Morphology of quantum wires of porous silicon

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The morphology of individual pores in porous silicon has been observed by scanning tunneling microscopy. There is a quasiregular arrangement of pores. The dimensions of the quantum wires which form have been found to be 30–100 Å.

Layers of porous silicon have recently attracted considerable research interest. This interest has been stimulated by the observation[1,2] of an intense photoluminescence in the visible part of the spectrum, with photon energies of 1.3–1.8 eV, from layers of porous silicon. It has been suggested[1–5] that a quantum size effect is responsible for the luminescence. According to theoretical work, the effect should be observed when the cross-sectional dimensions of the quantum wires are no greater than[5] 30 Å. The small dimensions of the quantum wires which form pose definite experimental difficulties in attempts to observe their structure and to compare their properties with proposed mechanisms. The method of scanning tunneling microscopy (STM), which is capable of a resolution at the atomic scale, may hold promise here.

In this letter we are reporting the use of STM for direct observation of the actual surface and the structure of individual pores of porous silicon. We have estimated the dimensions of the quantum wires which form.

The test samples were prepared on (111)-orientation samples of KÉS-0.01 *n*-type silicon. The layer of porous silicon was formed by the method of anodic etching in an alcohol solution of hydrofluoric acid ($HF–H_2O–C_2H_5OH$ in proportions of 1:1:2). The etching was carried out for 60 min in a fluoroplastic cell with platinum electrodes. The current, with a density $\simeq 30$ mA/cm^2, flowed in the direction perpendicular to the surface for 60 min (without external illumination). The thickness of the layer of porous silicon was $\simeq 50$ μm.

Figure 1 shows a photoluminescence spectrum recorded from the surface of such a layer. The pump source was an argon laser with an output wavelength $\lambda = 457.9$ nm. We see the broad luminescence peak characteristic of porous silicon. For these particular test samples, the spectral maximum is at a wavelength $\lambda \simeq 696$ nm. The width of the peak at half-maximum is $\simeq 140$ nm.

The surface relief of the porous silicon (Fig. 2) was observed with the help of a Skan-8 scanning tunneling microscope.[6] These measurements were carried out in air at room temperature. We used Ni–Cr tips fabricated by a mechanical cutting method. On a sample of pyrolytic graphite used as a reference, these tips provided a resolution at the atomic scale.

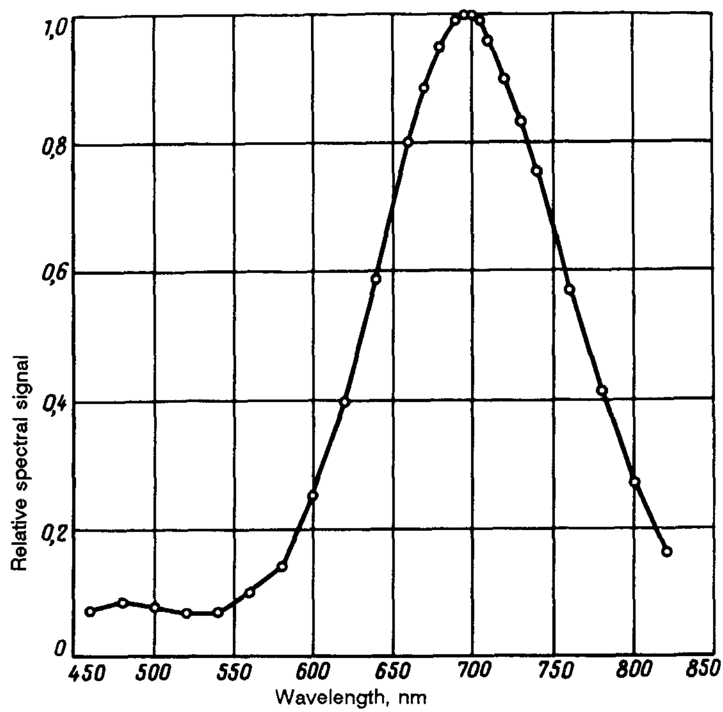

FIG. 1. Luminescence spectrum of porous silicon.

Figure 2a is an STM image of the surface of porous silicon; Fig. 2b is an STM image of a section through the porous silicon. These images were recorded under constant-current conditions. The observation of images of the surface of porous silicon at various magnifications suggests that the surface of the layer is of a fractal nature under these particular etching conditions. At the surface one can distinguish a relief with peak heights up to 100–130 Å and with peak widths of 20–30 Å at half-maximum. It is not possible to peer deeper in the actual structure of the pores near the surface because the dimensions of the tunneling probe are large in comparison with the pores. The morphology of the pores can be seen on a cleaved plane of a sample. Figure 2b shows the cleaved surface in isometry. The growth of the pores occurs along the direction of the current flow, perpendicular to the surface (along the Y axis). There is a quasiregular arrangement of pores, although the dimensions of the individual pores fluctuate substantially. The diameter of the pores also varies along their depth. Figure 3 shows profiles of the cross section of the observed surface of a section through a sample, taken at various depths. According to these results, the dimensions of the quantum wires which form range from 30 to 100 Å. The observed dimensions are thus greater than those calculated on the basis of a model.[5] One possible reason for the discrepancy is that in our case the photoluminescence was detected from the surface of the porous silicon, where there are structural features with dimensions <30 Å, as mentioned above (Fig. 2a). Intense photoluminescence has also been linked[7] with a

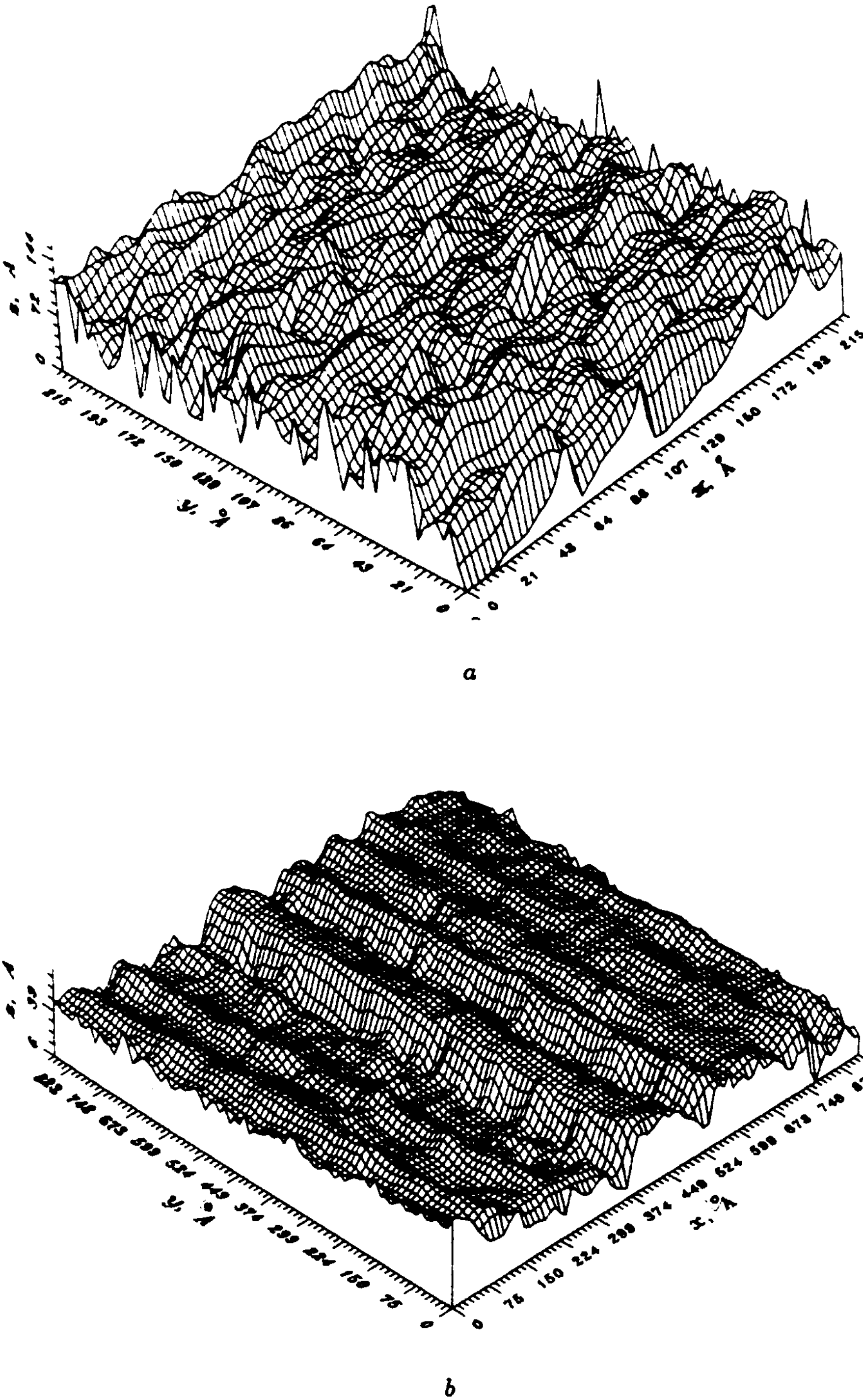

FIG. 2. STM images of porous silicon. *a*—Surface; *b*—cleavage plane.

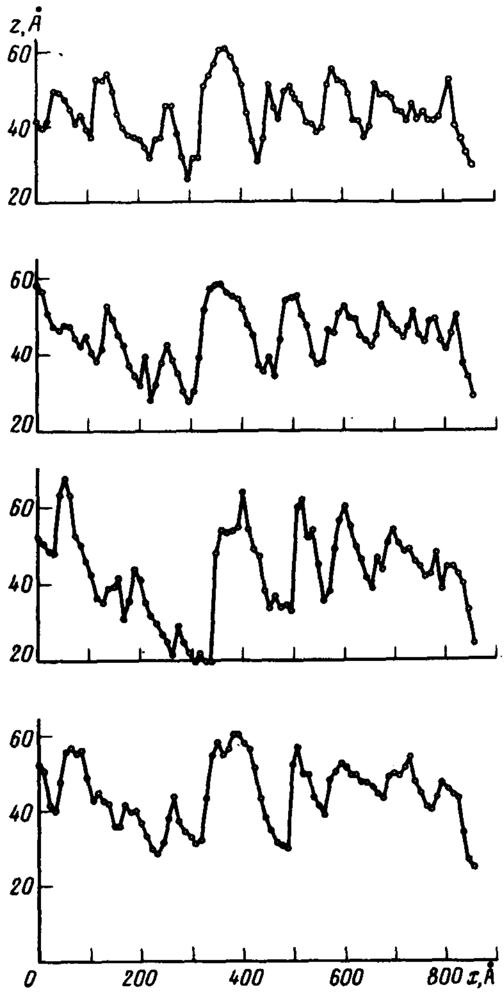

FIG. 3. X profiles of the cross-sectional dimensions of a section of porous silicon (Fig. 2b). The profiles are displaced from each other by 60 Å along the Y axis.

surface hydration effect, and it has been stated (for example) that the luminescence spectra near the surface and along the depth of pores are similar. However, the dimensions of the pores were not reported in Ref. 7. It follows from other papers that the properties of porous silicon depend strongly on the characteristics of the silicon, the time, and the particular features of the etching procedure. The structure of the porous silicon must therefore be studied directly in each specific case.

In summary, these results show that scanning tunneling microscopy makes it possible to observe the surface details of porous silicon and to estimate the actual dimensions of the quantum wires which form. These results can be used for quantitative estimates and for comparing experimental and theoretical results.

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