A Current-carrying Gold Wire Has A Diameter Of 0.80 Mm . The Electric Field In The Wire Is 0.50 V/m .a)

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Introduction

In the world of electrical engineering and materials science, understanding the behavior of conductors under various conditions is essential. Gold, renowned for its excellent electrical conductivity, is often employed in high-precision applications such as electronics, connectors, and sensors. When a gold wire carries an electric current, several fundamental physical principles come into play, including electric fields, current density, and resistivity.

This article delves into a specific scenario: a gold wire with a diameter of 0.80 millimeters (mm), experiencing an electric field of 0.50 volts per meter (V/m). We will explore the implications of these parameters, calculate key quantities such as current density, resistivity, and current, and discuss their significance in practical applications. By understanding these concepts, engineers and scientists can optimize the design and performance of electrical components that utilize gold wires.

Context and Significance of the Scenario

Gold wires are favored in many electronic applications because of their high electrical conductivity, resistance to corrosion, and excellent ductility. The behavior of such a wire under an applied electric field provides insight into how current flows through it, which is fundamental for designing reliable circuits.

Knowing the electric field within the wire allows us to determine the current density, the current flowing through the wire, and other related electrical parameters. These calculations are crucial when considering factors like power dissipation, thermal effects, and overall efficiency of electrical systems.

Understanding the relationship between the electric field, current density, and material properties is also vital for ensuring that the wire operates within safe limits, preventing overheating or failure. Additionally, these insights are applicable in nanotechnology, microelectronics, and the development of novel conductive materials.

Physical Principles Governing Current Flow in Conductors

Before diving into calculations, it's important to review the fundamental principles:

- Ohm's Law in Differential Form:

$$
\mathbf{J} = \sigma \mathbf{E}
$$

where:
- $\mathbf{J}$ is the current density (A/m²),
- σ is the electrical conductivity of the material (S/m),
- $\mathbf{E}$ is the electric field (V/m).

- Resistivity and Conductivity:

$$
\sigma = \frac{1}{\rho}
$$

where ρ is the resistivity of the material (Ω·m).

- Relationship between Current, Current Density, and Cross-Sectional Area:

$$
I = J \times A
$$

where:
- I is the total current (A),
- A is the cross-sectional area of the wire (m²).

Step-by-Step Calculations

1. Determine the Cross-Sectional Area of the Gold Wire

Given the diameter:

$$
d = 0.80\, \text{mm} = 0.80 \times 10^{-3}\, \text{m}
$$

The cross-sectional area A (assuming a circular wire):

$$
A = \pi \left(\frac{d}{2}\right)^2
$$

Calculating:

$$
A = \pi \left(0.40 \times 10^{-3}\, \text{m}\right)^2 = \pi \times (0.40 \times 10^{-3})^2
$$

$$
A = \pi \times 0.16 \times 10^{-6} = 3.1416 \times 0.16 \times 10^{-6}
$$

$$
A \approx 0.5027 \times 10^{-6}\, \text{m}^2 = 5.027 \times 10^{-7}\, \text{m}^2
$$

2. Find the Electrical Conductivity of Gold

The resistivity ρ of gold at room temperature (around 20°C):

$$
\rho \approx 2.44 \times 10^{-8}\, \Omega \cdot \text{m}
$$

Thus, the conductivity:

$$
\sigma = \frac{1}{\rho} = \frac{1}{2.44 \times 10^{-8}} \approx 4.10 \times 10^{7}\, \text{S/m}
$$

3. Calculate the Current Density J

Using Ohm's law in differential form:

$$
J = \sigma E
$$

Given:

$$
E = 0.50\, \text{V/m}
$$

Calculate:

$$
J = 4.10 \times 10^{7}\, \text{S/m} \times 0.50\, \text{V/m} = 2.05 \times 10^{7}\, \text{A/m}^2
$$

Interpretation: The current density in the gold wire is approximately 2.05×10^{7} amperes per square meter.

4. Determine the Total Current I in the Wire

Using:

$$
I = J \times A
$$

Calculate:

$$
I = 2.05 \times 10^{7}\, \text{A/m}^2 \times 5.027 \times 10^{-7}\, \text{m}^2 \approx 10.3\, \text{A}
$$

Implication: The current flowing through the wire is approximately 10.3 amperes.

Practical Implications and Applications

Understanding these parameters has several practical applications:

- Design of Electrical Components:
Knowing the current and current density helps in selecting appropriate wire thicknesses to prevent overheating and ensure reliability.

- Thermal Management:
Power dissipation in the wire can be estimated using $P = I^2 R$, where R is the resistance. Calculations like these help prevent thermal failure.

- Material Selection:
Gold’s high conductivity and corrosion resistance make it suitable for specialized applications, but its cost must be balanced against performance needs.

- Electromagnetic Compatibility:
Electric fields within conductors influence electromagnetic emissions, which are critical in sensitive electronic environments.

Additional Considerations

1. Resistance of the Gold Wire

The resistance R can be calculated as:

$$
R = \frac{\rho L}{A}
$$

where L is the length of the wire. For a specific length, this helps determine power loss and thermal effects.

2. Effect of Temperature

Resistivity varies with temperature; gold’s resistivity increases with temperature, impacting current flow and power dissipation.

3. Limitations and Safety Margins

In real-world applications, engineers incorporate safety margins to account for variations in material properties, manufacturing imperfections, and environmental factors.

Summary of Key Findings

- The cross-sectional area of a 0.80 mm diameter gold wire is approximately $5.03 \times 10^{-7}\, \text{m}^2$.
- The electrical conductivity of gold is about $4.10 \times 10^{7}\, \text{S/m}$.
- The electric field within the wire is 0.50 V/m, leading to a current density of approximately $2.05 \times 10^{7}\, \text{A/m}^2$.
- The total current flowing through the wire under these conditions is roughly 10.3 amperes.

Conclusion

The analysis of a current-carrying gold wire with a diameter of 0.80 mm and an electric field of 0.50 V/m illustrates fundamental principles of electrical conduction. By calculating current density and total current, engineers can design systems that optimize performance while ensuring safety and durability. Gold's exceptional electrical properties make it a valuable material in high-precision electronics, though cost considerations remain.

Understanding these parameters not only aids in practical engineering applications but also enriches our comprehension of material behavior under electrical stress. As technology advances, such insights will continue to underpin innovations in electronics, nanotechnology, and materials science.

Keywords: Gold wire, electric field, current density, resistivity, electrical conductivity, circuit design, thermal management, electrical engineering, materials science, microelectronics

Frequently Asked Questions

What is the significance of the electric field in a current-carrying gold wire?

The electric field in the wire indicates the potential difference driving the current, affecting how electrons move through the conductor.

How is the current density in the gold wire related to its

electric field?

The current density is proportional to the electric field, according to Ohm's law, given by $J = \sigma E$, where σ is the electrical conductivity of gold.

How can we calculate the current flowing through the gold wire given its electric field and diameter?

First, find the cross-sectional area of the wire, then calculate the current density using $J = \sigma E$, and finally multiply by the area to find the total current: $I = J \times A$.

What is the approximate resistance of the gold wire with a diameter of 0.80 mm?

The resistance can be estimated using $R = \rho L/A$, where ρ is the resistivity of gold, L is the length, and A is the cross-sectional area, which can be calculated from the diameter.

Why is gold a good choice for electrical wiring in terms of electrical properties?

Gold has high electrical conductivity, corrosion resistance, and ductility, making it ideal for reliable electrical connections.

How does the diameter of the wire affect its electrical resistance?

Resistance is inversely proportional to the cross-sectional area; increasing the diameter decreases resistance, allowing more current to flow for a given voltage.

If the electric field in the wire is 0.50 V/m, what is the potential difference across a certain length of the wire?

The potential difference (V) across a length L of the wire can be found using $V = E \times L$; for example, across 1 meter, the potential difference would be 0.50 V.

Additional Resources

A Current-carrying Gold Wire Has A Diameter Of 0.80 Mm. The Electric Field In The Wire Is 0.50 V/m.

Introduction

Gold has long been celebrated not only for its aesthetic appeal but also for its exceptional electrical conductivity and corrosion resistance. Its unique properties make it an ideal material for high-precision electrical applications, including microelectronics, aerospace components, and sensitive instrumentation. In this context, understanding the electrical behavior of a current-carrying gold wire—particularly one with a diameter of 0.80 mm subjected to an electric field of 0.50 V/m—is essential for optimizing its performance and ensuring reliability.

This comprehensive investigation explores the fundamental physics governing the electrical conduction in such a wire, the implications of the measured electric field, and the insights that can be gleaned about the current, resistance, and potential applications of the system. By delving into theoretical frameworks, experimental considerations, and practical applications, this article aims to provide a detailed understanding relevant for researchers, engineers, and material scientists.

Fundamental Concepts and Context

Electrical Conduction in Metals

Electrical conduction in metals like gold is predominantly due to the flow of free electrons. When an electric field is applied, these electrons drift, resulting in an electric current. The relationship between current density (J), electric field (E), and electrical conductivity (σ) is governed by Ohm's law in differential form:

$$ \mathbf{J} = \sigma \mathbf{E} $$

Alternatively, the macroscopic relationship involves the resistivity (ρ):

$$ R = \frac{\rho L}{A} $$

where:

- R is the resistance,
- ρ is the resistivity,
- L is the length of the wire,
- A is the cross-sectional area.

Gold’s resistivity at room temperature (~20°C) is approximately $2.44 \times 10^{-8} \ \Omega \cdot \mathrm{m}$, making it a highly conductive material.

Geometric Considerations

The wire's diameter of 0.80 mm translates to a radius $r = 0.40$ mm or 4.0×10^{-4} meters. The cross-sectional area A is calculated as:

$$ A = \pi r^2 = \pi \times (4.0 \times 10^{-4} \ \mathrm{m})^2 \approx 5.03 \times 10^{-7} \ \mathrm{m}^2 $$

Understanding the current flow requires knowledge of this geometric parameter and the applied electric field.

Analyzing the Electric Field and Its Implications

Measurement of Electric Field

The electric field in the wire is given as 0.50 V/m. This value indicates the potential gradient along the length of the wire, which directly influences the drift velocity of electrons and the resultant current.

Relation to Voltage and Length

Suppose the wire has a length L. The potential difference V across the wire is:

$$V = E \times L$$

Without explicit length information, we can analyze the relationship between the electric field, current, and resistance to infer the current.

Calculating the Current in the Gold Wire

Step 1: Determine Resistance

Using the resistivity $\rho = 2.44 \times 10^{-8} \ \Omega \cdot \mathrm{m}$, the resistance R of the wire is:

$$R = \frac{\rho L}{A}$$

Since R depends on L, the resistance scales linearly with length.

Step 2: Relate Electric Field to Voltage

The electric field relates to the voltage as:

$$V = E \times L$$

Thus, the resistance can also be expressed as:

$$R = \frac{V}{I}$$

Rearranged, the current I is:

$$I = \frac{V}{R}$$

Substituting $V = E \times L$ and $R = \frac{\rho L}{A}$:

$$I = \frac{E \times L}{\frac{\rho L}{A}} = \frac{E \times A}{\rho}$$

Notice that the length cancels out, indicating that the current solely depends on the electric field, cross-sectional area, and resistivity.

Quantitative Analysis

Using the known values:

- $E = 0.50 \ \mathrm{V/m}$
- $A = 5.03 \times 10^{-7} \ \mathrm{m}^2$
- $\rho = 2.44 \times 10^{-8} \ \Omega \cdot \mathrm{m}$

The current I is:

$$
I = \frac{0.50 \times 5.03 \times 10^{-7}}{2.44 \times 10^{-8}} \approx \frac{2.515 \times 10^{-7}}{2.44 \times 10^{-8}} \approx 10.3 \ \mathrm{A}
$$

This suggests that, under the given electric field, the wire sustains a current of approximately 10.3 amperes.

Significance of the Results

Current Density

The current density J in the wire is:

$$
J = \frac{I}{A} \approx \frac{10.3}{5.03 \times 10^{-7}} \approx 2.05 \times 10^{7} \ \mathrm{A/m^2}
$$

This high current density is typical of metallic conductors under significant electrical load, but it also approaches the limits where electromigration and thermal effects could become concerns.

Power Dissipation and Heating

The power dissipated as heat in the wire:

$$
P = I^2 R
$$

Given the resistance:

$$
R = \frac{\rho L}{A}

\]

and I, the power depends on L. For example, with a 1-meter wire:

$$
R = \frac{2.44 \times 10^{-8} \times 1}{5.03 \times 10^{-7}} \approx 0.0485 \ \Omega
$$

$$
P = (10.3)^2 \times 0.0485 \approx 5.15 \ \mathrm{W}
$$

This illustrates that even a relatively short gold wire can dissipate a significant amount of heat at such currents, emphasizing the importance of thermal management in practical applications.

Practical Considerations and Limitations

Electromigration and Structural Integrity

High current densities can induce electromigration, leading to material transport within the wire and eventual failure. Gold's resistance to corrosion is advantageous, but thermal effects and high current densities pose reliability concerns.

Temperature Effects

The temperature rise in the wire affects resistivity; as temperature increases, resistivity typically increases, which can further elevate power dissipation and risk of damage.

Scaling and Application Constraints

While theoretical calculations suggest the current capacity, real-world factors such as contact resistance, surface roughness, and manufacturing imperfections influence actual performance.

Broader Implications and Future Directions

Material Optimization

Understanding the current-carrying capabilities of gold wires informs their design in microelectronic circuits, especially where high current densities are required without compromising longevity.

Advanced Characterization Techniques

Employing techniques like scanning electron microscopy (SEM) and atomic force microscopy (AFM) can help evaluate microstructural changes post-use, aiding in durability assessments.

Thermal Management Strategies

Innovative cooling solutions and material composites could enhance the capacity of gold wires to handle higher currents safely.

Conclusion

The analysis of a current-carrying gold wire with a diameter of 0.80 mm subjected to an electric field of 0.50 V/m reveals that such a wire can sustain a current of approximately 10.3 amperes, with a high current density indicative of its excellent conductivity. These findings underscore gold's suitability for high-performance electrical applications but also highlight the necessity for careful thermal and structural management to prevent failure.

Understanding the interplay between electric fields, material properties, and geometry is critical for the optimal design of electrical components. As electronic devices continue to miniaturize and demand higher performance, insights derived from such fundamental studies will remain vital in advancing material science and electrical engineering.

References

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Note: Actual current and power calculations depend on precise length measurements and real-world conditions such as contact quality and temperature variations.

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