Materials Science in Semiconductor Processing 26 (2014) 690–694

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp

New materials for "quantum" storage of electric power

I.I. Grygorchak, B.A. Lukiyanets, O.V. Balaban *, T.M. Bishchaniuk, R.Ya. Shvets

Lviv Polytechnic National University, Bandera Str. 12, Lviv 79013, Ukraine

ARTICLE INFO

Available online 26 September 2014

Keywords:
Nanosized material
GaSe
MCM-41
Host–guest system
Dielectric constant
Loss tangent

ABSTRACT

The dielectric constant and the loss tangent of such nanostructured materials as MCM-41 with encapsulated into its pores, the ferroelectric liquid crystal (LC) or rhodamine 6G and B dyes, as well as the characteristics of the intercalated GaSe by the L-aspartic acid (LAA) are investigated. Influence of microwave irradiation on characteristics of the MCM-41 <LC> nanohybrid and impact of illumination along the crystallographic *c*-axis on the GaSe <LAA> nanostructure are described.

1. Introduction

Physical properties of such systems with reduced dimensionality as thin films, filaments and small particles are the subject of intense current scientific investigations. Materials implemented into a matrix with nanometer pores, i.e., the nanocomposite porous materials filled by various substances belong to such systems also. Properties and structure of the initial materials and encapsulated ones may significantly vary. The degree of filling of the porous matrix, interaction of particles with the walls of pores and interparticle interactions are the significant factors of such discrepancy. Especially strong size effects have an influence on the phase transitions of different types [1–4]. The results obtained based on these studies will initiate a new scientific and technical branch, namely the creation of quantum spin batteries and capacitors. Mechanisms of their work will provide theoretical possibility of achieving the specific energy and power inaccessible to the electrochemical processes [5–6].

In paper [7] the theoretical calculations of a system of vacuum nanotubes (called "digital quantum battery") are presented. It is a system of billion tiny capacitors with interelectrode distance of 10 nm. In PCT Patent 99/00012 a very thin dielectric layer with a large area of contact, which is realized in nanostructured ceramic composites, is proposed for energy storage. Here, the dielectric constant ε value is 2×10^6, and expected specific energy is ~1.6 MJ/kg.

Authors [8] found electromotive force of spin origin in a nanostructure with alternate magnetic and nonmagnetic nanolayers inside. Formed tunnel junction in it contained a huge number of quantum nanomagnets of a specific composition.

This combination realizes an electromotive force within 100–1000 s in a static magnetic field. The magnetic energy is transformed to the electrical energy due to magnetic quantum tunneling. Spin capacitor is proposed on the silicon field effect transistor basis, which provided electromotive force of ~0.1 V due to spin polarized injection.

2. Experimental details

To achieve high technical characteristics of the energy storage materials, we studied such structures as the semiconductor clathrates with cellular topology of the guest supramolecular cavitand and the multilayered nanohybridized inorganic/organic structures (Fig. 1).

Ordered mesoporous MCM-41 was the host material for the first type of nanostructures (Fig. 1a). This material has a hexagonal arrangement of one-dimensional mesopores with diameters ranging from 2 to 10 nm and wall

* Corresponding author. Tel.: +380 322582267.
E-mail address: ksjsha502@gmail.com (O.V. Balaban).

http://dx.doi.org/10.1016/j.mssp.2014.09.011
1369-8001/

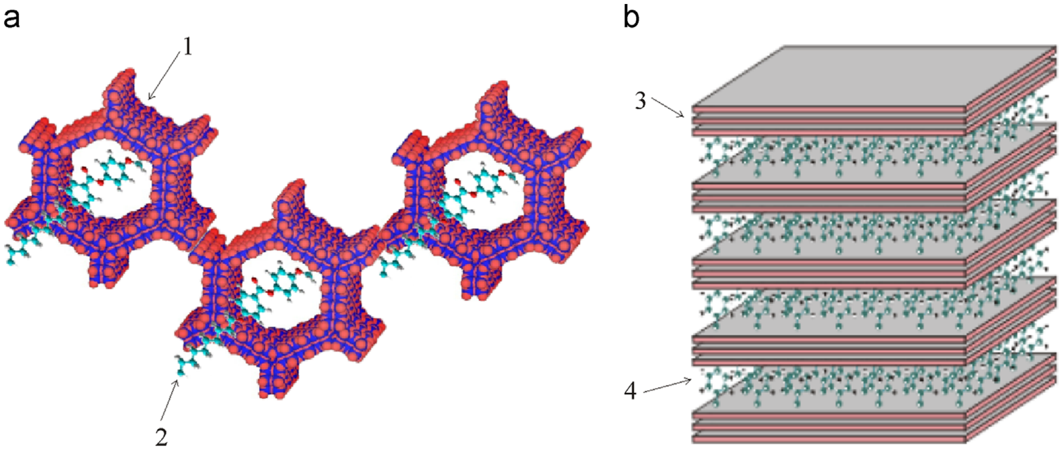

Fig. 1. The schematic representation of organic/dielectric (a), organic/semiconductor (b) structures. 1 is MCM-41 host material, 2 is LC or dyes organic guest, 3 is GaSe host material and 4 is LAA organic guest.

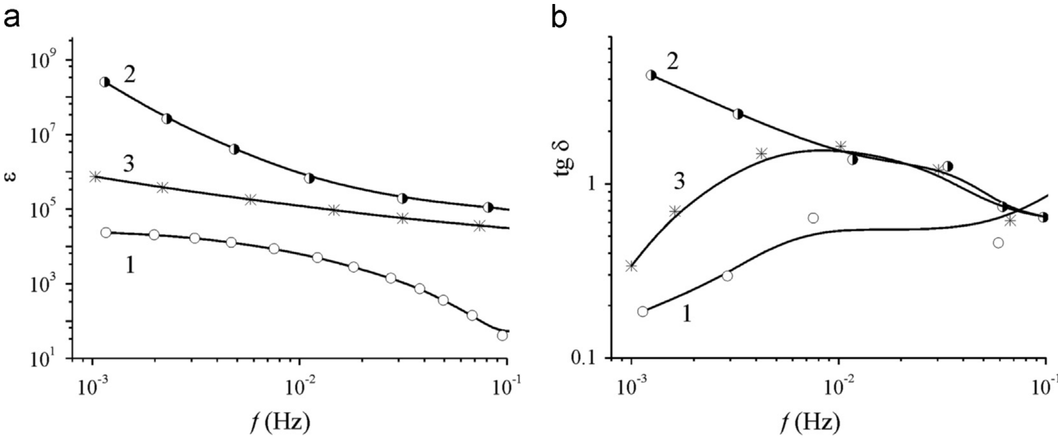

Fig. 2. Infra-low frequency dependence of the dielectric permittivity (a) and the loss tangent (b) of the initial matrix. MCM-41 (1), MCM-41 < LC > nanohybrid before (2) and after (3) microwave irradiation.

thickness within 0.6–0.8 nm. The walls of the channels are amorphous SiO_2. The pore size is about 37 Å. The specific channels surface is about 984 m^2/g [9]. The homogeneity of the pores, high surface area, and good thermal stability make MCM-41 an attractive molecular sieve for the application in catalysis, sorption of large organic molecules, chromatographic separations, as well as host for quantum confinement of guest molecules [10]. For the first type of nanostructures guests were rhodamine 6G and B dyes and a ferroelectric liquid crystal (LC) (Fig. 1a), which consists of the *C* achiral smectic (a phenylbenzoate derivative) and a chiral component. Implementation of guests into the MCM-41 matrix was achieved by using the known method that was described in [11,12]. According to it, the samples to study were formed at the same time. The samples were like a tablet 5 mm in diameter. The thickness of the MCM-41 with encapsulated LC (the MCM-41 < LC > structure), and MCM-41 with encapsulated rhodamine 6G and B dyes (MCM-41 < rhodamine6G >, MCM-41 < rhodamineB >) tablets were 1.4 mm, 0.65 mm and 0.75 mm accordingly. After encapsulation the MCM-41 < LC > nanohybrid was subjected to microwave irradiation during 10 s.

The gallium selenide (GaSe) layered semiconductor was used as a semiconductor matrix for the second type of nanohybrids (Fig. 1b). The layers of GaSe stacked together via van der Waals interactions. The GaSe semiconductors are characterized by the presence of so-called guest positions that are oriented perpendicularly to the crystallographic *c*-axis of the areas with weak van der Waals forces. Introduction of impurity ions, atoms, or molecules into the interior crystal spaces is known as the three stage reintercalation procedure, described in [13]. The size of formed sample was $5.4 \times 4.3 \times 0.9$ mm^3.

Impedance measurements in the direction of the crystallographic *c*-axis were performed in the frequency range of 10^{-3}–10^6 Hz with a measuring complex AUTOLAB (firm "ECO CHEMIE," Netherlands) equipped with computer programs FRA-2 and GPES.

3. Results and discussion

The mesoporous MCM-41 matrix and MCM-41 < LC > nanohybrid with their low electronic conductivity may be interesting especially for dielectronics. Because of a