Analysis of Electrical Properties of Nano Composites with LRC Circuit Simulation

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Abstract

In this work Nano particles (NP) are represented by a network of L-R-C equivalent circuit. The proposed circuit is simulated here using Circuit-Maker ® 2000. NPs are represented by C-R combinations to manifest the Coulomb blockade effect of a quantum dot. The capping material is represented by an inductor along with a resistance in series. Nine and sixteen NPs are simulated with capping matrix to represent different concentration of NPs. The dc CVC of these two types of NC with different concentration obtained by experiment and simulation study are compared and found to be consistent.

1. Introduction

Nano composites (NC) are complex systems constituted by nano particles (NP) surrounded by capping medium. NPs are molecular clusters; their average dimension is of the order of 10^{-9}m. They are chemically hyperactive due to high surface to volume ratio. Formation of larger clusters is prevented by encapsulation of the NPs with comparatively inert materials. Due to extremely small size, the NPs can be taken as quantum dots. The CVC of a quantum dot can be explained by Coulomb blocked phenomena. This Coulomb blockade model (CBM) is implemented here to get an equivalent model. The model can be found in the literatures [1, 2]. The internal structures of the nano composites are complicated in nature and exact solution is not readily available. The development of a simplified model with essential features of the original system can serve the purpose. The NPs are represented here by capacitor in parallel with a resistor. The surrounding capping material is represented by resistively coupled inductors. The proposed model of simulation and the results obtained from there are discussed in the following sections.

2. Sample Preparation

In situ production of ZnO nano-composite was performed from zinc acetate, analytical grade (CDH, India) and gum acacia (E. Merck Ltd., India). 1.0 g of $Zn(CH_3COO)_2$ was dissolved into 50 ml distilled water. About 3.0g of gum acacia powder was dissolved into 50 ml hot distilled water. These two solutions was mixed together and refluxed continuously at boiling temperature (~104 ºC) for 15 hrs to get first sample. Second sample was prepared with 2.0 g of $Zn(CH_3COO)_2$ instead of 1.0 g. These two samples were cast to form measurable pellets after adequate drying.

3. Experiment

The pellet is placed between two Cu electrodes. The DC CVC is measured with a voltage sweep from 0 V to 2 V in step of 20 mV. It was reported earlier that the sweep of measured current with supply voltage, for NC [3, 4], is generally oscillatory in nature. The measured currents for two samples are plotted in abscissa with applied voltage in ordinate. This graphical diagram is shown in Fig.1. Curve A and B in Fig.1. Respectively represent the CVC of higher and lower concentration of NC.

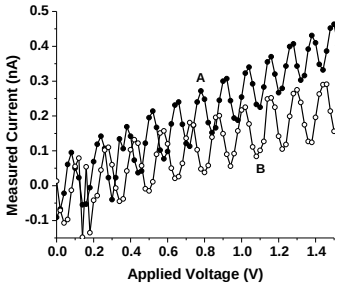

Fig. 1. DC CVC of ZnO nano composites.

This experimental CVC shows an oscillation in measured current with respect to applied voltage. It is clear from the figure that the conductivity increases with NP concentration in the sample.

4. The Circuit

The circuit consists into two parts. The first part simulates the source and second part is the model for sample simulation.

4.1 Sample Simulation

The model is developed on the basis of CBM of the quantum dot. The sample in reality is randomly oriented nano particles in the background of gum acacia. These NPs are considered as spherically symmetric particles. A single particle is represented by four identical capacitors with a resistance parallel with each capacitor, forming the four arms of a square. This nano particle square block (NPB) is represented in Fig.2.

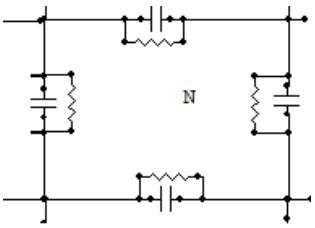

Fig. 2. Single nano particle square block.

Surrounding capping agent is implemented by an inductor with a resistance in series. This L-R combination is connected in each corner of the NPB. The sample placed between two electrodes is essentially a metal-insulator-metal (MIM) system. [5] The insulator is the nano composite under examination. The simulated model for the NC is an assembly of nine NPB each surrounded by L-R combinations. One terminal of the measuring probes is connected to the MIM through a resistance and another one is grounded. The circuit diagram is shown in Fig.3.

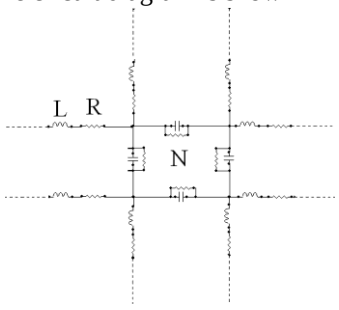

Fig. 3. The single NPB with L and R linking with other NPB.

As a result the NC is represented by a 3×3 matrix of NPB and L-R combinations. A second simulation was also carried out with 4×4 matrix of NPB and L-R combinations. The values taken for C, R and L are suitably chosen such that the magnitude of response current form simulation is close to the experimental results. This 3x3 and 4x4 matrices represented lower and higher concentration of NP respectively.

4.2 Source Simulation

The experiment with ZnO NC was performed with Kiethley 2400 source meter. The CVC was measured with stair-case mode of the voltage generator. The source used in the simulation is also a two-transistor stair-case generator. The relevant circuit diagram can be found in the literature [6].

5. Comparison of Results

The results obtained from simulation of the 3×3 and 4×4 L-R-C model of NP are shown in Fig.4. The CVC of the sixteen NPB indicates higher conductivity than nine NPB. There is a clear similarity in between the CVC obtained from experiments and the characteristics of the proposed circuit.

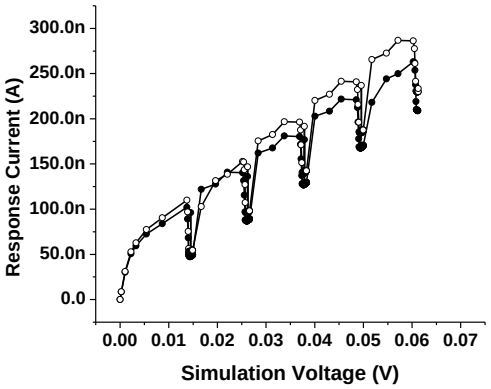

Fig. 4. The simulated CVC of the nano composites.

6. Conclusion

The proposed model is based on Coulomb blockade effect. A system of n× n (n=3,4) array of NPs oriented in a regular pattern forms nano-composites which are replaced by L-R-C combinations. The results obtained from simulated model and experiment is in good agreement. There is a clear similarity in between experiment and the characteristics of the proposed circuit for the CVC and nature of the obtained conductivity.

7. Acknowledgment

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