Controlling ionic currents in batteries using graphene gate electrode

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Abstract: We use DC electrical bias and AC induced optical effect to control the external current and voltage of wet-cell batteries.

Summary: Electrochemical reactions have been studied for many years. In wet batteries oxidation of the anode takes place and the positive metal ions are dissolved into an electrolyte. Reduction takes place in the other half of the battery at the cathode. The circuit is completed by drift and diffusion of ions in the electrolyte. The two-half cells are brought to contact via a graphene-coated membrane (a Teflon filter). Graphene – monolayer or, a few layers thick graphite, is a good gate electrode because it is less likely to oxidize and may be permeable to ions.

Schematic of the cell is shown in Fig. 1. In one half-cell, Zn electrode was immersed in $ZnSO_4$. In the other, a solid Cu electrode was immersed in $CuSO_4$. Graphene-coated 10 micron Teflon filter (the membrane) separated the two half-cells. Electrical control of the battery is made by applying a bias between the gate electrode (graphene) and one of the battery's nodes. We monitored the short-circuit current and the open circuit voltage as a function of the bias voltage.

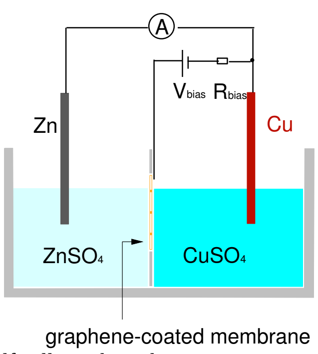

Fig.1. The two half-cells are brought into contact via a graphene-coated membrane (Teflon filter). Electrical bias is provided between the graphene and Cu (G-Cu) or G-Zn electrodes.

Only a few studies were devoted to optically induced effects in batteries. The effect of light on the plating of copper has been studied some hundred years ago. Photo dissociation of water was achieved in the presence of a catalyst. Here discuss these properties in the context of gated batteries.

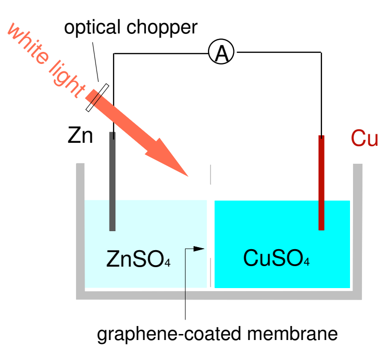

Fig.1. Light source illuminated the graphene membrane and/or the electrolyte and the cell's potential and current were monitored as a function of the light intensity, light frequency and light intensity modulations.

Light from an optical source was split into two: one arm illuminated the sample through an optical chopper while the other arm illuminated a reference detector. A lock-in amplifier along with the optical chopper enabled homodyne ac measurements. The reference frequency was taken as the optical chopper's frequency. The ac battery's open-circuit potential (V_{ac}) was measured as a function of the chopper's frequency and as a function of light intensity. We demonstrated that V_{ac} as a function of the chopper frequency behaved as a low pass filter. The effect could be explained by the light induced change on the copper ion concentration.

In Fig. 3 we show an experiment ascertaining the potential of the gate graphene electrode. It was measured with respect to a reference Ag/AgCl electrode. The bias potential V_{bias} was applied between G-Cu and G-Zn, respectively. Two points are noted: (1) the curve with respect to bias is linear and (2) The standard potential of graphene is very close to that of the copper.

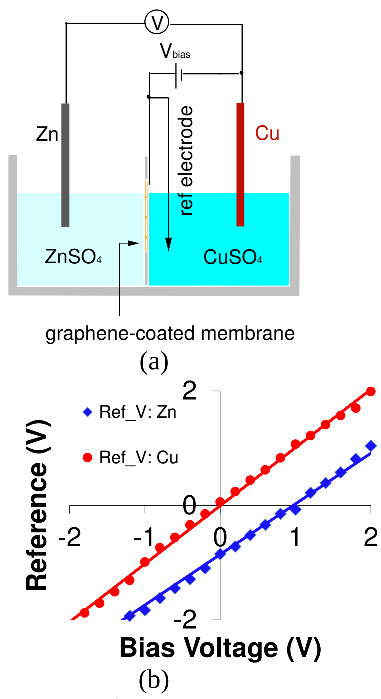

Fig. 3. (a) Experimental configuration. (b) The graphene electrode potential with respect to a reference electrode when a bias is applied between either G-Cu or G-Zn. (

Finally, we measured the light induced V_{ac} as a function of the bias voltage to find that we can tune the battery's electrical resonance. Such studies demonstrate that the battery may be treated as an active circuit element and not just as a power source.

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