

# Effect of Gas Type and Pressure on Particle Properties in Ag Nano Powder Production Using IGC Method

Mehmet TÜRKER<sup>1\*</sup> 

<sup>1</sup>Gazi University, Department of Metallurgy and Materials Eng., Ankara, 06560, Türkiye

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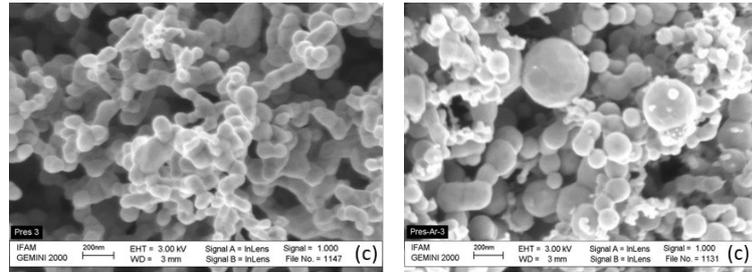
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## Anahtar Kelimeler

Elektro Deşarj  
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## Graphical/Tabular Abstract (Grafik Özet)

Polymer-based materials can be made electrically conductive by reinforcing them with conductive materials in particle form. The most advantageous of these are highly porous, conductive, low-volume Ag nanopowders. These are generally produced by IGC in a He gas. In this study, Ar was used as an alternative to He gas in the production of Ag nanoparticles, and the results were compared. Instead of production at the standard 20 mb pressure, samples were produced in He and Ar environments at pressures of 10 mb-40 mb, and the resulting powders were compared. In this study, the size, shape, and specific surface area of the powders produced under different parameters were examined and compared. It was found that the average size of the powders produced with He gas was 74 nm, exhibiting a more clustered structure and significant sintering contraction between particles; under the same conditions, it was determined that the powders produced with Ar gas were much larger (120 nm), more spherical, and exhibited less sintering contraction.



**Figure A:** SEM view of Ag nanopowders produced under different gas types and pressures. Ag nanopowders produced in a He environment at 40 mb pressure (left). Ag nanopowder produced in an Ar environment under the same conditions (right) / **Şekil A:** Farklı gaz türleri ve basınçlar altında üretilen Ag nanotozların SEM görünümü. 40 mb basınçta He ortamında üretilen Ag nanopowder (solda). Aynı koşullar altında Ar ortamında üretilen Ag nanopowder (sağda).

## Highlights (Önemli noktalar)

The properties of Ag nanopowders produced at different gas types and pressures, and their suitability as reinforcing elements in polymer matrices, were investigated. / Farklı gaz türleri ve basınçlarında üretilen Ag nanotozların özellikleri ve polimer matrislerde takviye elemanı olarak uygunlukları araştırıldı.

**Aim (Amaç):** The suitability of Ag nanopowders, produced in different environments, for use in polymer matrices and laptop production was investigated. / Farklı ortamlarda üretilen Ag nanotozların polimer matrislerde ve dizüstü bilgisayar üretiminde kullanım uygunluğu araştırıldı.

**Originality (Özgünlük):** In this study, the properties of Ag nanopowders obtained by using Ar gas at different pressures instead of He gas, the standard production medium, were determined/ Çalışmada, standart üretim ortamı olan He gazı yerine farklı basınçlarda Ar gazı kullanılarak elde edilen Ag nanotozların özellikleri belirlenmiştir.

**Results (Bulgular):** Powders produced in an Ar environment were larger, more spherical, and showed less sintering necking. An increase in powder size was observed in both environments depending on the increase in gas pressure/ Ar ortamında üretilen tozlar daha büyük, daha küreseldi ve daha az sinterleme boyunlanması gösterdi. Her iki ortamda da gaz basıncındaki artışa bağlı olarak toz boyutunda bir artış gözlemlendi.

**Conclusion (Sonuç):** It was determined that powders produced in a He environment are more suitable for the production of conductive polymers required for laptop manufacturing, as they are both small and sinter necking with each other, thus fulfilling the purpose of this study./ He ortamında üretilen tozların küçük ve birbiri ile sinter boyunlanması yaptığından bu çalışmanın amacına uygun olarak lap top yapımında gerekli olan iletken polimer yapımı için daha uygun olduğu tespit edilmiştir.



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IGC Method,  
Ag nanopowders,  
He and Ar atmosphere,  
Particle size and  
morphology

### Abstract

Polymer-based materials can be made electrically conductive by combining them with conductive materials in particulate form. Instead of traditional high aspect ratio fillers such as particles, fibers, and flakes, highly porous, conductive, low-volume nanopowders are produced for use in polymer matrix composites. These porous powders are generally produced using the inert gas condensation (IGC) method in a He atmosphere. In this study, Ar gas was used as an alternative to the commonly used He gas to produce silver nanoparticles at low pressures, and the results were compared. Instead of production at the standard 20 mbar pressure, samples were produced in He and Ar environments at 10 mbar, 20 mbar, and 40 mbar pressures, and the resulting powders were compared. In this study, a 1 mm Ag wire was evaporated in a W evaporator at 1500 °C and different pressures. The evaporated metal atoms nucleate homogeneously in contact with the carrier gas, grow, and collect in the filter at the back. In this study, the size, shape, and specific surface area of the powders produced at different parameters were investigated and compared. Powders produced under standard 20 mbar pressure with He gas had an average powder size of 74 nm, a more clustered structure, and significant sinter necking between particles, while powders produced under the same conditions with Ar gas were found to be much coarser (120 nm in diameter), more spherical, and exhibited less sinter necking.

## IGC Yöntemiyle Ag Nano Toz Üretiminde Gaz Türü ve Basıncın Parçacık Özelliklerine Etkisi

### Makale Bilgisi

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### Anahtar Kelimeler

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Ag nanopozları,  
He ve Ar atmosferi,  
Parçacık boyutu ve  
morfolojisi

### Öz

Polimer bazlı malzemeler, partikül formundaki iletken malzemelerle birleştirilerek elektriksel olarak iletken hale getirilebilir. Partiküller, lifler ve pullar gibi geleneksel yüksek en boy oranlı dolgu maddeleri yerine, polimer matris kompozitlerinde kullanılmak üzere yüksek gözenekli, iletken, düşük hacimli nanotozlar şeklinde üretilir. Bu gözenekli tozlar genellikle He atmosferinde inert gaz yoğunlaştırma (IGC) yöntemi kullanılarak üretilir. Bu çalışmada, düşük basınçlarda Ag nanopartiküller üretmek için yaygın olarak kullanılan He gazına alternatif olarak Ar gazı kullanılmış ve sonuçlar karşılaştırılmıştır. Standart 20 mbar basınçta üretim yerine, numuneler He ve Ar ortamında 10 mb, 20 mbar ve 40 mbar basınçlarda üretilmiş ve elde edilen tozlar karşılaştırılmıştır. Bu çalışmada, 1 mm'lik bir gümüş tel, 1500 °C'de ve farklı basınçlarda bir W buharlaştırıcıda buharlaştırılmıştır. Buharlaştırılan metal atomları, taşıyıcı gazla temas halinde homojen olarak çekirdeklenmekte, büyümekte ve arkadaki filtrede toplanmaktadır. Bu çalışmada, farklı parametrelerde üretilen tozların boyutu, şekli ve özgül yüzey alanı incelenmiş ve karşılaştırılmıştır. Standart 20 mbar basınç altında He gazı ile üretilen tozların ortalama toz boyutu 74 nm, daha kümelmiş bir yapıya ve parçacıklar arasında belirgin sinter boyunlaşmasına sahip olduğu bulunmuştur; aynı koşullar altında Ar gazı ile üretilen tozların ise çok daha iri (120 nm çapında), daha küresel olduğu ve daha az sinter boyunlaşması gösterdiği tespit edilmiştir.

### 1. INTRODUCTION (GİRİŞ)

Interest in a wide variety of nanostructured materials, with average grain or other structural domain size below 100 nm, has increased during the last two decades with the anticipation that their properties different from, and often superior to,

those of conventional materials that have phase or grain structures on a coarse scale [1-5]. The terms "nanoparticles," nanocrystalline, microcrystalline, nanophase, or nanostructured materials" began to be frequently used in conjunction with "nanoscale" or "nanosized" particles in the early 1990s. The term

"nanoparticles" is now generally used in the materials science community to refer to particles smaller than 100 nm in diameter [6-9]

Nanophase materials are usually produced by compaction of the powders of nanoparticles. They are characterised by a large number of grain boundary interfaces in which the local atomic arrangements are different from those of the crystal lattice [9, 10]. The small size of nanoparticles, which is responsible for the different properties (electronic, optical, magnetic, chemical and mechanical) of nanoparticles and nanostructural materials with respect to the bulk material, makes them suitable for the new applications. Due to their high surface area, small nanoscaled particles generally showed on a strong interaction [10-14].

Nanoparticles, having a size intermediate between molecular and solid-state structures, possess hybrid properties that are currently poorly understood, posing a challenge to theorists [9, 15, 16]. Some examples of these properties are: Lower melting and sintering temperatures, superplastic behavior, increased solid solution phase transition pressure, increased strength and hardness, increased ductility and toughness, higher coefficient of thermal expansion, lower effective Debye temperature, decreased ferroelectric phase transition temperature, higher self-diffusion coefficient, altered thermophysical properties, and catalytic activities.

Nanostructured materials are started to use in the different parts of the industry now [17-19]. Nanometer sized particles are the constituents of many paints and pigments, especially those manufactured by a gas-to-particle conversion process such as TiO<sub>2</sub> or SiO<sub>2</sub>. Silica powders prepared by flame combustion have a number of applications that involve improving the flow of the powders, such as those in toners. Silica powders are also used as a component of plastics. Carbon black is a large-commodity material (e.g., in toner cartridges) and made by a combustion process. Coated titania particles are used in sunscreens, where very good UV protection together with good optical transparency, is important.

In addition to these applications, nanoparticles are used in biomedical applications for both diagnostic and therapeutic purposes [20]. Many nanosized materials are also used in medical science.

This study aims to produce silver nanopowders for use in the manufacturing of particle-reinforced polymers with low reinforcement volume ratio but high conductivity, for use in laptop computer production. For this purpose, Ag nanopowders were

produced at different pressures using the inert gas condensation (IGC) method in low-pressure He and Ar atmospheres and the effects of production parameters on the properties of Ag nanopowders such as particle size, specific surface area and particle morphology were investigated. Although production is generally carried out in a helium atmosphere, the effect of Ar gas on particle size and properties was investigated due to its economic advantages and larger atomic diameter.

## 2. EXPERIMENTAL PROCEDURES

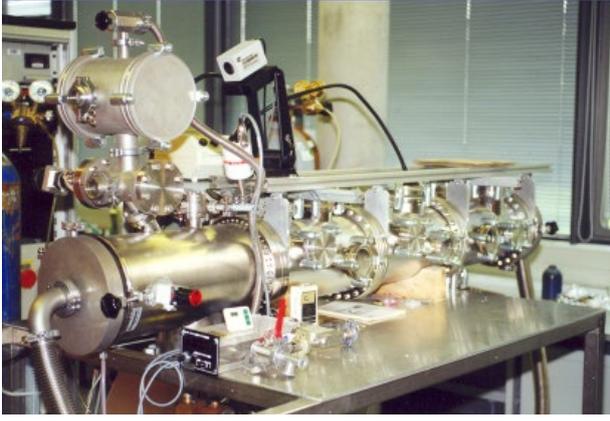
(DENEYSEL İŞLEMLER)

### 2.1. POWDER PREPARATION AND CHARACTERISATION (TOZ HAZIRLAMA VE KARAKTERİZASYON)

Silver nanopowders were produced by the Inert Gas Condensation (IGC) method in a low-pressure He atmosphere. For comparison, Ar, another inert gas with a larger atomic radius (188 pm), was used instead of He gas (140 pm), and the results were compared. This method is a closed-loop process, as also noted by B. Günther. The IGC method was first described by Pfund [21] and essentially consists of the following procedures: First, the powder processing chamber is evacuated to a base pressure of approximately 10<sup>-4</sup> mbar and then filled with an ultrapure inert gas (He or Ar), typically reaching a pressure of 10-50 mbar. The source metal is then vaporized into the flowing inert gas, where it forms nano-sized particles. These aerosol particles are collected in a suitable medium, such as a metal filter. Detailed information regarding the experimental method we used for the production of Ag nanomaterials in this study is provided in our previously published article [22-25].

The experimental setup used for the production of Ag nanopowders in this study is shown in Figure 1. Helium gas was generally used as both cooling agent and carrier gas for the nucleating metal particles. In some experiments Ar gas was used instead of He with different pressures.

In this experiment, Ag melt was fed from a 1 mm wire and was evaporated from a Joule-heated W boat with the background pressure of 20 mbar. The particles formed through homogeneous nucleation in both cooling and the carrier gas, and further enlarged in the coupling mode. [23, 26]. In the later stage, but still in the gas flow, the particles formed highly porous aggregate with substantial sinter neck formation. Ag powder deposits collected in the back filter were then sieved through a 0.5 mm sieve. The specific surface area of the powders were determined by volumetric nitrogen adsorption



**Figure 1.** View of the experimental setup used in this study to produce nanoscale Ag particles by inert gas condensation method. (Bu çalışmada Asal gaz yoğunlaştırma yöntemiyle nano ölçekli Ag parçacıkları üretmek için kullanılan deneysel düzeneğin görünümü.)

### 3. EXPERIMENTAL RESULTS AND DISCUSSION (DENEYSEL SONUÇLAR VE TARTIŞMA)

#### 3.1. POWDER SIZE AND MORPHOLOGY (TOZ BOYUTU VE YAPISI)

##### 3.1.1. Microstructure of powders produced in He and Ar atmospheres (He ve Ar atmosferlerinde Üretilen Tozların Mikro Yapısı)

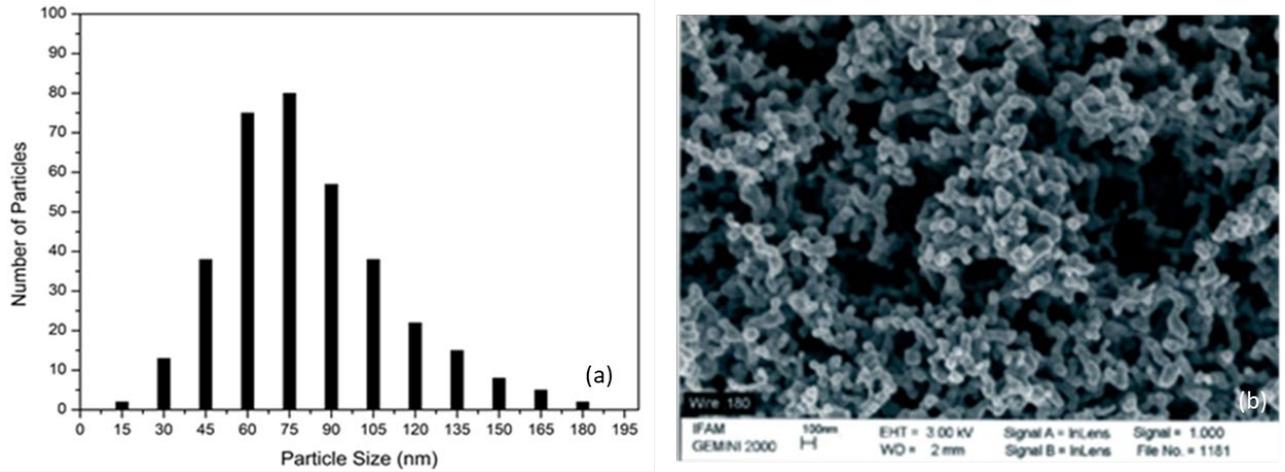
For comparison, the size and morphology of Ag nanopowders produced in pure He and Ar atmospheres at a standard production pressure of 20 mbar were evaluated by SEM. Size distributions were extracted from SEM micrographs over a population of up to 1000 particles per sample. To determine the powder size of Ag nanopowders, the Mean Linear Intercept (MLI) and BET (Brunauer, Emmett, and Teller methods) methods were used, and a size histogram was plotted based on these data (Fig. 2.a and Fig. 3.a). The primary particle size of Ag powders produced in pure He was found to range from 15 to 180 nm, with an average particle size of approximately 74 nm. Particles were generally spherical in shape although some irregularly shaped particles were also found in some areas. These particles have generally been observed to have a chain-like structure, and upon closer examination, it has been seen that the particles are connected to each other in a sinter necking manner. (Fig.2.b). This type of chain like structure is particularly desirable for this study, which focuses on the production of conductive polymers by infiltration.

Under the same conditions, using Ar gas instead of He gas reduced the necking between particles, leading to the production of larger and more spherical powder particles. With Ar gas, particle sizes ranged from 30 to 430 nm, with an average particle size of 120 nm (Fig. 3.b). In the author's previous work, it was reported that adding 10 ccm of oxygen to He gas resulted in a significant reduction in powder size (44 nm), while the powder particles were quite spherical [25, 31].

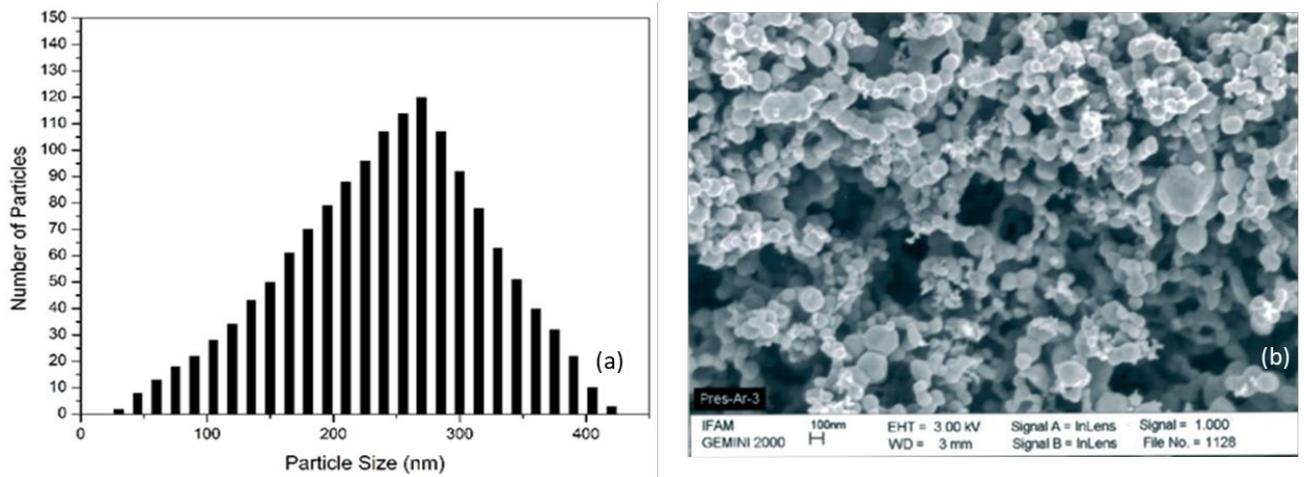
Figures 2(a) and 3(a) show the size histogram graph of Ag powders produced in a pure Ar atmosphere, respectively, while Figures 2(b) and 3(b) show their microstructures. As can be seen in Fig. 2(b) and Fig. 3(b), when comparing the appearance of the powder particles, the powder produced with He gas is smaller, has a more interconnected, chain-like structure, and is more tightly packed. On the other hand, Ag nanopowders produced in an Ar atmosphere (Fig. 3.b) have a more spherical structure and sometimes consist of abnormally large particles.

During the synthesis of nanoscale particles using the IGC method, it is known that particles grow by coalescing, especially as a result of collisions on the evaporator. Particle coarsening is even greater when the temperature is sufficiently high and the particle surfaces are clean. In this experiment, it is assumed that very little reaction occurs between the carrier gas and the particles or the W evaporator when highly pure helium is used as the carrier gas [23, 31]. This leads to the formation of a very clean particle surface without a surface oxide layer and facilitates the growth of particles along the sinter necks. Since such sinter necks provide continuity between particles, they are considered favorable for the electrical conductivity of silver powders in the polymer matrix.

In experiments using Ar gas instead of He gas, coarser and more spherical powder particles were observed. This is because Ar gas, which has a larger atomic diameter than He, collides with the fine nanopowders rising from the hot evaporator, causing them to remain in the hot region for a longer period. This leads to the coalescence and growth of the very small molten particles that have evaporated.



**Figure 2.** Size histogram (a) and SEM view (b) of Ag nanopowders produced in a 20 mbar He atmosphere. (20 mbar He atmosferinde üretilen Ag nanopowder'ların boyut histogramı (a) ve SEM görüntüsü (b))



**Figure 3.** Size histogram (a) and SEM view (b) of Ag nanopowders produced in a 20 mbar Ar atmosphere. (20 mbar Ar atmosferinde üretilen Ag nanopowder'ların boyut histogramı (a) ve SEM görüntüsü (b))

### 3.2. Effect of He and Ar Gas Type and Pressure on Particle Size and Morphology (He ve Ar Gazı Türü ve Basıncının Parçacık Boyutu ve Morfolojisi Üzerindeki Etkisi)

In order to determine the effect of gas type and pressure on powder size and structure, powders were produced at 10, 20, and 40 mbar pressures in Ar and He atmospheres. Other parameters such as wire feed rate and evaporator temperature were kept constant.

BET results and SEM analysis show a direct relationship between gas pressure and particle size. Increasing gas pressure led to larger particle sizes (Fig. 4 and Fig. 5). Similar pressure-dependent trends were observed in both atmospheres. Powders produced in an Ar atmosphere have much larger particles compared to powders produced in a He atmosphere. At 20 mbar pressure, the average particle size of powder produced in an Ar atmosphere was approximately 120 nm, while the average particle size of powder produced in a He

atmosphere under the same production conditions was approximately 75 nm.

Another important point to highlight is the morphology of the powders. Powders produced in an Ar atmosphere had an almost perfectly spherical shape with a small amount of sinter necking. However, powders produced in a He atmosphere had a less spherical shape and more sinter necking. Fig. 4 a-c and Fig. 5 a-c show the structure and morphology of powders produced in Ar and He atmospheres at pressures of 10, 20, and 40 mbar, respectively. Previous studies [21] have reported that the intentional addition of oxygen to He gas results in the formation of almost perfectly spherical powders particles.

The primary reason for the increase in particle size with increasing pressure in the powders produced in both environments is that the molten Ag powders, which are very small and rise from the evaporator, collide with a large number of Argon or Helium atoms due to the high pressure, causing the small

particles to coalesce and become larger.

Another factor affecting particle size is related to the atomic diameter of the gas that cools the produced Ag powders and carries them to the filter behind the IGC setup. Indeed, under the same conditions, production with Ar gas, which has a larger atomic diameter (188 pm) than He (140 pm), causes the large Ar atoms to collide more effectively with the Ag nanopowders that have not yet solidified on the hot evaporator; this leads to the powders remaining in the hot region for a longer time, coalescing and growing. This results in the formation of larger particles compared to powders produced with helium gas (140 pm), which has a smaller atomic diameter.

### 3.3. The Amount Of Tungsten And Oxygen In Ag Nanopowder (Ag Nanotozdaki W ve Oksijen Miktarı)

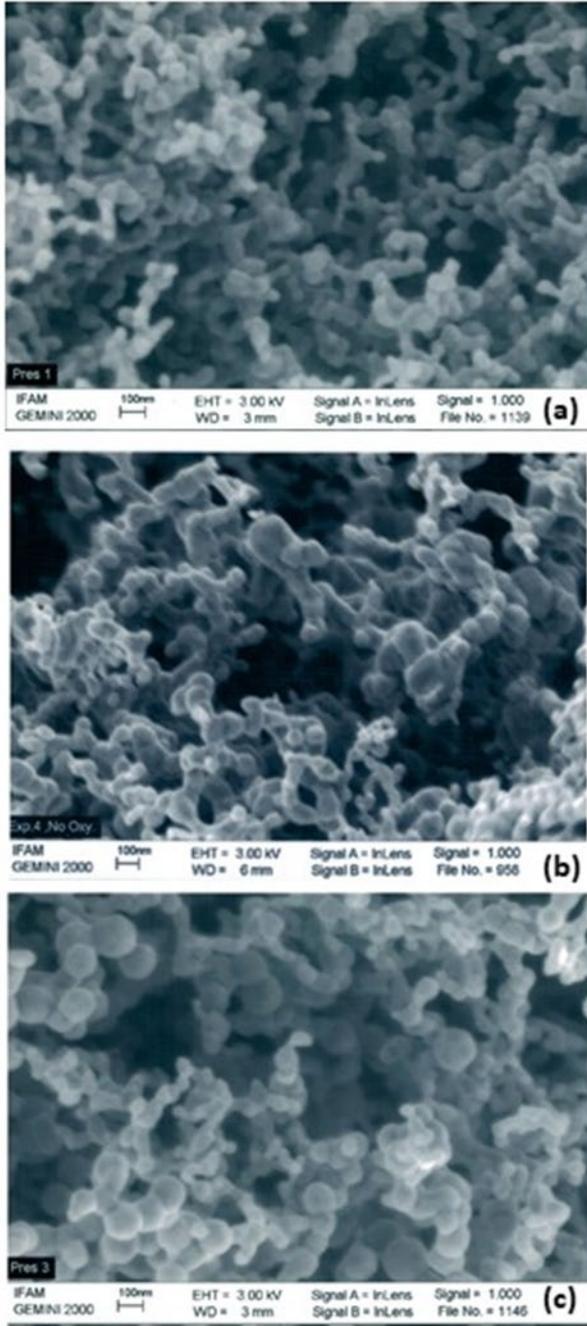
Ag nanopowders were produced in pure He and Ar atmospheres at different pressures. After evacuating the chamber to 0.08 mbar, it was filled with pure He or Ar gases at the standard production pressure of 20 mbar. Other parameters such as evaporator temperature, wire feed rate, and gas pressure were kept constant throughout the experiments. After the production of Ag nanopowders, the tungsten content and oxygen amount were analyzed by atomic emission spectroscopy. Approximately 3200 ppm tungsten (wt%) was obtained in Ag powders produced in pure He or Ar atmospheres. The oxygen content was also found to be slightly higher than the W amount in the powders, at 3700 ppm. These are thought to be due to residual oxygen in the chamber [23]. In this method, Ag melt was fed through a wire and evaporated from a Joule-heated W boat that was held at 1500 °C during the process. Due to residual oxygen within the chamber, the W evaporator reacted, forming WO<sub>3</sub> which sublimates at a temperature over 800 °C. This substance mixes with the coolant and carrier gas, becoming an impurity that mixes with the particles during the formation of silver nanopowders.

### 3.4. Effect of Gas Pressure on the Specific Surface Area of Powder (Gaz Basıncının Toz Özgül Yüzey Alanına Etkisi)

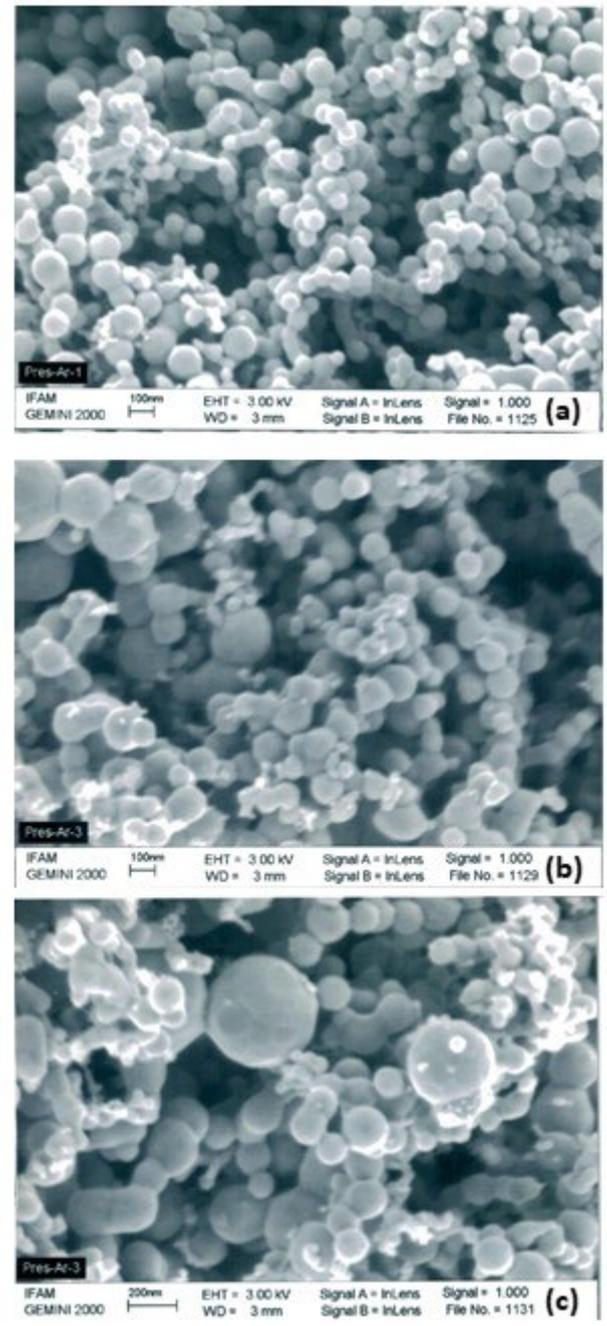
To determine the effect of gas type and pressure on the properties of Ag nanoparticles, powders were produced in Ar and He atmospheres at different pressures (10 mbar, 20 mbar, and 40 mbar). BET result showed that (Fig.6) powders produced in He atmosphere had much higher specific surface area than that seen on the powders produced in Ar. It means that particle size in He atmosphere is much smaller than that was produced in Ar atmosphere. In addition, a direct relationship has been determined between the gas pressure inside the chamber and the specific surface area of the particles produced. Increasing the gas pressure resulted in decreasing the specific surface areas of both environments.

BET results indicated that when powders were produced under helium atmosphere, the specific surface area of the powders decreased from 13.4 to 7.8 m<sup>2</sup>/g with increasing the He pressure from 10 to 40 mbar respectively. Similar trend, with lower specific surface area, has been observed during the production of powders in Ar atmosphere. Specific surface area of particles decreased from 5.9 to 2.3 m<sup>2</sup>/g with increasing the Ar gas pressure from 10 to 40 mbar.

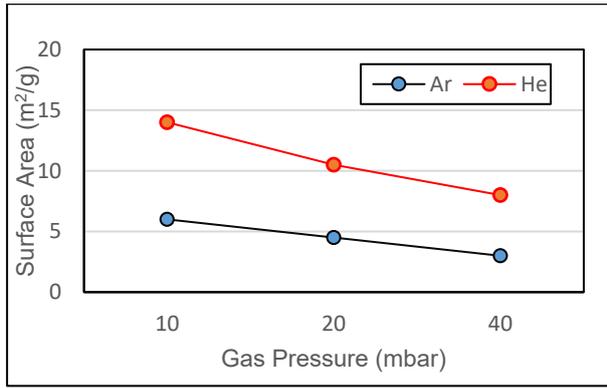
According to the data obtained from this study and the literature, the average particle diameter for a given gas type increases almost proportionally with pressure. Furthermore, an increase in the atomic weight of the carrier gas creates a favorable environment for the formation of larger particles. Cooling metal atoms through collisions with non-reactive gases is most effective when both atomic types have approximately the same mass (the most effective case for moment transfer). Therefore, if the pressure and/or the atomic mass of the inert gas used for cooling increases, supercooling is possible in a more confined region. [24]. The above explanation is consistent with the results obtained in this study, as larger particles are formed during the production of particles in an Ar atmosphere and at higher gas pressures.



**Figure 4.** SEM images of Ag nanopowders produced at different pressures in a He environment. (a) 10 mb, (b) 20 mb, (c) 40 mb. The increase in powder size with increasing pressure is clearly visible in the microstructure images. (He ortamında farklı basınçlarda üretilen Ag nanopowder'ların SEM görüntüleri. (a) 10 mb, (b) 20 mb, (c) 40 mb. Artan basınçla birlikte toz boyutundaki artış, mikro yapı görüntülerinde açıkça görülmektedir.)



**Figure 5.** SEM images of Ag nanopowders produced at different pressures in a Ar environment. (a) 10 mb, (b) 20 mb, (c) 40 mb. It is clearly seen in the microstructure images that the powder size increases with increasing pressure, and highly spherical powder particles are formed compared to powders produced with helium. (Ar ortamında farklı basınçlarda üretilen Ag nanopowder'ların SEM görüntüleri. (a) 10 mb, (b) 20 mb, (c) 40 mb. Mikro yapı görüntülerinde, basınç arttıkça toz boyutunun arttığı ve helyum ile üretilen tozlara kıyasla oldukça küresel toz parçacıklarının olduğu açıkça görülmektedir.) [22]



**Figure 6.** Effect of gas types and pressures on the specific surface area of Ag nanopowders. (Gaz türü ve basıncın Ag nanotozların birim yüzey alanına etkisi) [22].

## 5. CONCLUSIONS (SONUÇLAR)

Ag nanopowders were produced in Ar and He environments at pressures of 10, 20, and 40 mb, and the effects of production parameters on powder properties were investigated. The following results were obtained:

- Powders produced in a He atmosphere have a much smaller particle size and show more sinter necking. Powders produced in an Ar atmosphere have a much more spherical structure and show less sinter necking.
- When Ag nanosilver powders produced using He and Ar gases under different gas pressures were examined, an increase in powder particle size was observed depending on the increase in pressure.
- In both gas-based productions, low amounts of oxygen and  $WO_3$  were detected in Ag nanopowders. These are thought to originate from the gas used during production and the W evaporator. The detection of oxygen and  $WO_3$ , albeit in very small amounts, in both powders indicates that this type of production should be carried out in a more controlled environment.
- Based on the above data, this study, which aims to produce Ag nanoparticle-reinforced materials with good electrical properties by polymer infiltration and to use this material in laptop manufacturing, suggests that powders produced at low pressures in a He atmosphere are suitable. These fine and interconnected powders will experience less interruption in electrical conductivity. The fact that powders produced at low gas pressures have a finer structure is preferred because it results in the use of fewer reinforcement element

## ACKNOWLEDGEMENT (TEŞEKKÜR)

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## DECLARATION OF ETHICAL STANDARDS (ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

## AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

**Mehmet TÜRKER:** He conducted the experiments, analyzed the results and performed the writing process.

Deneyleri yapmış, sonuçlarını analiz etmiş ve maklenin yazım işlemini gerçekleştirmiştir.

## CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

## REFERENCES (KAYNAKLAR)

- [1] Suryanarayana, C. and B. Prabhu, Synthesis of nanostructured materials by inert-gas condensation methods, in Nanostructured materials. 2007, Elsevier. p. 47–90.
- [2] Musa, I., N. Qamhieh, and S.T. Mahmoud, Ag nanocluster production through DC magnetron sputtering and inert gas condensation: a study of structural, Kelvin probe force microscopy, and optical properties. *Nanomaterials*, 2023. 13(20): p. 2758.
- [3] Goldstein, A., Handbook of nanophase materials. 1997: CRC Press.
- [4] Suryanarayana, C., The structure and properties of nanocrystalline materials: issues and concerns. *Jom*, 2002. 54(9): p. 24–27.
- [5] Averbach, R. and H. Hofler, Processing and properties of nanophase materials. *Microcomposite and Nanophase Materials*, The Mineral and Materials Society, Ed. by DC Van Aken et al, 1991: p. 27–39.
- [6] Mekuye, B. and B. Abera, Nanomaterials: An overview of synthesis, classification,

- characterization, and applications. *Nano select*, 2023. 4(8): p. 486–501.
- [7] El-Khawaga, A.M., A. Zidan, and A.I. Abd El-Mageed, Preparation methods of different nanomaterials for various potential applications: A review. *Journal of Molecular Structure*, 2023. 1281: p. 135148.
- [8] Edelstein, A., *Nanoparticles from a supersaturated vapor*, in *Nanophase Materials: Synthesis—Properties—Applications*. 1994, Springer. p. 73–80.
- [9] Kodas, T. and M. Hampden-Smith, *Aerosol Processing of Materials* Wiley-VCH. New York, 1999: p. 19.
- [10] Bandyopadhyay, A.K., *Nano materials*. 2008: New Age International.
- [11] Kumar, P.M., et al., Nanophase alumina synthesis in thermal arc plasma and characterization: correlation to gas-phase studies. *Materials Science and Engineering: B*, 1999. 63(3): p. 215–227.
- [12] Wu, X., et al., Thermal properties of nanocrystalline silver. *MRS Online Proceedings Library*, 1992. 286(1): p. 149–153.
- [13] Weißmüller, J., R. Birringer, and H. Gleiter, Interface in Nanostructured Amorphous and Crystalline Solid. *Microcomposite and Nanophase Materials*, The Mineral and Materials Society, Ed. By DC Van Aken et al, 1991: p. 1–13.
- [14] Nieman, G., J.R. Weertman, and R. Seigel, Mechanical behavior of nanocrystalline Cu, Pd and Ag samples. 1991, Argonne National Laboratory (ANL), Argonne, IL (United States).
- [15] Jena, P., et al., Clusters-A New Source for Atomically Engineered Materials. *MRS Online Proceedings Library (OPL)*, 1990. 206: p. 3.
- [16] Choi, S.J. and M.J. Kushner, Simulation of Gas Phase Clustering of Nanocrystals in Sputter Discharges. *MRS Online Proceedings Library (OPL)*, 1990. 206: p. 283.
- [17] Noman, M.T., M.A. Ashraf, and A. Ali, Synthesis and applications of nano-TiO<sub>2</sub>: a review. *Environmental science and pollution research*, 2019. 26(4): p. 3262–3291.
- [18] Zhuang, C. and Y. Chen, The effect of nano-SiO<sub>2</sub> on concrete properties: a review. *Nanotechnology Reviews*, 2019. 8(1): p. 562–572.
- [19] Ding, J., et al., *Synthesis and Processing of Nanocrystalline Powder*, ed. by DL Bouvill. 1996, TMS.
- [20] Abdelsalam, S.I., A. Magesh, and P. Tamizharasi, Optimizing fluid dynamics: An in-depth study for nano-biomedical applications with a heat source. *Journal of Thermal Analysis and Calorimetry*, 2025. 150(4): p. 2781–2793.
- [21] TÜRKER, M., Effect of oxygen content on the properties and electrical conductivity of Ag nanopowders produced by IGC.
- [22] Turker, M., Effect of production parameters on the structure and morphology of Ag nanopowders produced by inert gas condensation. *Materials Science and Engineering: A*, 2004. 367(1-2): p. 74–81.
- [23] Günther, B., M. Türker, and J. Mehlich. Influence of W/O-content on DC-conductivity of Ag-nanopowders. in *World Conference on Powder Metallurgy & Particulate Materials (PM2TEC) 2002*. 2002.
- [24] Grangvist, C. and R. Buhman, Ultrafine Metal Powders. *Journal of Applied Physics*, 1976. 47: p. 2200.