





determine the shape and thickness of the fabricated samples.

The NI ELVIS II+ module was used to measure the current-voltage characteristics of the samples in the voltage range  $U = 0 - 3$  V; the measurement step was 10 mV. The hysteresis behavior in the current-voltage characteristics of the samples was obtained by Keysight B1500A Semiconductor Analyzer. Two ohmic contacts of InGa alloy in the coplanar configuration were deposited on the samples' surface by thermal installation to obtain electrical characteristics as shown in Figure 2.

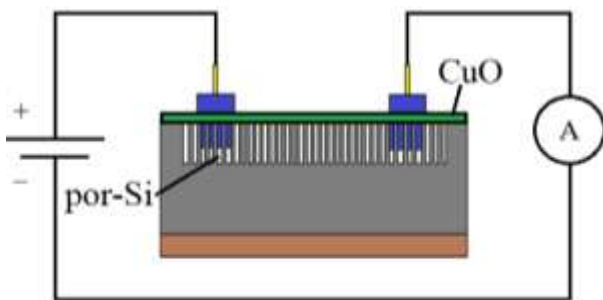


Fig. 2: Configuration of contacts for measurements

### 3 Results and Discussion

Figure 3 shows cross-sectional and top-view SEM images of the por-Si sample, which was etched for 3 min. Due to electrochemical etching in hydrofluoric acid, the pores were formed with a thickness of 5.16  $\mu\text{m}$ . It can be seen from Figure 2b that pores and air voids are randomly distributed over the entire surface. The porosity value of the por-Si sample was calculated by formula (1) and amounted to 52.6%.

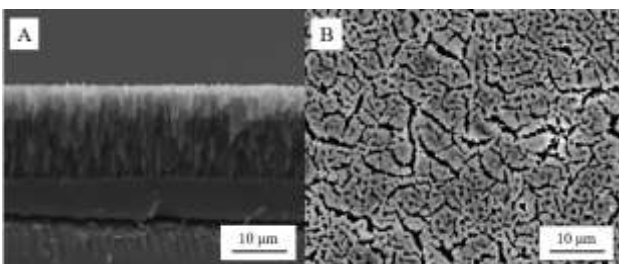


Fig. 3: Cross-sectional (A) and top-view (B) SEM images of the por-Si sample

We performed EDX measurements in conjunction with SEM to analyze the chemical composition of nanostructured material. The result of this study is presented in Figure 4. Silicon is the powder's dominant element.

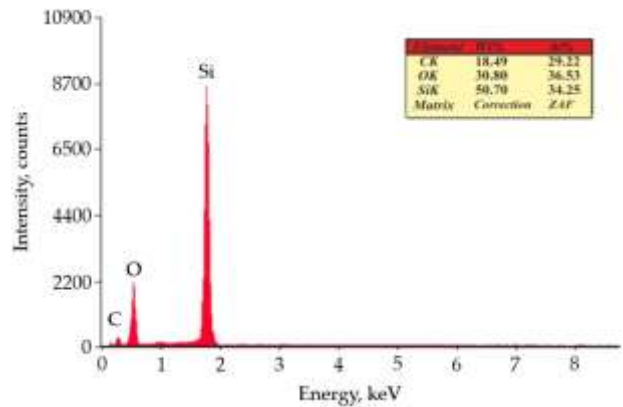


Fig. 4: EDX spectrum of por-Si sample

SEM images of por-Si and CuO/por-Si samples are shown in Figure 5. As can be seen from the figure, the CuO layer which was installed on the surface of the por-Si sample also has a porous structure. Consequently, the pores of the por-Si substrate are not completely closed, which provides a higher surface area and a diffusion channel.

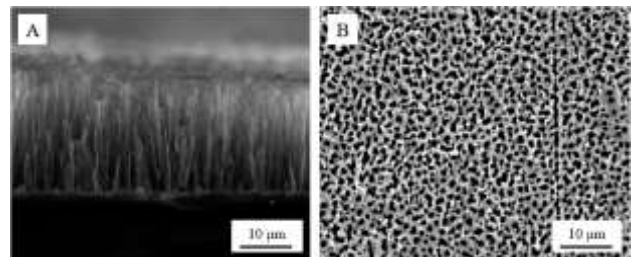


Fig. 5: Cross-sectional (A) and top-view (B) SEM images of the CuO/por-Si samples

Figure 6 shows the current-voltage characteristics of the por-Si sample with measurement intervals of 15 s, 18 s, 1 min, and 3 min, respectively, and shows a positive shift in the current-voltage characteristics after each measurement. It shows that the electrical properties of the por-Si sample depend on the applied voltage and the previous state. After 3 min, the current value of the film returns to its initial state (reset). Accordingly, it is found that the typical memristive behavior of the por-Si sample can be analyzed based on the measurement results. Figure 7 shows the current-time dependence at a voltage of 1.2 V.

At this stage, the phenomenon of hysteresis allows using memristors as memory cells. In some aspects of electronics, they will probably be able to replace semiconductor transistors. The theoretical model described in this work is more straightforward than the modeled theory in published work, [28].

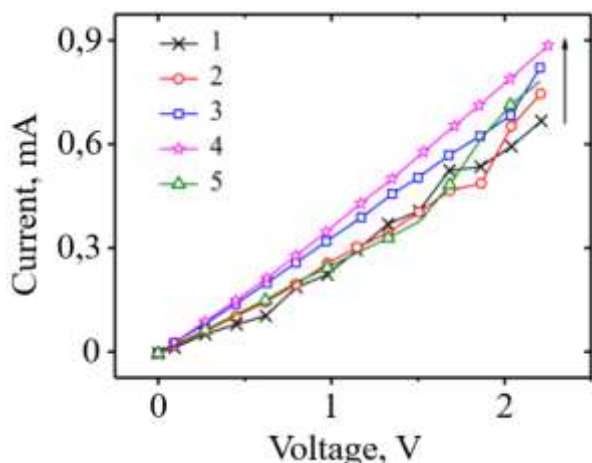


Fig. 6: Current-voltage characteristics at different time intervals, where (1) Initial state, (2) 15 sec, (3) 18 sec, (4) 1 min, (5) 3 min

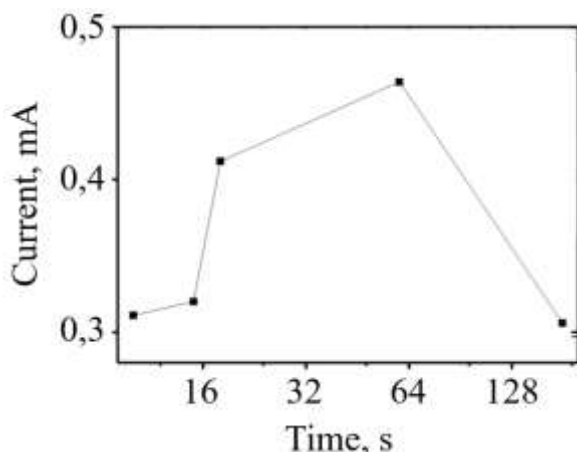


Fig. 7: Current-time dependence at 1.2V

Obtaining nanostructured por-Si films with the properties of a memristor is more accessible than getting structures based on  $\text{TiO}_2$  and  $\text{ZnO}$ . The por-Si memristor does not have the problems of three-terminal memristors [19], such as relatively low switching speed, high power consumption, and lack of a high-density massive structure. In a previous paper [36], the authors of this paper pointed out the presence of hysteresis curves of current-voltage and capacity-voltage characteristics of semiconductor films based on por-Si. The data obtained indicate the memristive properties of the films. So far, we obtained similar physical properties for semiconductor films based on por-Si with the addition of  $\text{CuO}$ .

The resulting por-Si film also had a hysteresis in the current-voltage characteristics, as in [36]. It was also found that the hysteresis area increased when this film was illuminated by a xenon lamp Oriol Sol3A ( $I = 0.1 \text{ W/cm}^2$ ,  $\lambda \text{VS}$ ). Hysteresis in the current-voltage characteristics of the por-Si are shown in Figure 8.

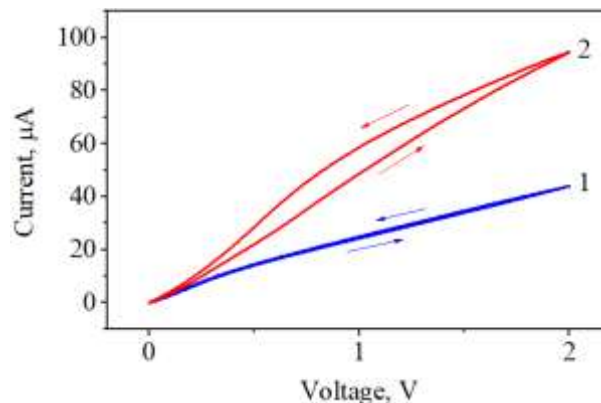


Fig. 8: The current-voltage characteristics of por-Si in the dark (1) and under illumination (2)

$\text{CuO}/\text{por-Si}$  sample was also exposed to light from a xenon lamp. Exposure to radiation increases the hysteresis area several times, indicating the film's large memristive properties. Graphs and calculations of the hysteresis area in the current-voltage curves are shown in Figure 9:

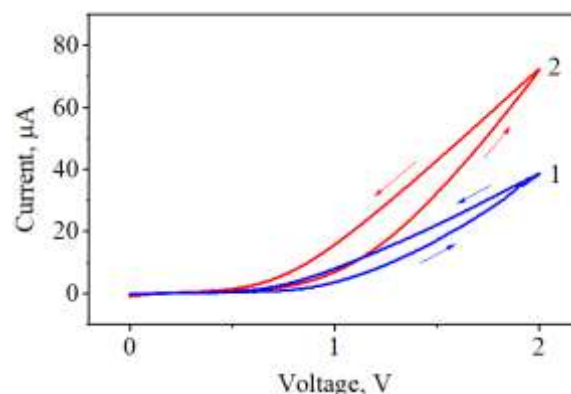


Fig. 9: The current-voltage characteristics of  $\text{CuO}/\text{por-Si}$  in the dark (1) and under illumination (2)

The hysteresis areas were processed and calculated using the Origin package, and their analytical form is presented as follows, [37]:

$$S_H = \frac{1}{2} \begin{vmatrix} X_1 & Y_2 \\ Y_1 & Y_2 \end{vmatrix} + \begin{vmatrix} X_2 & X_3 \\ Y_2 & Y_3 \end{vmatrix} + \dots + \begin{vmatrix} X_n & Y_1 \\ Y_n & X_1 \end{vmatrix} \quad (2)$$

As mentioned earlier, the hysteresis curves indicate the presence of memristance properties, and the larger the area, the better these properties manifest. The comparison tables of hysteresis areas depending on illumination are shown in Table 1.

According to data presented in Table 1, the illumination of the films contributes to an increase in the memristor properties. The hysteresis area increases almost 10 times after illumination for the por-Si sample and 2 times for  $\text{CuO}/\text{por-Si}$ .

Table 1 Hysteresis areas dependency on illumination

Hysteresis areas	Samples	
	Por-Si	CuO/por-Si
S1	1.06	5.09
S2	11.2	10.7
S2/S1	10.6	2.1

The properties of films based on por-Si suggest they could be used to create memory cells with optical control. The observed increase in hysteresis when exposed to light is attributed to numerous defects and traps on the por-Si surface, which are crucial for current transfer within the por-Si structure. The nonlinear hysteresis seen in the current-voltage characteristics of these materials is a result of potential barriers within their structure. Additionally, the hysteresis area expands due to the photocurrent generated by incident photons. Photons have enough energy to lift an electron from the valence band to the conduction band. Thus, when light falls on the surface of the samples, their conductivity increases, which leads to an increase in hysteresis. The hysteresis observed in the current-voltage characteristics suggests that resistive switching is mainly driven by the electrochemical migration of oxygen ions through a conduction path within the porous materials, [33]. The deposition and annealing process of CuO leads to the generation of oxygen vacancies. As diffusion constants depend on particle size, with diffusion in bulk being much slower than in nanoparticles due to shortened transport paths, confinement of the metal oxides to a nanoscale size enhances the ionic transport within the porous channels, [38].

#### 4 Conclusion

To conclude, por-Si holds great potential for advancing silicon-based memristive structures, offering a wide array of future applications. The results showed that with appropriate modification, for example by introducing a metal oxide on the surface, improved memristive properties can be achieved. In this work the typical memristive behavior of nanostructured por-Si and metal oxide layer deposited on it was demonstrated and analyzed. Additionally, it was found that obtaining a por-Si nanofilm with memristive properties is simple and does not require additional efforts to develop the device. It was also observed that the hysteresis areas in the current-voltage characteristics of CuO/por-Si significantly increased when exposed to illumination. These characteristics facilitate the development of memory cells and crossbar

structures with optical control. Thus, modified nanostructured semiconductors based on por-Si can be essential in successfully implementing practical memristors using economical materials and simple fabrication technologies.

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#### Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work the authors used Grammarly and DeepL platforms in order to check the grammar of sentences and improve the language of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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#### **Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)**

The authors equally contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

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#### **Conflict of Interest**

The authors have no conflicts of interest to declare.

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