Formation of a conducting phase in Porous Glasses

Doycho I.[1], Lepikh Ya.[1], Filevska L.[1], Rysiakiewicz-Pasek E.[2], Grinevych V.[2,3]

[1]Odesa I.I. Mechnikov National University, Dvoryanska str., 2, Odesa 65082, Ukraine. E-mail: lfilevska@gmail.com

[2 2]Department of Experimental Physics, Wrocław University of Science and Technology, Poland

[3]Odesa State University of Intelligent Technologies and Communications

Introduction

Porous silicate glasses with column structure may be used as matrices for the formation of nanoparticles' ensembles for sensors due to the peculiarities of their structure. At the same time, rather considerable intrinsic electrical resistance of such systems, causes their usage mainly for luminescent-type sensors. At the present work it is suggested to form inside the pores the nanoparticles' ensemble of a conducting substance for significant reduce of the sample resistance. This attitude will make it applicable as an active element in resistive type sensors. Such substance is a carbon, which in the form of graphite exhibits excellent conductive properties..

Methods

To create a carbon conductive phase, the porous glass of any type should be saturated with aqueous solution of glucose. At the consequent heating to 150 ºC, it is easily reduced directly in the matrix cavities to carbon in the form of highly dispersed graphite with the release of water. This process, described by the equation

$$C_6H_{12}O_6 \xrightarrow{(t)} 6C + 6H_2O,$$

lasts about 24 hours. Its completion can be fixed visually by sample blackening. After this treatment, the initial resistance of standard size samples 1×0.5×0.1 cm^3, having several teraOhms is reduced by several orders of magnitude I.

Results

Types of porous silicate glasses with column structure depending on the thermodynamic conditions of production and subsequent chemical processing

	The low phase separation temperature in the original glass is -490 ºC	The high phase separation temperature in the original glass is -650 ºC
Type of glass after etching of the unstable phase	A	C
Type of glass after tinning	B	D

Water vapor, always present in the atmosphere, saturates the pores to a certain extent thus reducing the electrical resistance of the system. This makes it possible to use porous glass as an active element of a resistive type humidity sensor. The presence of a wide range of pore sizes (from about 10 to 100 nm in different types of glasses) corresponds to the hydrophilicity of the system in a wide range of humidity.

The size distribution of pours for different types of porous glasses, obtained by the water adsorption-desorption method

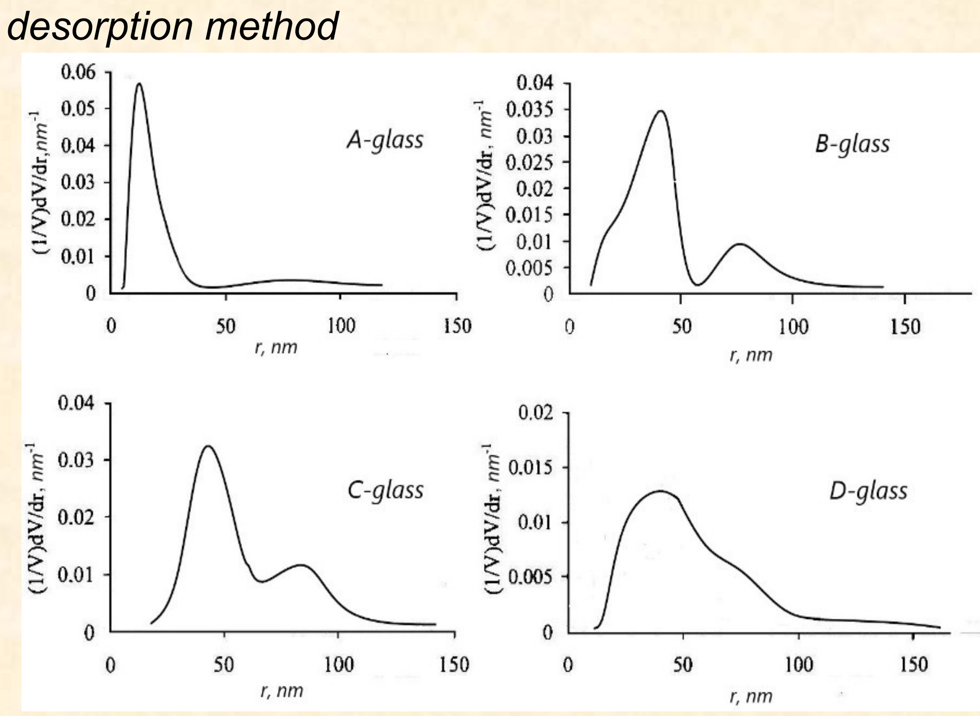

Fig. 1.

After a glass sample was immersed in a glucose solution, kept in it for a certain time, and then subjected to annealing at a temperature of about 180 C, an ensemble of carbon nanoparticles in the form of graphite is formed inside the pours. Due to the basic properties of graphite, this procedure is able to reduce the initial resistance of the obtained system by several orders of magnitude. The particular reduction in resistance will depend on the initial concentration of the glucose solution and on the type of glass used due to the separation properties of the residual silica gel.

The resistance dependence of graphite nanoparticles ensemble in type B glass on humidity at room temperature

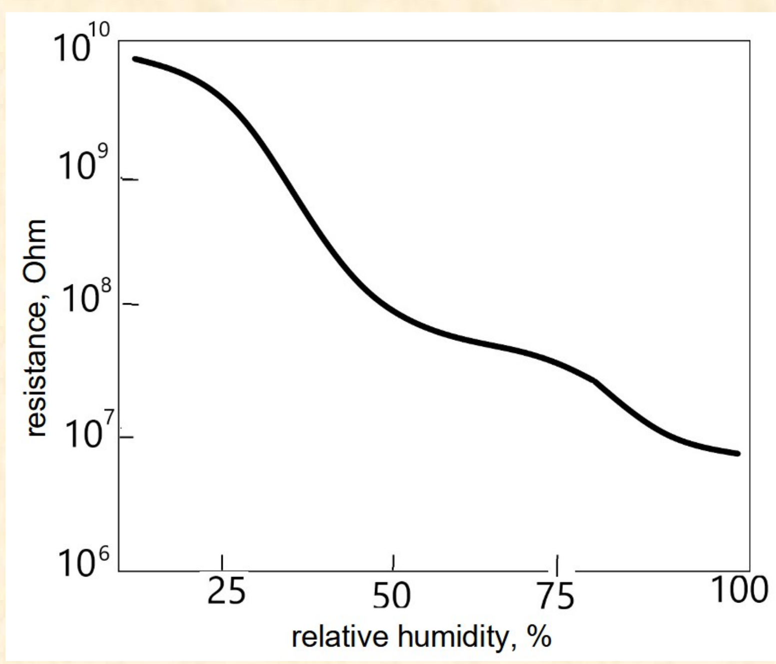

Fig. 2.

Using of 40% glucose solution concentration and in type B glass reduces the resistance of the glass by almost two orders of magnitude. For such systems, an increase of the environment humidity leads to a resistance decrease of the system to the megohm range, and such resistances are quite easily fixed.

In order to create an ohmic contact to any silicate porous glass plate, it should be subjected to partial primary carbon treatment. Usually, the dimensions of a standard flat-parallel plate are 10x5x0.5mm. So, if we immerse the end of the plate in a glucose solution to a depth of 0.5÷1 mm, we will get a typical problem of diffusion from a stable source..

The glucose driving stage into a porous glass according to Fick's second law

$$C_x = C_0 \operatorname{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)$$

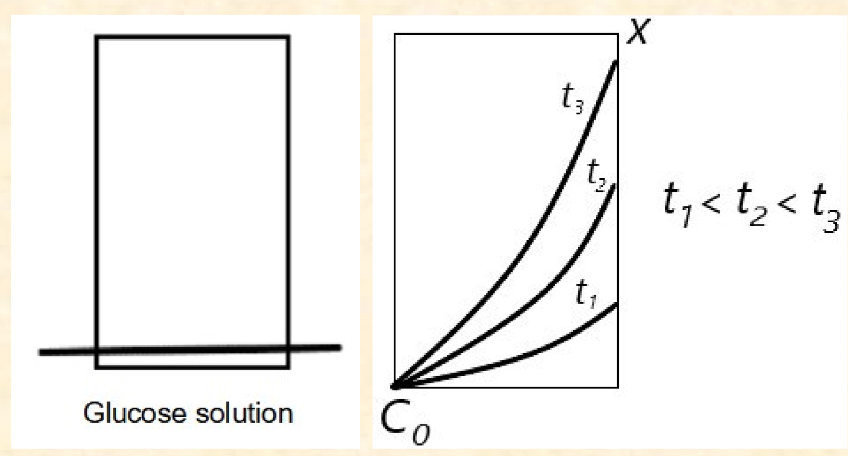

Fig. 3.

At the stage of driving according to Fick's second law, for time t at a distance x from the interface between the glucose solution and the plate, we have the glucose concentration $C_x = C_0 \mathrm{erfc}(x/2\sqrt{(Dt)})$, where C_0 is the initial concentration of the permeating solution. The coefficient D is a certain analogue of the diffusion coefficient and is called the impregnation coefficient. It depends on the type of glass and the temperature at which the impregnation occurs. The configuration of the glucose-saturated part of the plate depending on the saturation time is shown in figure 3. If necessary, it can be changed by acceleration. This is a certain analogue of the problem of diffusion from a limited source. If it is assumed that the concentration of glucose at the interface coincides with C_0, then the new concentration C_{x2} will be determined by the expression $C_{x2} = C_0 \exp(-x2/4Dt)$. The change in glucose distribution corresponding to the specified expression is shown in Fig. 4. Having chosen the right configuration of impregnated glucose, the aforementioned heat treatment can form an ensemble of graphite nanoparticles in a limited part of the plate. With the help of conductive silicone paste, an ohmic contact will be made to the porous plate at the location of this ensemble

Formation of graphite nanoparticles in glass as a result of acceleration

$$C_{x1} = C_x \exp\left(-\frac{x^2}{4Dt}\right)$$

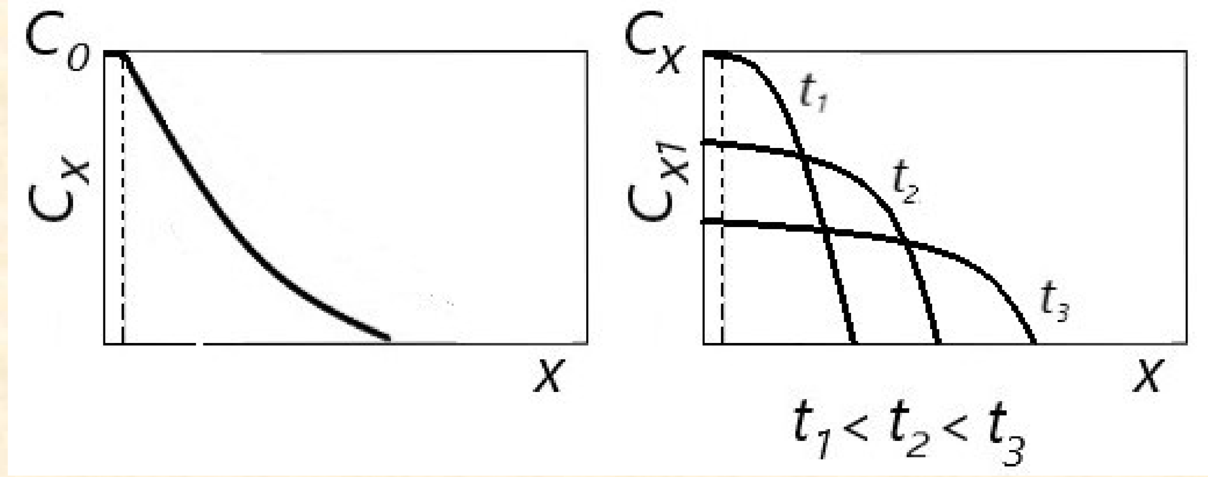

Fig. 4.

Conclusion

Primary carbon treatment can reduce the initial electrical resistance of porous glass or create an ohmic contact to an ensemble of nanoparticles in said glass. A certain type of porous glass, after proper processing, may be used as an active element of a resistive type humidity sensor, capable of operating at any temperature that does not destroy the system.

Contacts: Odesa I.I. Mechnikov National University, Dvoryanska str., 2, Odesa 65082, Ukraine. E-mail: lfilevska@gmail.com