Porous Silicon Structures for Biomaterial and Photonic Applications

by

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Abstract

The primary research aim in this thesis is to demonstrate the versatility of porous silicon based nanomaterials for biomaterial and photonic applications. In chapter 2 of this thesis, the suitability of porous silicon as a biomaterial was investigated by performing different surface modifications on the porous silicon films and evaluating biocompatibility of these surfaces *in vitro*. The porous silicon surfaces were characterized by means of atomic force microscopy (AFM), scanning electron microscopy (SEM), diffuse reflectance infrared spectroscopy (DRIFT) and interferometric reflectance spectroscopy (IRS). Cell attachment and growth was studied using fluorescence microscopy and cell viability assays. Both fabrication of the porous silicon films and subsequent surface modifications were demonstrated. Polyethylene glycol functionalised porous silicon prevented cell attachment, whilst collagen or fetal bovine serum coating encouraged cell attachment. Surface modifications were also performed on porous silicon films with different pore sizes and the influence of pore size and surface modification on primary hepatocyte growth was recorded over a course of 2 weeks by means of laser scanning confocal microscopy (LSCM), toxicity and metabolic assays. On collagen-coated surfaces with average pore sizes of 30 nm, multilayer cells stacks were formed. This stacking behaviour was not observed on samples with smaller pore sizes (10 nm), or in the absence of collagen. Hepatocytes remained viable and functional (judging by a metabolic assay) for 6 days, after which they generally underwent apoptosis. Collagen-coated porous silicon films showed later onset of apoptosis than porous silicon films not coated with collagen or collagen-coated flat silicon.

In chapter 3 of this thesis, the nitrogen laser of a laser desorption/ionization (LDI) mass spectrometer was used to selectively ablate regions on porous silicon films that had been functionalised with a non-fouling polyethylene oxide layer, affording a microscale patterning of
the surface. Surface characterization was performed by means of AFM, SEM, LDI mass spectrometry, DRIFT and IRS. This approach allowed the confinement of mammalian cell attachment exclusively on the laser-ablated regions. By using the more intense and focussed laser of a microdissection microscope, trenches in a porous silicon film were produced of up to 50 micron depth, which allowed the construction of cell multilayers within these trenches, mimicking the organization of liver cords in vivo. Fluorescent staining and LSCM was used to study cell multilayer organization.

To gain a better understanding of how surface topography influences cell attachment and behaviour, porous silicon films were fabricated containing a gradient of pore sizes by means of asymmetric anodisation (chapter 4). These gradients allowed the investigation of the effect of subtle changes of pore size on cell behaviour on a single sample. Analysis by means of LSCM and SEM showed that pore size can dictate cell size and area as well as cell density. In addition, a region of pore size where cell attachment and proliferation was strongly discouraged was also identified. This information can prove to be useful for designing non-biofouling surface topographies.

Using the same asymmetric anodisation setup, photonic mirrors gradients were produced and overlaid over one another to produce multidirectional lateral photonic mirror gradients that display a series of roving spectral features (photonic stop-bands) from each gradient layer (chapter 4). These multidirectional photonic gradients have the potential to serve as optical barcodes or contributing to the development of graded refractive index devices such as lenses for high quality image relay and graded-index optical fibers.
Acknowledgements

During my PhD candidature, I have the great fortune of receiving help in one form or another from many people. Firstly, I would like to give my upmost gratitude to my parents for supporting me financially throughout the past 8 years being a student at university. Without their kind support, I wouldn’t be able to come to the point of writing this thesis. My advisor, Professor Nico Voelcker had guided me patiently throughout my PhD and had always imparted his knowledge without any reservations. Tough may it be, he had taught me one of the most important virtues of being a good researcher, i.e. being critical and demanding to oneself is more important than being critical towards others. As such, I had benefited tremendously under his guidance and my appreciation for his inputs and tutorage can only grow over time. Of course without the kindness conferred from my ever accomodating co-supervisor Professor Greg Barritt, I wouldn’t be able to get this far into my candidature. I would also like to express my thanks to both Steve McInnes and Martin Cole for their contributions towards some of the presented data as well as for their friendship which had made my stay in Adelaide very unforgettable. I would also want to express my appreciations toward my girlfriend, Taeko, who had supported me emotionally throughout all tough times and without her support, I would have found it rather hard to continue in many occasions.

Finally I would like to thank everyone in the School of Chemistry for their help and making my stay at Flinders University one of the most memorable phases of my life.
Declaration

I declare that this thesis is my own original work, conducted under the supervision of Prof. Nicolas Hans Voelcker. It is submitted for the Doctor of Philosophy in the Physical Sciences at the School of Chemistry, Physics and Earth Sciences at Flinders University, South Australia. To my knowledge, no part of this research has ever been submitted in the past, or is being submitted, for a degree or examination at any other University.

October 2008
The following is a list of peer-reviewed publications arising during my time as a PhD student at Flinders University from 2004-2008, of which paper 1, 3, 5 and 6 are used to present the main results in this thesis.


Abbreviation list

AFM        Atomic force microscopy
APTES     3-aminopropyl triethoxysilane
APTMS     3-aminopropyltrimethoxysilane
DIOS     Desorption/ionisation on silicon
DMEM     Dulbecco’s modified Eagle Medium
DRIFT     Reflectance infrared fourier transform spectroscopy
FBS     Fetal bovine serum
FDA     Fluorescein diacetate
H4IIE     Hepatoma cells
HDFS     Heptadecafluoro-1,1,2,2-tetrahydrodecyl dimethylchlorosilane
HF     Hydrofluoric acid
IRS     Interferometric reflectance spectroscopy
LSCM     Laser scanning confocal microscopy
MALDI     Matrix-assisted laser desorption/ionisation
PBS     Phosphate buffered saline
PC12     Rat pheochromocytoma cells
PDMS     Polydimethylsiloxane
PEG     N-(triethoxysilylpropyl)-O-polyethylene oxide urethane
PFPS     Pentafluorophenyl dimethylchlorosilane
pSi     Porous silicon
SEM     Scanning electron microscopy
SK-N-SH     Neuroblastoma cells