Light-harvesting nanomaterials for removal of carbon dioxide (CO$_2$)

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INTRODUCTION

Global warming is one of the major concerns and challenges that we face this century. Over the past decade, research activities have moved towards the artificial conversion of carbon dioxide (CO$_2$) into fuels or valuable chemicals, through thermochromic, biological, electrochemical or photostatic methods. In the long term, the artificial photosynthesis and photocatalytic conversion of CO$_2$ using solar energy and nanocatalysts is the most attractive and efficient route for reducing CO$_2$. In our project, we developed a fabrication method for copper nanorod based metamaterials that have a high reactive surface area and can be used as an efficient nanocatalyst for plasmon-driven catalytic conversion of CO$_2$.

FABRICATION METHOD OF PHOTOCATALYSTS

The Cu nanorod metamaterials were fabricated using magnetron sputtering, chemical etching and electrochemical techniques based on anodic alumina oxides (AAO) templates [1]. This method has the ability to create large-area arrays with tunable nanometric dimensions. This is important for both the plasmonic properties but also the photo-catalytic activity of Cu materials, which are strongly dependent on the geometry and size, as well as the oxidation state of the Cu$_2$O surface [2]. Our fabrication method is highly controllable and can be easily applied to large surface areas, with an added benefit of high uniformity. Furthermore, the ability to tune their optical properties in the visible region is also crucial for photocatalysis because 43% of the solar energy lies in the visible light regime.

In addition, we have developed a core-shell Cu$_2$O plasmonic metamaterial by electrochemically oxidising Cu nanorods surfaces in aqueous solution at room temperature. The ultrathin copper oxide films were controllably fabricated with nanometric precision by applying a redox potential determined via cyclic voltammetry (CV).

PHOTO-ELECTROREDUCTION OF CARBON DIOXIDE (CO$_2$)

Various catalysts have been investigated, identifying active and selective candidates that show higher photocatalytic performance than natural photosynthesis. In our project, we studied the electrochemical and photo-electrochemical behaviour of copper nanorod-based catalysts. As expected for a hot carrier-driven process, the plasmonic photocathode copper nanorods exhibit a linear photocurrent response with respect to the incident laser power.

SUMMARY

Copper-based nanocatalysts present a great opportunity for driving photo-electrochemical reactions, such as CO$_2$ reduction reactions, at the nanoscale using hot carriers from plasmonic metal nanostructures in the presence of light irradiation. First, we developed a highly-controllable and inexpensive fabrication method of copper-based nanomaterials with various dimensions and hence a tunable optical response. In addition, we tackled the problem related to an oxidation of copper by harvesting Cu$_2$O thin layer as a carrier extraction layer and an additional catalytic material that we electrochemically formed via anodisation process with nanometric precision.

The performed photoelectrochemical characterisation of the array of Cu nanorods and core-shell Cu$_2$O nanomaterials showed an enhanced performance, comparable with other plasmonic enhanced reduction approaches with significant stability at the applied reduction potentials.

To summarise, the combination of the well-known catalytic behaviour of metallic copper with plasmonic catalytic enhancement of the array of copper nanorods presents the opportunity to explore this system’s potential as an efficient and selective photocatalyst for CO$_2$ reduction reaction.

REFERENCES


Graphs and tables related to photocatalytic performance and characterization are included.