Ultrathin Porous Nanocrystalline Silicon Membrane for Electrical Sensing and Nanofluidics

by

Maryna N. Kavalenka

Submitted in Partial Fulfillment
of the
Requirements for the Degree
Doctor of Philosophy

Supervised by
Professor Philippe M. Fauchet

Department of Electrical and Computer Engineering
Arts, Sciences and Engineering
Edmund J. Hajim School of Engineering and Applied Sciences

University of Rochester
Rochester, New York
2012

Abstract

Membranes made of an ultrathin porous nanocrystalline silicon (pnc-Si) film are well suited for many applications due to their key attributes, including thinness (15-30 nm), pore diameters (5-80 nm) and porosity (0.5-15 %). This thesis in an investigation into the unique properties of pnc-Si material in the context of gas transport, sensing and nanofluidics. The first part of the thesis investigates the flow properties of the material, and shows that membranes based on pnc-Si exhibit gas permanences that are several orders of magnitude higher than in other similar membranes. The components of the flow due to ballistic transport and transport after collision with the pore walls are quantified as a function of pore diameter. In addition, we demonstrate that changing the pore interior from silicon to carbon leads to flow enhancement resulting from a change in the nature of the molecule-pore wall interactions. Integrating pnc-Si material into nanoscale devices is considered next. A novel approach to the fabrication of a capacitive sensor for organic vapor detection using a pnc-Si membrane metallized with gold as a porous electrode is presented. We show that the

ultrathin nature of the pnc-Si allows for fast analyte vapor permeation to the receptor material. Finally, we describe a technique for effectively depositing gold electrodes on different sides of the membrane that is used to fabricate an ultrathin electroosmotic pump. These metallized pumps are shown to achieve significantly higher flow rates compared to bare pnc-Si membranes when low voltages are applied directly across the membrane.