of the test data. The peak values of channel and SG ΔTs are predicted within about $\pm 30\%$ of the test data.

1 Vijayan, P. K., Ph D thesis, IIT, Bombay, 1988.
2. Vijayan, P. K., Venkat Raj, V., Mehta, S. K. and Date, A. W., 85-WA HT-17, Paper published at the Winter Annual Meeting of ASME, Miami Beach, Florida, November 17–21, 1985.
3. Vijayan, P. K. and Date, A. W., Int. J. Heat Mass Transfer, 1990, 33, 2479–2489.
4 Vijayan, P. K., Mehta, S. K. and Date, A. W., Int. J. Heat Mass Transfer, 1991, 34, 2219–2230.
5 Vijayan, P. K. and Date, A. W., Nucl. Eng. Des., 1992, (to appear).
6. Vijayan, P. K., Nagdaune, R. K. and Venkat Raj, V., Paper presented at the National Systems Conference, Regional Engg. College, Kurukshetra, India, 1987.
7. Vijayan, P. K., Nagdaune, R. K. and Venkat Raj, V., Proceedings of the Indo-Polish Seminar on Development of Advanced Codes and Methods for Transient and Accident Analysis of Nuclear Power Plants, Bombay, 1988, pp. 10 1–10 26.
8. Nagdaune, R. K., Vijayan, P. K. and Venkat Raj, V., Report No. 005/DEV/05011-2 (PO), November 1987.
9. Vijayan, P. K., Venkat Raj, V. and Pilkhwal, D. S., Thermosyphon Tests conducted on unit 1 of Narora Atomic Power Station, BARC Report under publication.
10. Vijayan, P. K., Venkat Raj, V. and Mehta, S. K., Proceedings of the 11th National Heat and Mass Transfer Conference, December 21–23, 1991, Madras, India.
11. Caplan, M. Z., Gulshani, P., Holmes, R. W. and Wright, A. C. D., Proceedings of Specialists' Meeting organized by the IAEA, Budapest, Hungary, 1983.
12. Kukita, Y., Nakamura, H., Tasaka, K. and Chauliac, C., Nucl. Sci. Eng., 1985, 99, 289–298.
13. Vijayan, P. K., Venkat Raj, V., Nagdaune, R. K. and Pilkhwal, D. S., Third International Symposium on Small and Medium Sized Nuclear Reactors, August 21–23, 1991, New Delhi, India.

RESEARCH COMMUNICATIONS

Pore size dependence on doping concentration in porous silicon

R. M. Vadjikar and R. V. Nandedkar
Centre for Advanced Technology, Indore 452 013, India

The dependence of pore size on doping concentration in porous silicon layers is reported here. Porous silicon layers were fabricated on $N^+/N/N^+$-doped silicon wafers by electrochemical etching at current density of $40\ mA/cm^2$ for 50 min, under ambient light conditions. Scanning electron microscopy results show that pore sizes change as the doping concentration changes in the silicon wafer. These results are discussed in view of the pore formation mechanism.

THE fabrication of porous silicon layers by electrochemical dissolution of single crystal silicon has been known since 1956[1]. The high reactivity and large surface area of porous silicon layers has spurred further investigations for several applications. The capability of easily forming an oxide layer on porous silicon has been utilized for electronic isolation in semiconductor fabrication processes such as silicon-on-insulator (SOI) and fully isolated porous oxidized silicon (FIPOS)[2,3]. Thick and stress-free silicon nitride/oxynitride films have been produced from porous silicon[4]. Fabrication of conducting tungsten films and silicon carbide layers is under investigation[5,6]. Surface micromachining of silicon has been reported by using porous silicon as a sacrificial layer[7]. The highly reactive nature of porous silicon has been used for chemical sensors applications[8].

In spite of the considerable interest in porous silicon,

its basic formation mechanism and material properties are still not well-established. Theunissen[9] proposed that the origin of etch channels is because of local breakdown of electric field barrier at the surface of silicon. The precise location of such a breakdown is dependent on crystal defects, impurities, fluctuations in dopant concentration and electrochemical dissolution conditions. Beale et al.[10] have extended this model and explained the formation of porous silicon films by suggesting that the Fermi level of silicon in porous silicon is pinned near the mid-gap. This causes the silicon–electrolyte system to behave like a Schottky barrier diode. The current flow through the Schottky barrier, by tunneling or thermionic emission, causes silicon dissolution at some locations. Once the pores are initiated at such locations, their propagation is explained by preferential current flow through the lower resistivity electrolyte rather than through fully depleted porous silicon. The Beale model does not explain all aspects of porous silicon formation[11]. More recently, Smith et al.[11] have proposed a diffusion-limited model. This model explains pore formation by availability of diffusion-controlled electrons/holes at the silicon–electrolyte interface. Lehmann and Gosele[12] have proposed a quantum confinement model for porous silicon formation. They suggest that the bandgap in porous silicon increases due to quantum charge confinement within the small dimensions of silicon wires formed in porous silicon. The increased bandgap leads to charge depletion which limits further dissolution of silicon wires. The dependence of pore morphology on the doping concentration and type has been reported by several investigators[9,13,14]. Electro-

chemical etching conditions and ambient light conditions can also influence pore morphology[15,16].

In this communication we report on the dependence of pore size on doping concentration, in the anodically biased silicon wafer. The cross-sectional morphology of the porous silicon layers was observed in a scanning electron microscope JEOL 330A operated at 25 kV. In our experiments porous silicon layers were grown in a 1:1 ethanol:48% HF electrolyte using a power supply working as a current source. The experimental arrangement consisted of a teflon cell, an inert cathode, the silicon anode, a magnetic stirrer and a digital multimeter. The current density was kept at 40 mA/cm² and the duration of the experiment was 50 min. The silicon wafer used as anode had base resistivity of 30 ohm-cm. Both sides of the wafer were diffused with phosphorus to get a $N^+/N/N^+$ structure in the wafer. The details of the diffusion process have been reported elsewhere[17]. Only one of the faces of the above silicon wafer was exposed to the electrolyte, the remaining parts of the wafer were covered with acid-resistant wax.

The formation of a brown layer on the surface of the anode gave visible evidence of porous silicon formation. Further confirmation was obtained by observing yellow-orange luminescence by exposing the wafer to UV radiation from a nitrogen laser. This observation of luminescence in these samples suggests that the origin of luminescence is from surface chemical species formed during the etching process, as also reported elsewhere[18,19].

The results are illustrated in Figures 1 and 2. Figure 1 gives a view of the cleaved edge of the sample. The transition in pore size, at depth of about 10 μm, is very clear. Figure 2 is a higher magnification view of the same edge. The pore size changes from less than 1 μm

to approximately 5 μm. The transition region is not very smooth, probably due to the doping technique used. This observation is in rough agreement with other techniques of measuring junction depth such as by ball grooving and bevelling.

Ligeon et al.[20] have reported that impurity profiling can be done in p-type silicon by monitoring the potential changes during porous silicon formation. While the dependence of pore size on doping concentration has been previously reported[9,14], these investigators have not reported the effect of dopant concentration variation on pore size, on the same wafer. Our results suggest that the morphology of porous silicon, fabricated under galvanostatic conditions, can give a very good indication of dopant concentration, and especially of abrupt changes in dopant concentration in a silicon wafer. The pore initiation region, having smaller pore sizes than the bulk, as reported by Searson et al.[21], is not observed in our samples.

The discussions of pore formation mechanisms generally assume that all potential drops except those in the space charge region and the Helmholtz layer are constant[14]. The Helmholtz region controls the charge transfer and the pore propagation, while the semiconductor space charge region controls the morphology.

Searson and Zhang[22] report that reaction control for N-type silicon is predominantly by semiconductor space charge effects, while for N^+, P^+ and p-type silicon are generally under Helmholtz reaction rate control. Hence it appears that in our samples the change in morphology with increasing dopant concentration is related to increasing role of space charge effects in pore formation.

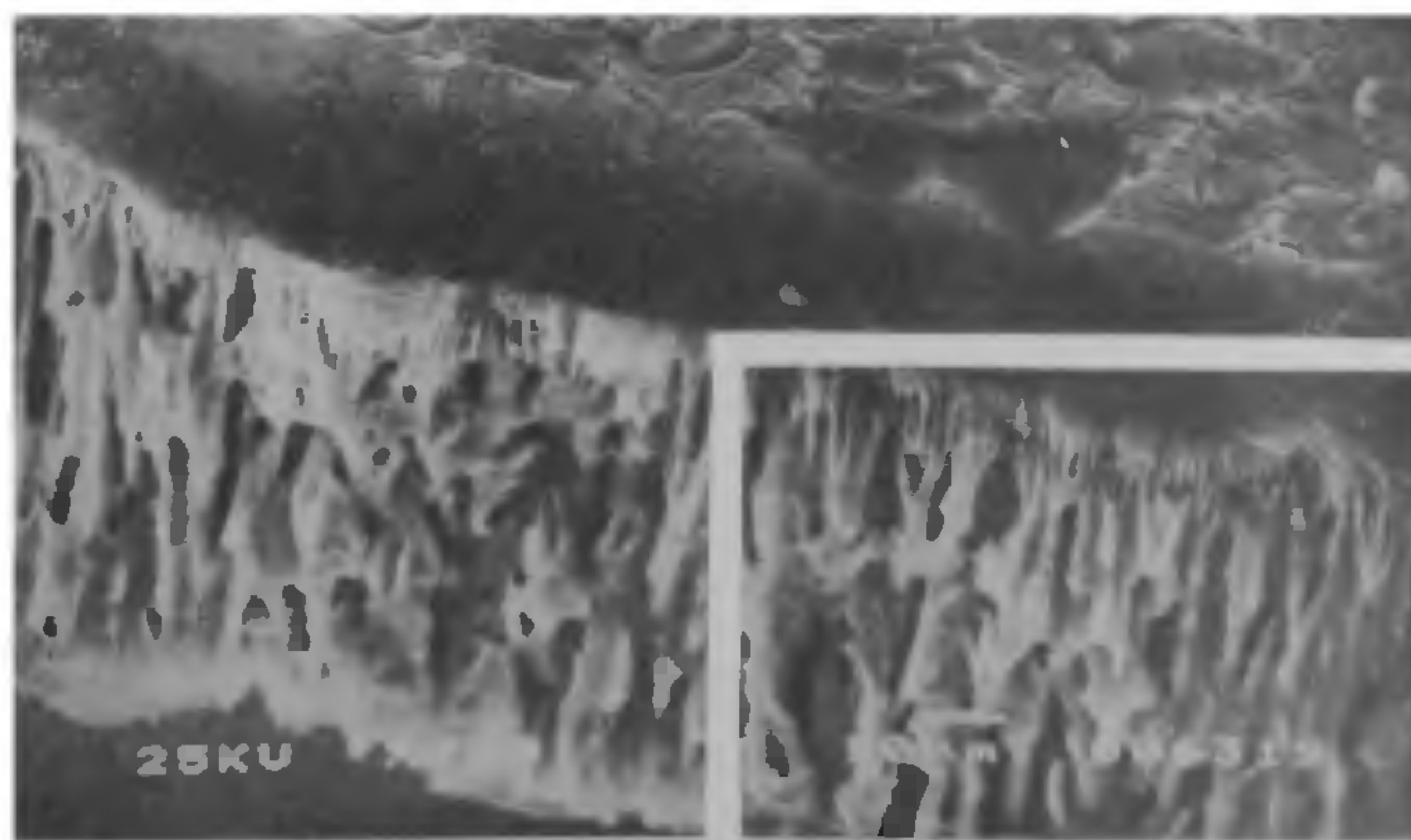In conclusion, we report that pore morphology can be used as an indication of doping concentration

Figure 1. Scanning electron micrograph showing cleaved edge of porous silicon layer on $N^+ N N^+$ sample

Figure 2. Higher magnification micrograph of boxed corner in Figure 1, showing the transition region in the N⁺/N/N⁺ sample

changes in silicon. The pore size changes in our N^+/N samples from about 1 μm to approximately 5 μm, the corresponding change in resistivity is from 10 milli-ohm cm to 30 ohm cm. The depth of N^+ region on N-type wafer is about 10 μm as estimated by this technique and roughly agrees with other techniques of junction depth measurement.

1. Uhlir, A., Bell. Syst. Tech. J., 1956, 35, 333–335.
2. Tu, X. -Z., J. Vac. Sci. Technol., 1988, B6, 1530–1532.
3. Imai, K. and Unno, H., IEEE Trans. Electron Devices, 1984, ED-31, 297–302.
4. Smith, R. L., Chuang, S. -F. and Collins, S. D., Sensors Actuators, 1990, A23, 825–831.
5. Blewer, R. S., Tsao, S. S., Tracy, M. E. and Gutierrez, G., J. Electrochem. Soc., 1988, 134, 477–481.
6. Delnes, J. L., Ku, S. -M., Poponiak, R. and Tsang, P. J., U.S Patent No. 4, 028, 149, June 7, 1977.
7. Smith, R. L. and Collins, S. D., Sensors Actuators, 1990, A23, 829–836.
8. Smith, R. L. and Collins, S. D.; IEEE Trans. Biomed. Eng., 1986, BME-33, 83–89.
9. Theunissen, M. J. J., J. Electrochem. Soc., 1972, 19, 351–360.
10. Beale, M. I. J., Benjamin, J. D., Uren, M. J., Chew, N. G. and Cullis, A. G., J. Cryst. Growth, 1985, 73, 622–636.
11. Smith, R. L., Chuang, S. -F. and Collins, S. D., J. Electron. Mater., 1988, 17, 533–542
12. Lehmann, V. and Gosele, U., Appl. Phys. Lett., 1991, 58, 856–858.
13. Searson, P. C., Appl. Phys. Lett., 1991, 59, 832–833.
14. Smith, R. L. and Collins, S. D., J. Appl. Phys., 1992, 71, R1–R22.
15. Asano, T., Higa, K., Aoki, S., Tonouchi, M. and Miyasato, T, Jpn. J. Appl. Phys., 1992, 31, L373–L375.
16. Koshida, N. and Koyama, H., Jpn J. Appl. Phys., 1991, 30, L1221–L1223.
17. Vadjikar, R. M., Jain, B., Gupta, P. K., Nandedkar, R. V. and Bhawalker, D. D., submitted for publication.
18. Brandt, M S., Breitschwerdt, A., Fuchs, H. D., Hopner, A., Rosenbauer, M., Stutzmann, M. and Weber, J., Appl. Phys, 1992, A54, 567–569.
19. Vadjikar, R. M., Nandedkar, R. V. and Bhawalkar, D. D.,
20. Ligeon, M., Muller, F., Herino, R. and Gaspard, F., J. Appl. Phys., 1989, 66, 3814–3819.
21. Searson, P. C., Macaulay, J. M. and Ross, F. M., J. Appl. Phys., 1992, 72, 253–258.
22. Searson, P. C. and Zhang, X. G., J. Electrochem. Soc., 1990, 137, 2539–2545.

Radioactive intensities of coastal sediments of Chilka lake, east coast of India

B. K. Sahu, B. B. Pradhan*, P. K. Panigrahy**
Department of Marine Science, Berhampur University, Berhampur 760 007, India
*Regional Forensic Science Laboratory, Berhampur 760 004, India
** Regional Research Laboratory, Bhubaneswar 751 013, India

Radioactive intensity measurements have been made on heavies of the foreshore and backshore sediments of the landward coast of the main channel of Chilka lake. The values range from 117.2 to 234.2 counts per minute and are almost equal to the normal background radiation. A highest intensity of radioactivity was observed in the foreshore in contrast to the backshore. It was found that the intensity of radioactivity was proportional to the average monazite content and the level of radioactive intensity in the region may be because of occurrence of monazite in trace.

RADIOACTIVITY of beach sands, ocean bottom sediments,