Effect of Electrolytic Parameters on Patterns of Electrodeposited Copper Fractals Considering High Concentration of the Electrolyte

Viji. V.R[1], Praveen. K.H[2]

[1]Assistant Professor of Physics, University College, Palayam, Thiruvananthapuram, Kerala-695034, India
[2]Assistant Professor of Physics, Sree Narayana College, Punalur, Kerala-691305, India.

Abstract
Electrodeposition of metals using salts of the metal as electrolyte under certain conditions results in dendritic patterns that exhibits fractal character. The underlying process responsible for development of dendritic treelike structures with complex branches is the Diffusion Limited Aggregation (DLA). We studied the growth of electrodeposits from copper sulphate at high concentrations of the electrolyte solution under different conditions and the effect of voltage, time and concentration on the nature of electrodeposit is studied.

Keywords: Electrodeposition, copper sulphate, fractal, Diffusion Limited aggregation (DLA)

Introduction

In electrodeposition an electrolyte is placed between two electrodes and certain amount of emf (Electro Motive Force) is applied. The electrostatic force on the charged ions makes them drift towards the respective electrodes which in turn result in accumulation of ions at the electrodes. The positive ions like Cu++ are attracted towards the negative electrode (cathode) and negative ions like SO4-- toward the positive electrode (anode). The accumulation of positive ions at the cathode results in electrodeposition. Under certain operating conditions electrodeposition gives rise to formation of dendritic patterns with branching patterns. These dendritic electrodeposits in most of the cases exhibit scaling Fractal Characteristics. Objects having self-similarity and scale invariance are fractals. The peculiar dendritic patterns exhibiting fractal character develop because of a process called Diffusion Limited Aggregation (DLA). In DLA, the movement of metal ions with positive charge in an electrolyte, in addition to electrostatic force is under the influence of zigzag random motion (Brownian motion). Superimposition of this random motion on the directional motion due to electrostatic force makes the ions wander in the electrolyte and the path travelled becomes zigzag rather than straight. In the recent past, practical applications of the principle of Diffusion Limited Aggregation processes has increased the pace of research and development in this area. For experimental studies of growth of dendritic patterns and fractals electro-deposition process is well suited. Concept of Fractal model is being used for the forecasting the trends of the random events like prices in the share market.

Experimental

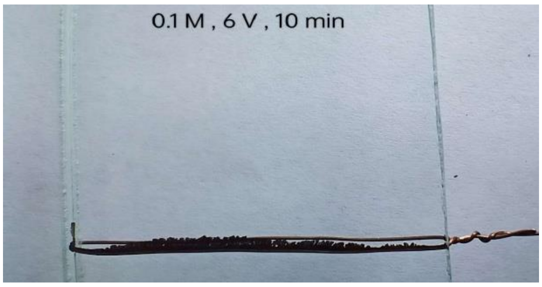
The process of electrodeposition of metals, such as copper, often results in the formation of fractals. These fractal structures are of significant interest because they model various natural phenomena and help us understand complex growth processes. In this experiment, we investigate the fractal geometries formed during the electrodeposition of copper from a copper sulphate solution. To begin, we prepare a copper sulphate solution, which is used as the electrolyte for the electrolysis process. Copper sulphate pentahydrate is used for this purpose, and its molar mass is 249.685 grams per mole. To create a 0.1 M copper sulphate solution, we dissolve 2.49685 grams of copper sulphate pentahydrate in 100 millilitres of distilled water. This solution is stirred well to ensure that all the copper sulphate dissolves completely, resulting in a clear, homogeneous electrolyte solution. The next step involves setting up the experimental apparatus. We start by cleaning two glass slides thoroughly to ensure no impurities interfere with the experiment. This is done using cotton and a suitable cleanser to remove any residues or contaminants. For the electrolysis process, we use a 12-volt DC power source. Copper wires are connected to the positive and negative terminals of this power source. The wire attached to the positive terminal will serve as the anode, and the wire connected to the negative terminal will be the cathode. These wires are placed between the glass slides which are arranged horizontally and pressed together to form a narrow gap. To secure them in place, we use clips. Copper sulphate solution is then carefully poured between the slides using a filler. This setup creates a space where the electrolysis can occur. Proper illumination is crucial for capturing clear images of the fractal structures. Therefore, the setup is illuminated with a light source positioned to avoid shadows and ensure even lighting across the entire setup.

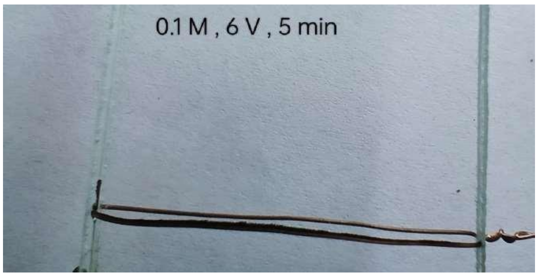
In water copper sulphate dissociates into copper ions (Cu^{2+}) and sulphate ions (SO_4^{2-}). When the power source is switched on, the copper sulphate solution undergoes electrolysis. At the anode, sulphate ions react and form additional copper sulphate. This reaction releases copper ions into the solution. These copper ions are then attracted towards the cathode due to the electric field, and gain electrons and deposit as solid copper. This deposition occurs in a manner known as diffusion-limited aggregation (DLA), which results in the formation of fractals. To study the fractal growth, we capture photographs of the electrodeposition process at various time intervals like 5,10,15,20 and 25 minutes using a camera. Ensure that we obtain detailed images that can be analysed accurately. Also, we conduct the experiment under different conditions to examine their effects on fractal formation. This includes varying the voltage supplied (6V,8V,10V,12V) while keeping the concentration of the copper sulphate solution constant. We also vary the concentration of the copper sulphate solution like 0.1,0.2,0.3,0.4 and 0.5M. Here we study fractal formation at higher concentrations.

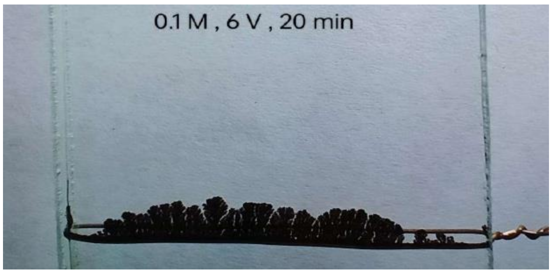
The structures so obtained exhibit complex branching patterns that are self-similar across different scales. This experiment provides insights into the fractal nature of copper electrodeposition. By varying experimental parameters such as voltage and concentration, and by analysing the resulting fractal patterns, we gain a deeper understanding of the factors influencing fractal growth.

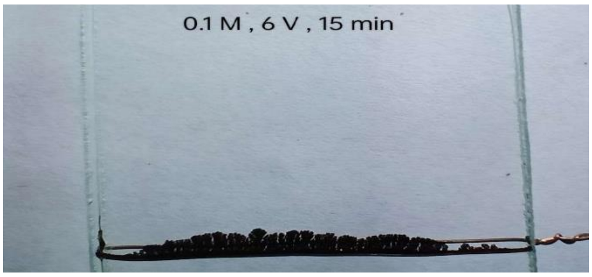
Results and discussion

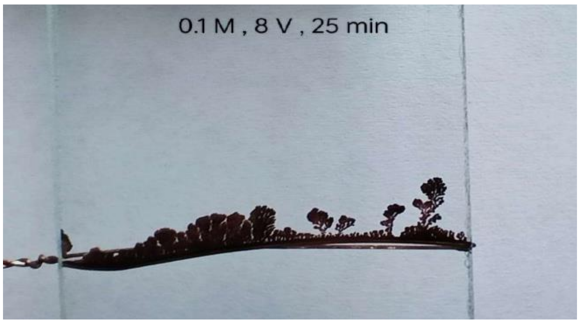
The project was conducted to study about the fractals formed by electrodeposition of copper by analysing variation of its dimension with various parameters like voltage, concentration and time, particularly using comparatively highly concentrated electrolyte. We conducted the experiment with electrolytes having concentrations 0.1M, 0.2M, 0.3M, 0.4M and 0.5M, for each concentration we have repeated the experiment by varying the voltage (6V, 8V, 10V and 12V) and for each voltage we took the photographs of fractal at different time (5min, 10min, 15min, 20min and 25min). The photographs obtained for same concentration and same voltage at different times and at different voltages for same time and same concentration and at different concentrations for same time and same voltage are shown below,

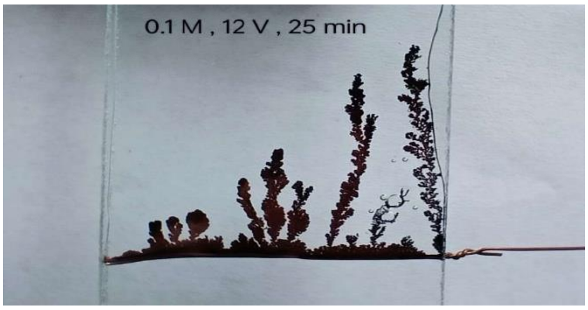


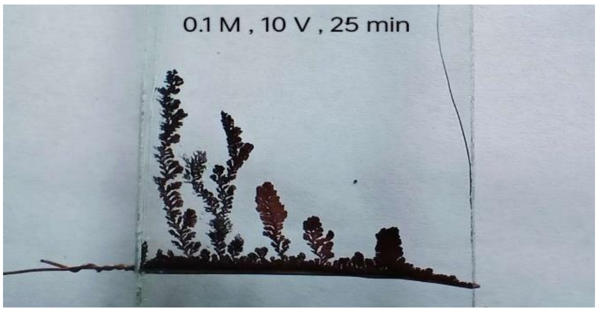


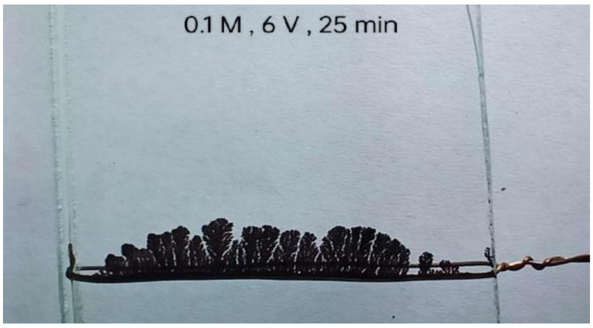


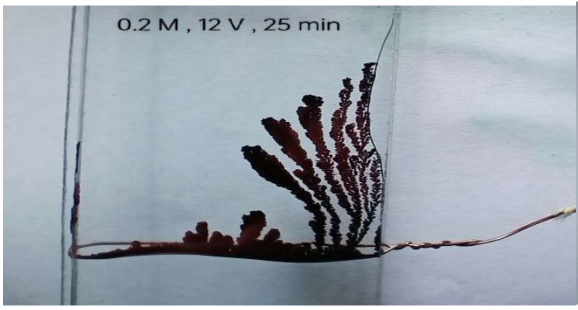


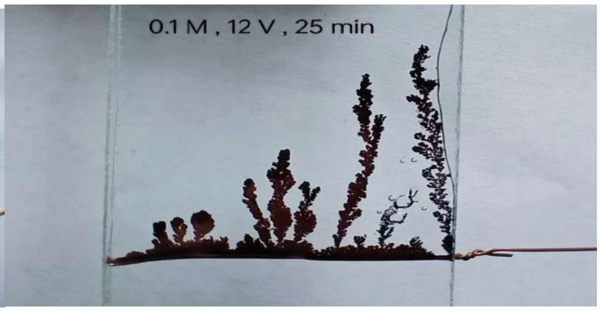


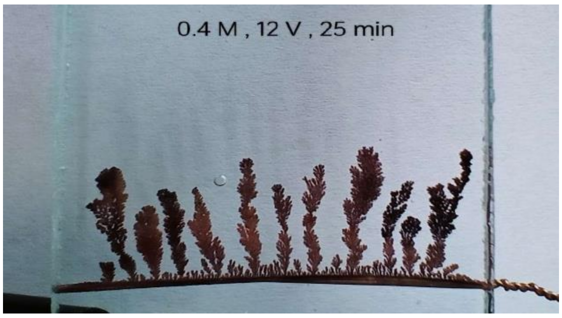


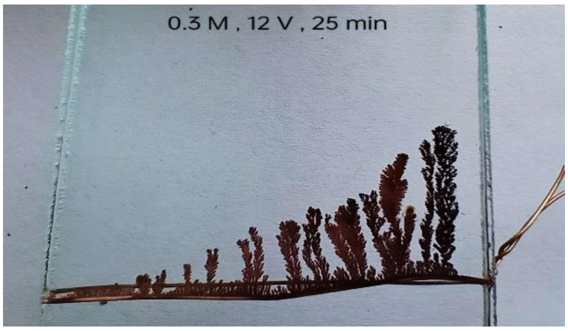


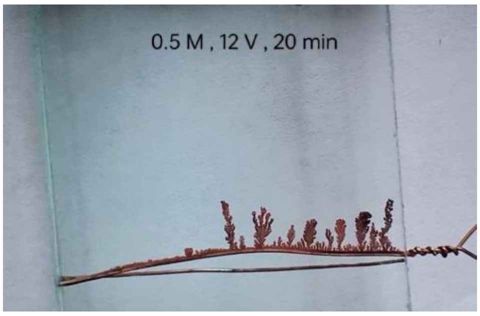


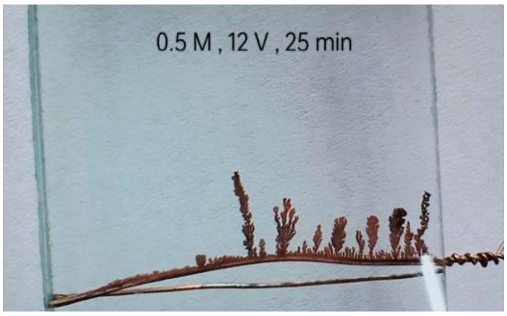












From these figures it is seen that the growth of fractals increases with time and voltage. The growth of fractals increases with increase in concentration for comparatively low concentrations but growth is becoming small at comparatively high concentrations.

Influence of time

For studying variation of properties of fractals with time, the growth of fractals for a constant voltage at different time are analysed for each concentration of the electrolyte. Time plays a crucial role in the deposition of fractal structures during the electrolysis of copper. Initially, when the electrolysis process begins, the amount of copper deposition on the cathode is relatively low. However, as the time progresses, more copper atoms accumulate on the cathode, leading to the formation of increasingly complex fractal structures. During this initial period, the deposition rate is relatively high. As time goes on, the rate of deposition slows down, although the overall amount of copper deposited continues to increase. The growth of these fractal structures is most noticeable at the tips of the branches of the fractals. As deposition time increases, these tips continue to extend and branch out, creating more intricate and detailed fractal patterns. Consequently, with longer deposition times, there is a noticeable increase in the complexity and number of branches. In summary, while the deposition rate is initially fast, it slows down over time. The fractal structures become more complex with longer deposition times, characterized by increased branching.

Influence of voltage

For studying the variation of fractal properties with voltage, the growth of fractals at 25min for a particular concentration are analysed for different voltages. The applied voltage has a significant impact on the rate of copper deposition and the resulting fractal structures. At lower voltages, the deposition process occurs at a slower rate. This is because lower voltages lead to lower currents, which means fewer copper atoms are being transported to the cathode. As the voltage is increased, the current through the electrolyte also increases. This higher current facilitates the deposition of more copper atoms onto the cathode. As a result, the rate at which copper is deposited accelerates, leading to a more rapid formation of copper fractals.

With increasing voltage, not only does the deposition rate increase, but the reaction rate also rises. This heightened reaction rate contributes to more significant and faster branching of the fractal structures. In summary, higher applied voltages enhance the deposition rate and reaction rate, resulting in more extensive and intricate branching of the fractal structures.

Influence of concentration

For studying variation of properties of fractals with concentration, the structure of fractals for a constant voltage and at constant time are analysed for different concentrations of the electrolyte. Concentration plays a crucial role in the deposition of fractal structures during the electrolysis of copper. The higher concentration facilitates the deposition of more copper atoms onto the cathode. As a result, the rate at which copper is deposited accelerates, leading to a more rapid formation of copper fractals It is seen that the branching decreases as concentration becomes very high. This may be due to collision suffered by copper ions in the electrolyte. At high concentration of the electrolyte the number of copper ions and hence the collision suffered by them increases.

Conclusion

During the electrolysis process using copper sulphate as the electrolyte, the electrochemical deposition of copper leads to the formation of fractal structures. This fractal growth occurs due to the movement of copper ions under the influence of an applied electric field and their random motion in the aqueous solvent, which follows Brownian motion. The results show that the fractal growth increases with both longer deposition times and higher applied voltages. This indicates that both factors contribute to the more intricate and complex growth of the copper fractals. It is observed that as the deposition time increases, the size and complexity of the fractal structures also grow. Higher voltages result in increased current, which accelerates the deposition of copper ions on the cathode. This enhanced deposition rate contributes to more complicated branching and a greater fractal dimension. Additionally, the concentration of electrolyte also affects the growth of fractals. As concentration becomes very high it will be difficult to obtain fractal structures.

In summary, the formation and complexity of copper fractals during electrolysis are significantly influenced by the deposition time and applied voltage. Longer deposition times and higher voltages lead to larger and more complex fractal structures. But high concentration of the electrolyte limits fractal growth.

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