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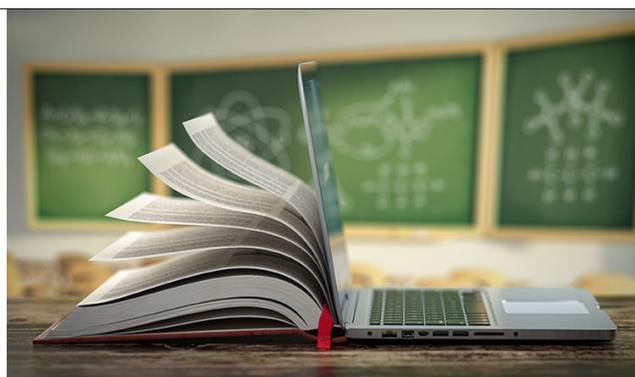
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**B Kazarkin, A S Mohammed, A Stsiapanau, S Zhuk, Y Satskevich and
A Smirnov**

Belorussian State University of Informatics and Radioelectronics (BSUIR), Minsk,
220013, Belarus

E-mail: kazarkin_boris@mail.ru

Abstract. We report a transparent conductor based on Al nanomesh, which was fabricated through Al anodization and etching processes. The Al anodization was performed at low temperature condition to slow down the anodization rate to achieve the well-controlled thickness of an Al nanomesh. By careful controlling of the anodization process, we can fabricate Al nanomesh transparent conductors with different sheet resistance and optical transparency in the visible spectrum range. We shall show that Al nanomesh transparent conductor is a strong contender for a transparent conductor dominated by ITO.

1. Introduction

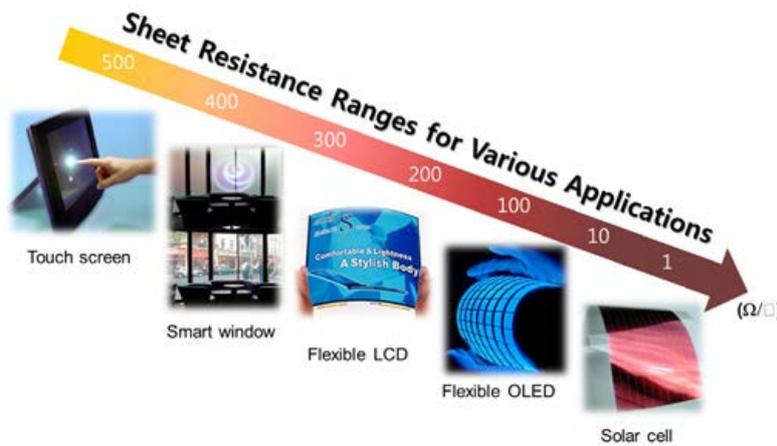
The main interest in considering of porous aluminum oxide is the technology of its manufacturing. Electrochemical anodizing of Al results in a relatively ordered structure of aluminum oxide. This technology doesn't require photolithography processing, therefore it's could be quite cheap [1-2].

To obtain nanomesh aluminum structure it's necessary to use features of growth of aluminum oxide. This structure is optically transparent and electrically conductive. These parameters depend on geometrical structure of porous alumina films [3].

In addition to good optical transparency and almost metallic conductivity, ultrathin aluminum nanomesh film is flexible and durable. In order to obtain an aluminum nanomesh with various pores size, it's necessary to change anodizing voltages, content and concentration of an electrolyte. It allows one to change the basic electro optical properties, such as optical transparency and electrical conductivity.

Aluminum nanomesh films can be used also as a substitute for ITO in light emitting devices, solar cells and other optoelectronic applications. It is possible also to fabricate a high resistance transparent ultrathin film if needed.





	Sheet resistance	Optical transmission	Ease of customisation	Haze	Ease of patterning	Thickness	Stability	Flexibility	Reflection	Low cost
ITO-on-glass	3	3	3	3	3	1	4	1	1	1
ITO-on-pet	3	3	3	3	3	1	4	2	1	1
Silver Nanowires	4	4	3	1	3	4	1	5	4	3
Graphene	1	5	2	5	3	5	2	5	5	1
Carbon Nanotubes	3	4	3	5	3	3	5	5	5	2
PDOT:PSS	1	3	3	1	4	2	1	5	3	5
Micro Fine Wire	4	1	5	2	5	1	2	5	3	5
Metal Mesh (emboss)	5	3	1	2	5	5	4	4	3	5
Metal Mesh (direct print)	5	1	1	2	5	2	2	4	3	5
Metal Mesh(etching)	5	3	2	2	5	2	2	4	3	5
Other nanotechnology	5	4	5	2	5	4	3	5	2	3

Excellent	5
Good	4
Moderate	3
Moderate-to-Poor	2
Poor	1

2.Methodology

It is possible to achieve many useful structures by anodizing the bi-layer structures, where top porous anodic oxide is used as a template for anodizing or etching the bottom layer. Masking makes easier the pore nucleation process in the bottom layer, therefore more regular porous structures in less aggressive electrolytes can be formed in the bottom layer.

In this paper we will describe how to get a transparent conductive aluminum nanomesh film on a glass substrate using low temperature non lithography low cost anodizing technology. We propose to change anodizing parameters in the final stage of the process, which allows to open transparent windows and leave a nanomesh from aluminum residues.

The technology for the fabrication of aluminum nanomesh films with needed parameters is presented in Fig. 1

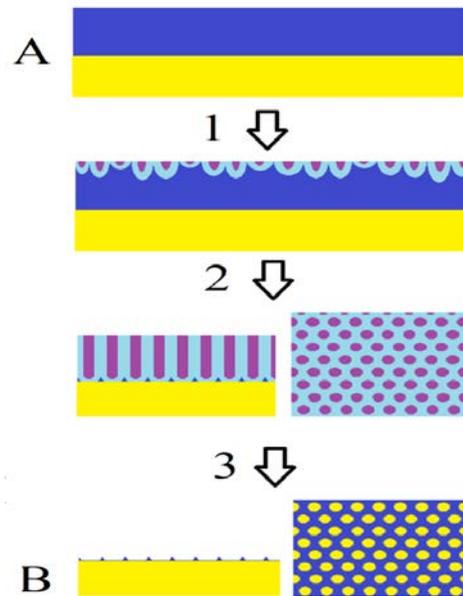


Figure 1. Al nanomesh manufacturing process: A - a glass substrate with initial aluminum layer; 1- start of the anodizing process; 2- stop anodizing; 3-etching of porous Al_2O_3 ; B- aluminum nanomesh on a glass substrate.

3.Results

In our experiments we used $1 \times 1 \text{ cm}^2$ glass substrates covered with magnetron sputtered aluminum film of 200 nm thick. Aluminum nanomesh was obtained by anodic oxidation of aluminum in anodizing cell (Fig. 2) at a temperature of 10^0C in 2% solution of phosphoric acid at anodizing voltage of 100 V. Chromic acid solution (potassium dichromate) was used to etch of porous aluminum oxide. Images of obtained samples are shown in Fig. 3.

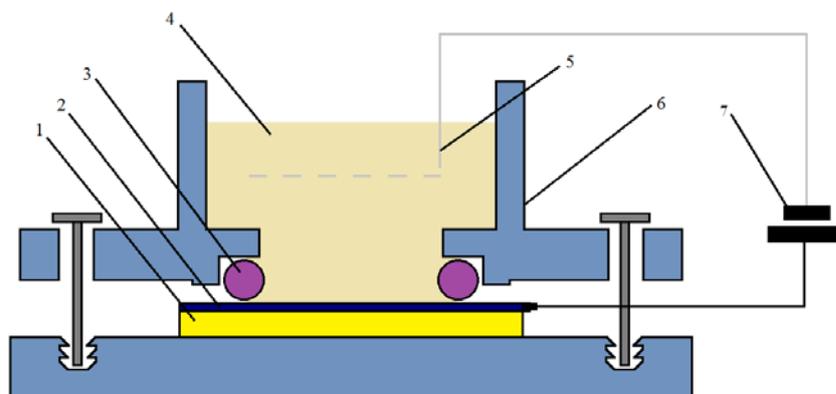


Figure 2. Electrochemical cell: 1- glass wafer; 2- deposited aluminum; 3- O-ring; 4- electrolyte; 5- platinum electrode with platinum net; 6- cell body; 7 – power source.

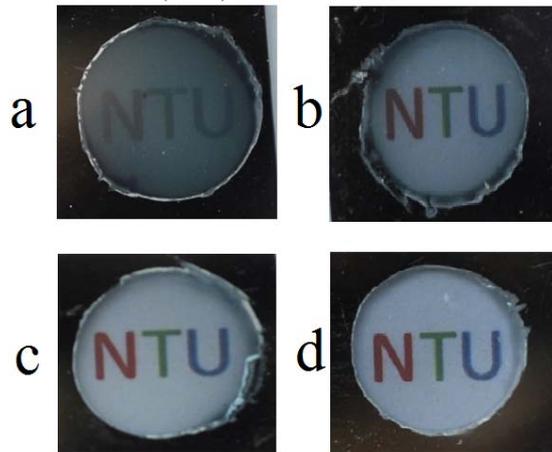


Figure 3. Obtained samples aluminum nanomesh on glass wafers: a- $R_s=3 \text{ Ohm/sq}$; b- $R_s=16 \text{ Ohm/sq}$; c- $R_s=1 \text{ KOhm/sq}$; d- $R_s=17 \text{ KOhm/sq}$.

Morphology of obtained nanomesh structures was obtained with SEM SUPRA-55WDS(Fig.4-5).

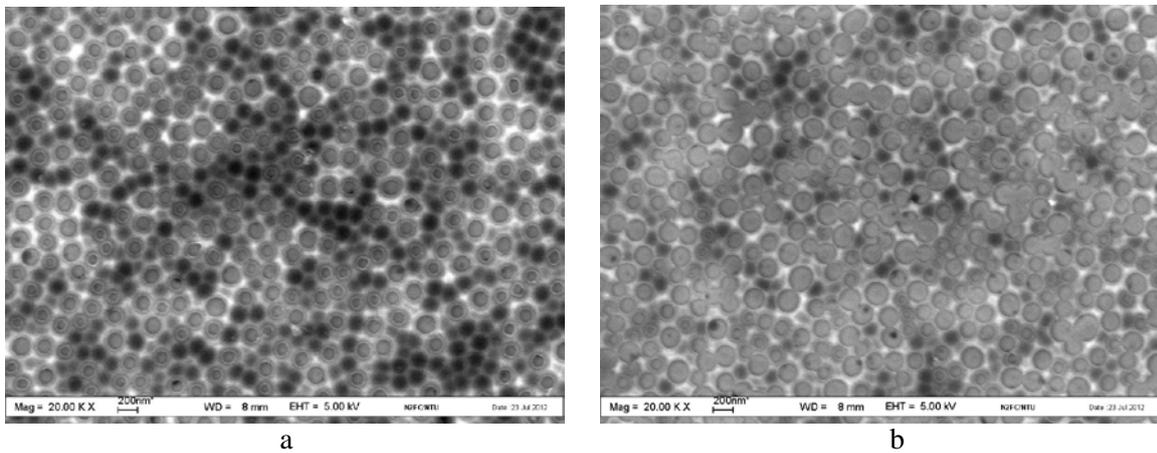


Figure 4. SEM images of nanomesh: a - $R_s=3 \text{ } \Omega/\square$; transparency=17%, b - $R_s=16 \text{ } \Omega/\square$; transparency=39%.

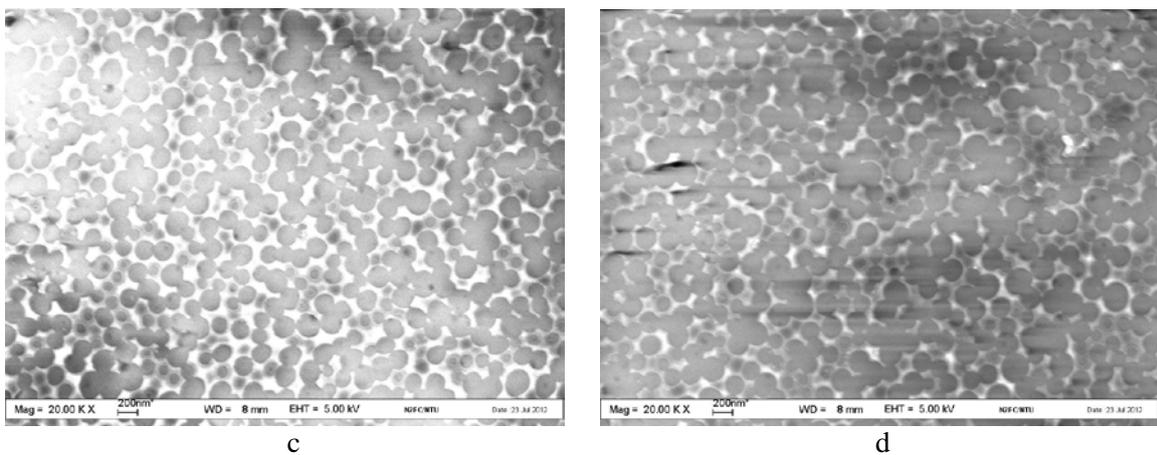


Figure 5. SEM images of nanomesh: c - $R_s=1 \text{ K } \Omega/\square$; transparency=57%, d - $R_s=17 \text{ K } \Omega/\square$; transparency=63%.

Through the method of anodic oxidation of aluminum, we were able to obtain an aluminum nanomesh with different values of transparency (from 17% to 63%) and sheet resistance (from $3 \Omega/\square$ to $17\text{K}\Omega/\square$). SEM-images (Fig. 1 a-d) clearly show the structure of the obtained nanomeshes. The sizes of the porous (150-200 nm) and inter porous distances (200-250 nm) are almost equal.

The spectral characteristics of the samples are shown in the Figure 3.

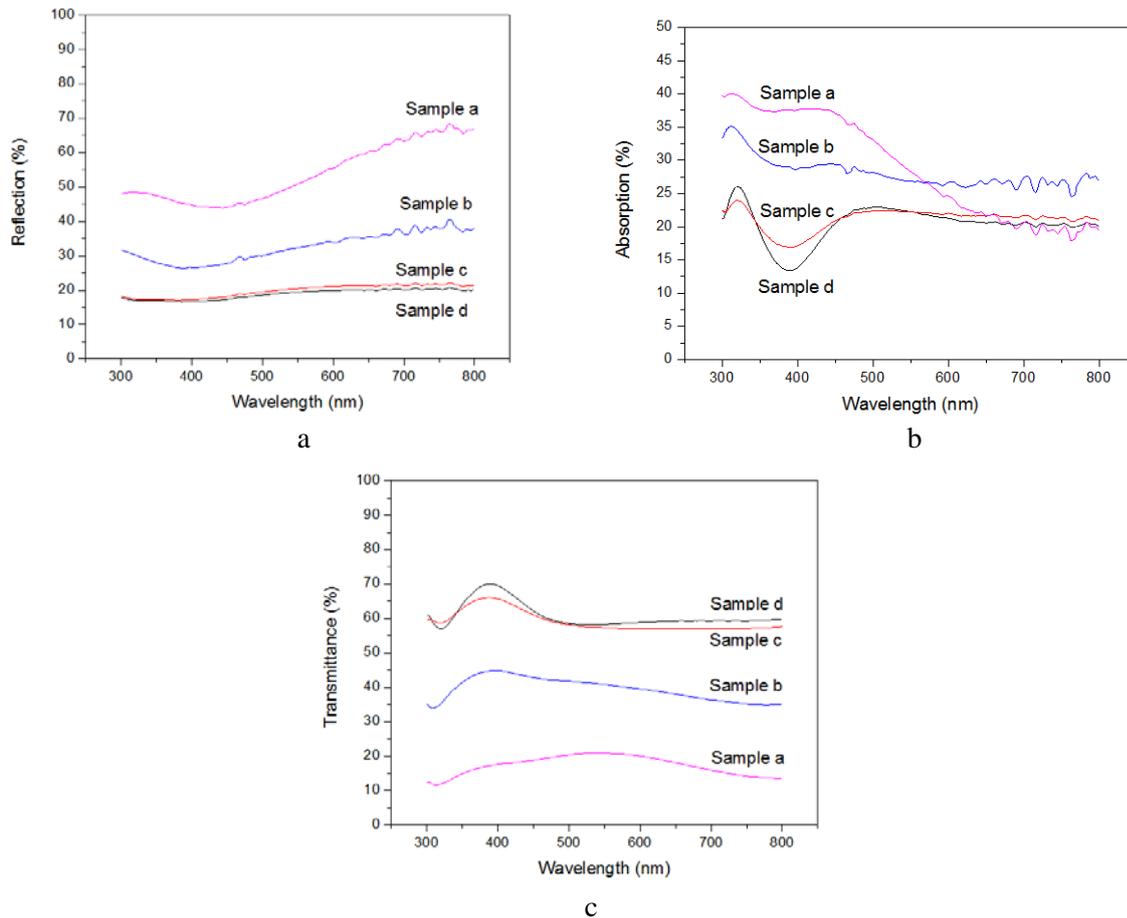


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Using the features of the porous alumina growth allowed us to obtain a cheap ultra-thin material with good optical properties and conductivity of a metal. Aluminum nanomeshes are cheaper than ITO, and it gives the new advantages in manufacturing areas. We believe that the unique structure, optical and electrical properties of nanomesh films can be used in various research objectives and production purposes.

References

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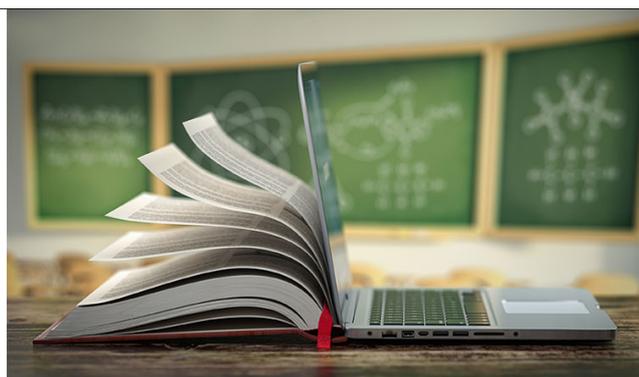
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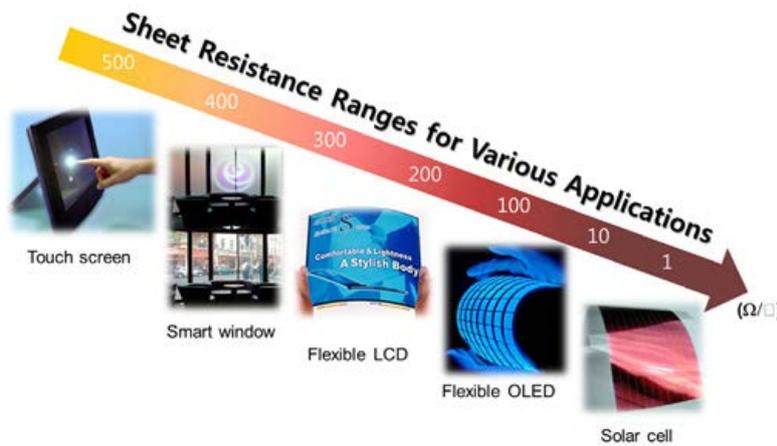
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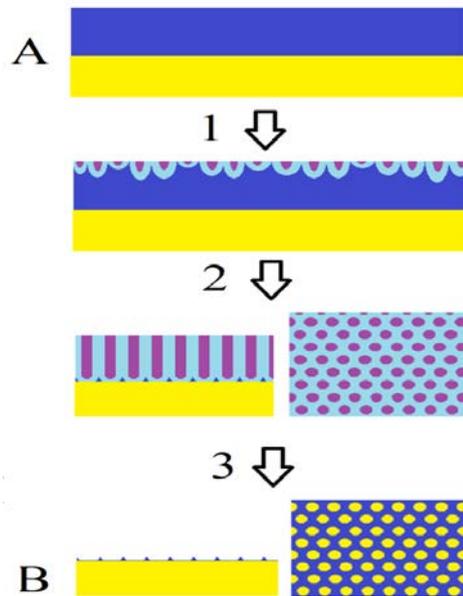


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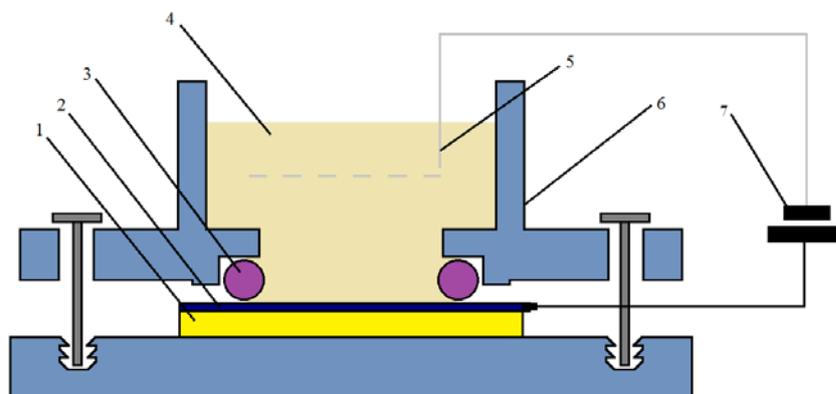


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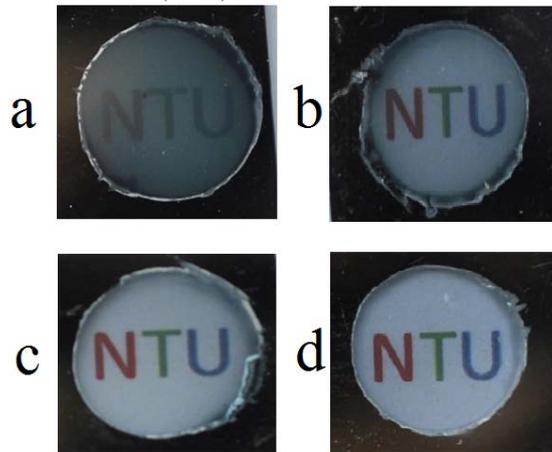


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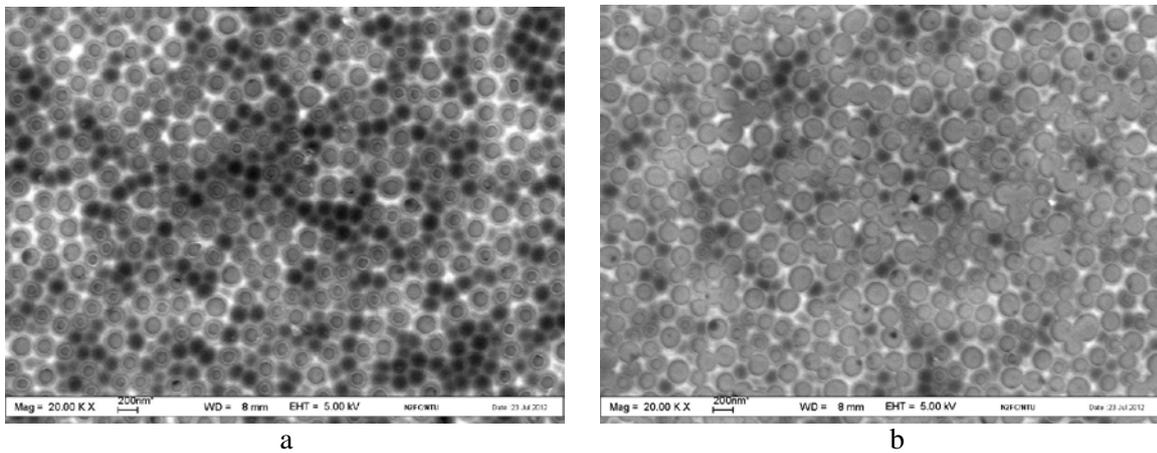


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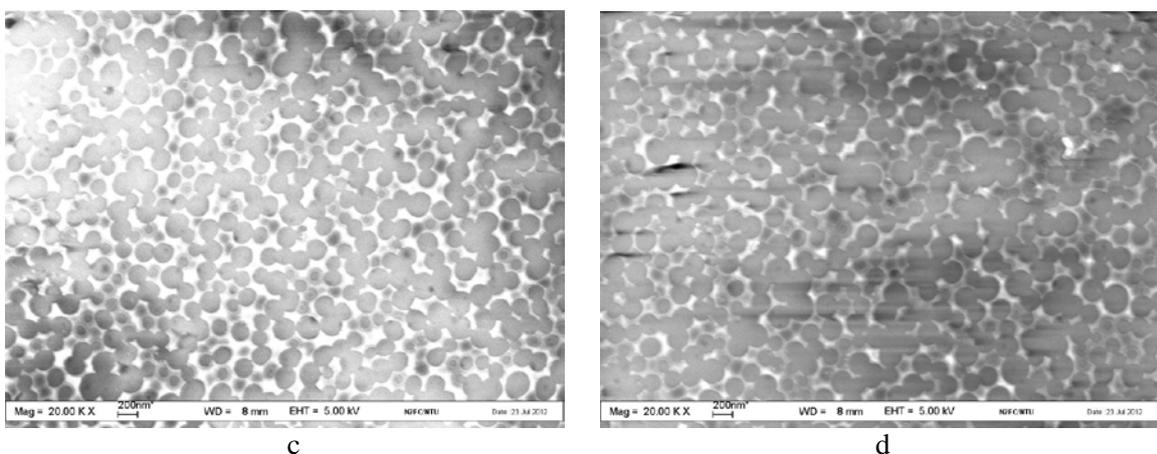


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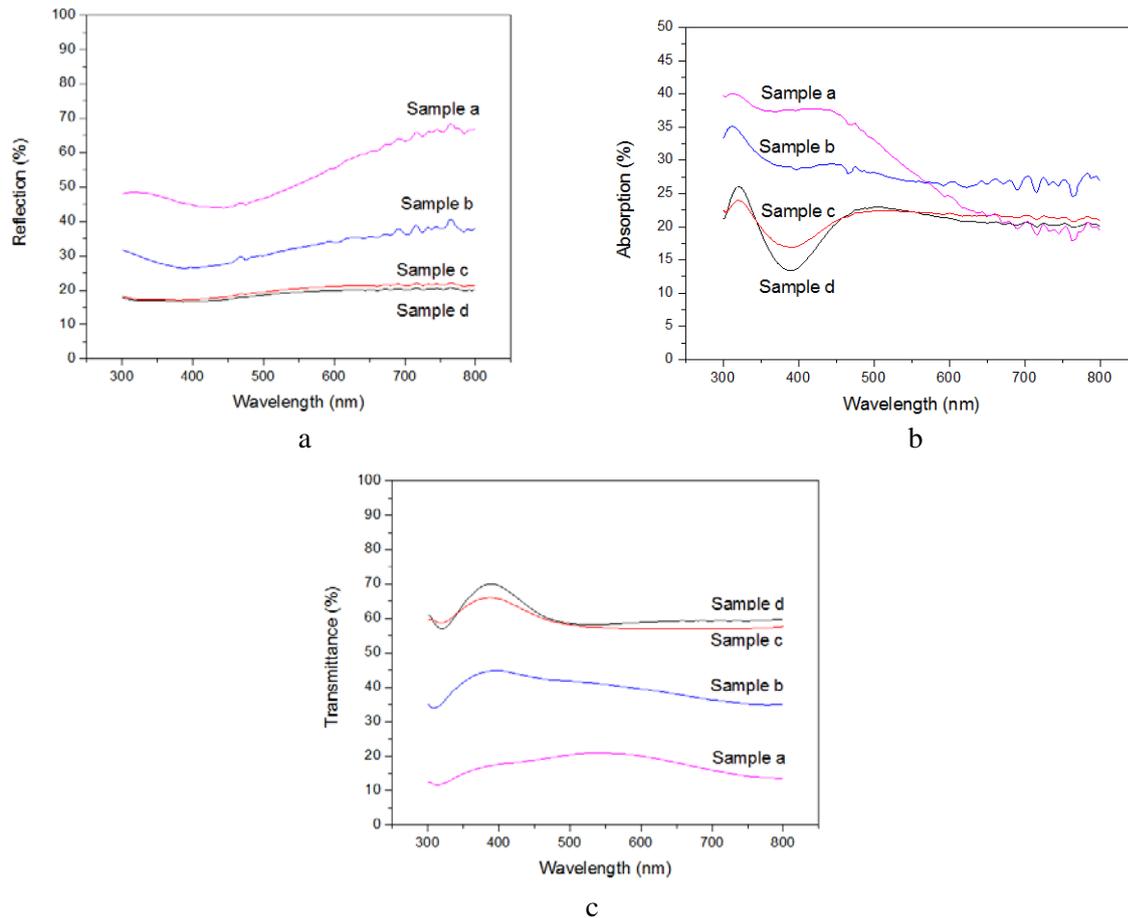


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