Plasma-Liquid System

A plasma liquid system is extensively used for nanomaterial synthesis and is also called an atmospheric pressure Microplasma or Microplasma electrochemical synthesis, as shown in Figure 6. Ming and colleagues [61] reported the synthesis of cuprous oxide nanoparticles by microplasma electrochemical synthesis. It consisted of a stainless-steel tube (0.7 mm inside diameter, 8 cm length) placed 3 cm away from the copper electrode. A 2 mm space was maintained between the liquid surface and the capillary tube end. The argon gas flow was connected to the tube, and the glass rotameter was used to control the flow rate at 60 ml/min. The discharge was ignited by applying a high voltage, keeping the current constant. The precursors used in this synthesis were NaOH, NaCl, and $NaNO_3$ with H_2O ethylene glycol or DI water as solvents. The plasma was generated at the interface of the gas solution. A Ballast resistor stabilized the current and voltage. A magnetic stirrer was used to stir the solution gently to avoid agglomeration. The sediments collected were washed and centrifuged many times.

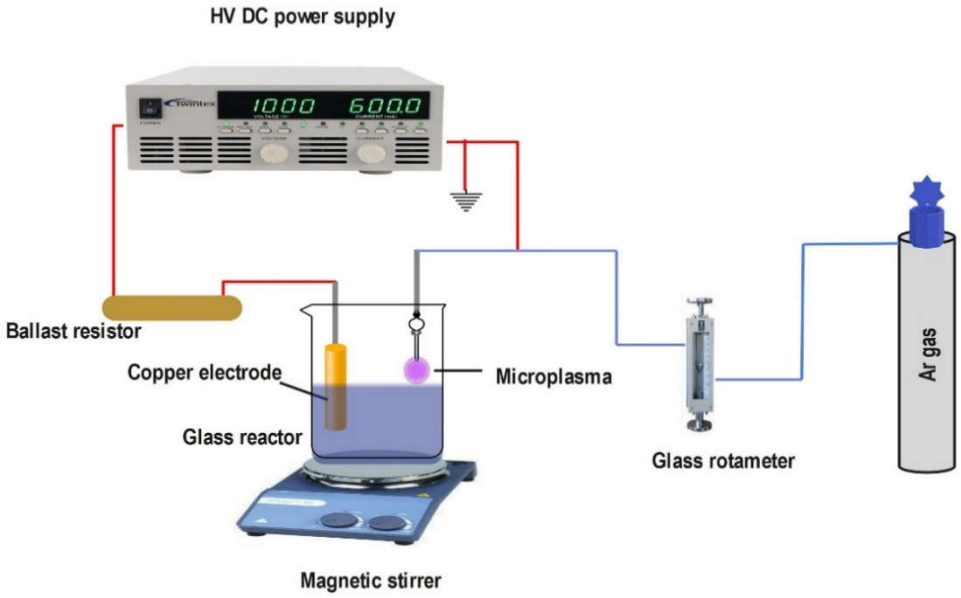

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Figure 6. Schematic diagram of atmospheric pressure plasma method for nanomaterials synthesis (redrawn from Reference [61]).

3. Literature Review

Thong and colleagues [62] synthesized silver nanoparticles using a D.C. helium Microplasma jet and examined the stabilizing effect of sucrose at various molar concentrations added to the $AgNO_3$ solution. In this setup, the gap between the surface of the solution and the capillary was kept small to lower the voltage required to cause the Microplasma to ignite. Bisht et al. [63] reported the synthesis of silver nanoparticles using atmospheric pressure microplasma. Silver nitrate solution in DI water was used as a precursor. In order to avoid agglomeration, sucrose was used as a stabilizing agent. They synthesized silver nanoparticles with uniform radii ranging from 7-13nm. The Microplasma caused the reduction and nucleation of aqueous metal ions into nanoparticles without using any chemical reducing agents. The obtained nanoparticles were analyzed by dynamic light scattering (DLS), SEM, and UV visible absorption. Kondeti et al. [64] described the surfactant-free synthesis of silver nanoparticles using Argon and Ar +0.64% H_2 plasma. A sinusoidal voltage wave modulated at 20 kHz with a 20% duty cycle and 13.4 MHz radio frequency to generate the plasma. It was observed that Ar+0.64%H_2 synthesized nanoparticles of small size with a maximum 2-3nm diameter, whereas Ar gas plasma synthesized nanoparticles of broad size distribution. Shepida et al. [65] demonstrated the formation of silver nanoparticles in a solution of $AgNO_3$ and sodium polyacrylate, a non-toxic surfactant. This setup used tungsten wire as a cathode, and the voltage was kept constant at 250V. The silver nanoparticles in the range 2-20 nm were formed at a concentration of 0.05- 0.2mMol L^{-1} of $AgNO_3$ with 0.5 gL^{-1} of NaPA. The synthesized silver nanoparticles had established antimicrobial activity against staphylococcus aureus, Escherichia coli, and candida albicans. Huang et al. [66] declared the synthesis of silver nanoparticles by plasma-assisted electrochemical technique. They demonstrated that the interparticle spacing and the size of nanoparticles in the solution could be adjusted by altering the synthesis parameters so that the plasmonic response could be tuned. It was evident that larger-sized, highly dispersive silver nanoparticles were produced at higher solution concentrations and higher temperatures. Additionally, they revealed that silver nanoparticle synthesis can be accomplished without using a stabilizer, allowing control of nanoparticles dispersion. Shuaib et al. [67] synthesized AgNPs using the Microplasma technique. They investigated the role of variation in the molar concentration of fructose on the size of nanoparticles. They concluded that AgNPs with better efficiency against fungi and bacteria can be obtained by using 2mM fructose sample, due to the production of Ag^+ ions. Lin et al. [68] demonstrated the combination of Gemini surfactant with AgNPs to attain a stable nano-surfactant system with strong anti-bacterial activities. Plasma-aided technique prepared high-quality crystalline nanostructures, where electrons acted as reductants, replacing conventional chemical reducing agents. The surfactants stabilized the silver nanoparticles by preventing AgNPs from aggregating. Antibacterial studies were conducted against S. aureus and E. coli, demonstrating the synergetic effects of the compounding systems [69]. Habib et al. [55] reported the silver nanoparticle synthesis in a quick and environment-friendly way using an atmospheric pressure plasma jet. They examined the role of variations in $AgNo_3$ (precursor) and citrate concentration and determined the optimal conditions for synthesizing silver nanoparticles. They found their effective applications in the bio-medical field (antibacterial activities), photonic, and catalytic activities. Saleem et al. [70] demonstrated that by changing the type or concentration of capping agents in optimized Microplasma parameters, the size of AgNPs could be modified, and therefore, it influenced the stability of AgNPs. The results from DLS indicated that Polyvinyl Alcohol (PVA) capped AgNPs were the most stable over 15 days compared to Polyvinyl Pyrrolidone PVP capping agents and sucrose. The AgNP's size variations were within the range of less than 5nm limit. They suggested that these stability results had practical applications in cancer therapy. Skiba et al. [71] examined the catalytic effect of silver nanoparticles synthesized by a non-equilibrium low-temperature plasma technique. The characteristics and formation of nanoparticles were analyzed by DLS, ultraviolet-visible spectroscopy, and scanning electron microscopy. Then, silver nanoparticles were effectively

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used in the catalytic reduction of 4-NP, and they demonstrated outstanding catalytic performance with a quick reaction time. Iqbal et al. [72] reported that the atmospheric Microplasma approach was successfully employed to generate two- dimensional stumbled silver nanosheets. SEM analysis was used to verify the surface morphology of the synthesized nanosheets, and it showed that their lateral dimensions increased as the precursor concentration increased. The antibacterial activity of silver nanosheets was found to be highly effective against various types of bacteria and to be correlated with the size of nanosheets.

Iqbal and co-workers [73] reported the synthesis of ZnO nanostructure using different ionic surfactants and non-ionic fructose using the Microplasma technique. This study investigated the modification in the surface of hexagonal ZnO with surfactants. The structural study demonstrated the crystalline structure with a hexagonal phase of synthesized ZnO nanostructures. Significant antibacterial activity against the tested pathogens was found in the antibacterial study. Schwan et al. [74] successfully synthesized morphology-controlled ZnO nanoparticles using zinc powder and oxygen with an atmospheric pressure plasma jet. It was discovered that the rate of oxygen in carrier gas and plasma, the energy within the reactor, and the discharge current all affected the particle's morphology. Jain et al. [75] described the synthesis and deposition of ZnO nanocrystalline materials by atmospheric pressure plasma synthesis. Radiofrequency power generated plasma and the precursor was metallic zinc wire. The aggregation of synthesized nanostructures formed a porous film at the substrate. The synthesized nanostructures were thoroughly studied and characterized by UV-visible absorption, transmission electron microscopy, and X-ray diffraction. Abdullah et al. [76] demonstrated the capability of atmospheric pressure plasma jets to prepare high-purity, nanometer-sized ZnO in the gas or liquid phase. The obtained ZnO nanocrystals were characterized by transmission electron microscopy, Fourier transformation infrared (FTIR), and X-ray powder diffraction. The findings revealed that electrolytic media, current density, and reaction temperature influenced the morphology of ZnO nanocrystals.

Rawi and co-workers [42] reported the synthesis of core-shell nanoparticles of Ag-ZnO by an atmospheric pressure plasma jet technique and described their antibacterial and antifungal properties. The characterization of these Ag-ZnO core-shell nanoparticles was done by different techniques such as ultraviolet-visible spectroscopy (UV-vis), transmission electron microscopy (TEM), XRD, energy dispersive X-ray spectroscopy (EDX), and field emission scanning electron microscopy (FE-SEM). The pureness of synthesized Ag-ZnO core-shell N.P.s was proved by XRD and EDX analysis. The antibacterial activity of these core-shell nanoparticles was evaluated on two different types of gram-positive (Staphylococcus aureus and Staphylococcus epidermidis) and gram-negative bacteria (pneumonia and Escherichia coli). Furthermore, the antifungal activity of these core-shell N.P.s was evaluated against two distinct types of yeast. Khalid et al. [77] observed the formation of gold-silver core-shell nanoparticles using cold atmospheric pressure Microplasma. They revealed that the precursor concentration affected the average size of particles; the average size of particles increased with the increase in concentration. The review of plasma configuration and their use for synthesis of silver, zinc-oxide and core-shall nanoparticles is also summarized in Table 1.

Table 1. A literature review of atmospheric plasma configurations for synthesizing silver, zinc oxide, and silver-zinc oxide core-shell nanomaterial.

No.	Plasma Configuration	Nanomaterials	Applications	Capillary Diameter	Precursor	Gas Flow Rate	Voltage & Current	Ref.
01	Atmospheric Pressure Microplasma jet	Silver	Optoelectronics, sensing, biomedical applications	Internal diameter 0.26mm	$AgNO_3$ + sucrose	26sccm	2mA	[62]
02	Atmospheric Pressure Microplasma	Silver	Nanosensors	Internal diameter 0.7mm	$AgNO_3$ + sucrose	25sccm	0-15kV	[63]

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03	R.F. atmospheric pressure Microplasma jet	Silver	Photovoltaic	Internal diameter 5.25mm	$AgNO_3$	1.5slm		[64]
04	Microplasma Synthesis	Silver	Antibacterial activity	Internal diameter 0.1mm	$AgNO_3$+ NaPA		250V	[65]
05	Atmospheric Microplasma electrochemistry	Silver	Plasmonic applications as sensing	Internal diameter 0.175mm	$AgNO_3$ + fructose	25sccm	3mA and 2kV	[66]
06	Plasma liquid synthesis	Silver	Anti-bacterial and antifungal activities	Internal diameter 0.34mm	$AgNO_3$ + fructose	100 sccm	15mA and 600V	[67]
07	Plasma-aided green and controllable synthesis	Silver	Antibacterial activity	Internal diameter 0.5 mm	$AgNO_3$ + Acetone	30 sccm		[68]
08	Atmospheric pressure Plasma jet	Silver	Bioactivity, catalysis	Internal diameter 3.7mm	$AgNO_3$+ trisodium citrate	3 L/min	8A	[55]
09	Microplasma assisted synthesis	Silver	Cancer therapy	Internal diameter < 1mm	$AgNO_3$+ PVA, PVP & sucrclose	600 sccm	3-5 kV	[70]
10	Atmospheric discharge plasma	Silver	Catalytic properties	Internal diameter 2.4mm	$AgNO_3$+ AlgNa		500-1000V	[71]
11	Atmospheric pressure Microplasma	Silver	Anti-bacterial activity	Internal diameter 0.2 mm	$AgNO_3$ + fructose	150 sccm	1000V	[72]
12	Atmospheric pressure Microplasma electrochemical process	Zinc oxide	Antibacterial applications	Internal diameter 0.2 mm	$Zn(NO_3)_2$ + surfactant	150 sccm	1000V	[73]
13	Atmospheric pressure plasma jet technique	Zinc oxide	Piezoelectric sensors		Zinc powder	10L/min	200-400A	[74]
14	Atmospheric pressure plasma (R.F. Power)	Zinc oxide	Light-emitting diodes	Internal diameter 0.7mm	Zinc wire	150 sccm		[75]
15	Atmospheric pressure plasma jet	Zinc oxide	Solar cells, Gas sensors	Internal diameter 0.6mm	Zinc anode + NaOH+ HNO_3+ sucrose	60ml/min	3kV 5-10 mA	[76]
16	Atmospheric pressure Microplasma Jet	Ag-ZnO core shells	Antimicrobial activity		$AgNO_3$ + $Zn(NO_3)_2$		13kV	[42]
17	Atmospheric pressure Microplasma	Au-Ag core shells	Optical and biological properties	Internal diameter 1mm	$AgNO_3$ + $HAuCl_4.3H_2O$	2 l/min	10kV	[77]

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4. Summary of Review

Some important factors influencing nanoparticle size, morphology, and properties are discussed here and are summarized in Table 2. In nanoparticle synthesis, solution/ precursor concentration affects nanoparticles' size and anti-microbial properties. Early studies revealed that increasing precursor concentration enhanced nanoparticles' size and anti-microbial properties. Another factor that is significantly important in nanoparticle size and morphology is processing time. The increase in processing time (5-45 mins) causes an increase in the size of nanoparticles and improves the crystallinity of nanoparticles. The concentration of the stabilizing agent or surfactants added to the precursor to avoid agglomeration is important. (Usually, fructose and sucrose are used as stabilizers in the synthesis of nanoparticles. The increase in concentration or molar ratio of surfactants or stabilizing agents increases the average size of nanoparticles. The gas flow rate also affects nanoparticle size; when the flow rate rises, the nanoparticle size decreases. All these factors are of great importance in nanoparticle synthesis of silver and zinc oxide, as they affect the structural properties and their biomedical applications. By altering these factors, the properties of nanoparticles can be varied.

Table 2. Summary of influence of control parameters on the properties of silver, zinc oxide, and core-shell nanoparticles.

Material	Control parameters	Effect of Parameters	Ref.
Silver	Solution concentration	• The size of nanosheets increases with increase in solution concentration, • Antibacterial activity of silver nanosheets enhanced with an increase in solution concentration	[72]
		• The average size of nanoparticles increases with an increase in precursor concentration • An increase in precursor concentration causes a significant increase in the inhibition zone against bacteria and fungi.	[78]
		• The large size and highly dispersive nanoparticles formed by increasing solution concentration	[66]
ZnO	Processing time	• An increase in processing time improves the crystallinity	[76]
		• The average diameter and size of nanoparticles increase with the increase in processing time.	[79]
Silver		• Increasing the exposure time to plasma increases the average size of nanoparticles.	[63]
Silver	Stabilizing agent concentration	• The greater the concentration of fructose as a stabilizing agent, the more dispersed and relatively smaller nanoparticles are formed, and it reduces agglomeration. At greater fructose concentrations, the smaller nanoparticles have enhanced properties against bacteria.	[67]
Silver	Stabilizing agent concentration	• The average size of nanoparticles decreases by increasing the molar ratio of sucrose in the precursor.	[62]
Molybdenum oxide	Gas flow rate	• The size of nanoparticles reduces as the flow rate of gases rises.	[80]

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5. Conclusion and final remarks

The atmospheric pressure plasma is an advanced and novel technique that can produce nanoparticles at ambient conditions. It has low thermal temperatures, faster processes, simplified equipment, and a cheap, eco-friendly system with various dimensions and configurations. Recent studies are presented here for nanomaterial synthesis by different configurations of atmospheric pressure Microplasma depending on the slight difference in their setups. This brief review revealed that silver and zinc oxide and their core-shell nanomaterials have great biological properties such as antibacterial, anticancer, and antifungal. The contribution of numerous control parameters like electrode dimension, flow of gas, type of gas, precursors concentration, operating voltage and current, distance between electrodes, and configuration of plasma system on nanoparticles characteristics (size, shape, and applications) is summarized. Nowadays, wide research is being conducted on atmospheric pressure microplasma nano synthesis. Still, there is a broad scope for the development of research, and a research gap is provided in this article. Although silver and zinc oxide nanoparticles by this technique are widely reported, the literature on their core-shell nanoparticles is very limited and needs to be investigated in the future, specifically the pros and cons of such core-shell nanoparticles for biomedical applications.

Author Contributions: Conceptualization, M.N., A.K., and M.R.M.; validation, B.A., U.R., M.N. and A.K.; resources, M.N.; writing—original draft preparation, A.K. and M.N.; writing—review and editing, U.R., B.A., O.A., F.A. and E.T.; supervision, M.N. and M.R.M.; project administration, M.N. All authors have read and agreed to the published version of the manuscript.".

Funding: This manuscript received no fundings.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data is provided in this article.

Conflicts of Interest: The authors declare no conflicts of interest.

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