Design and Applications of Novel Microfluidic Separation Systems

By

Miriam H. Levy

An Abstract of a Thesis Submitted to the Graduate

Faculty of Rensselaer Polytechnic Institute

in Partial Fulfillment of the

Requirements for the degree of

DOCTOR OF PHILOSOPHY

Major Subject: Chemical and Biological Engineering

Examining Committee:

Prof. Steven M. Cramer, Thesis Adviser

Prof. Joel Plawsky, Member (Project Co-Advisor)

Prof. Marc-Olivier Coppens, Member

Prof. Linda McGown, Member

Rensselaer Polytechnic Institute
Troy, New York

December 2010

ABSTRACT

Lab-on-a-chip devices seek to combine an entire analytical process within a single miniaturized format. Within these devices separations comprise an important unit operation, often in the form of chromatography. Monolithic materials have proven themselves as excellent stationary phase materials for capillary and chip based devices; however, little work has been done in applying monoliths for use in disposable polymeric devices. To this end, this work seeks to design and apply photopolymerized silica sol-gel based monoliths for electrochromatographic separations in PDMS microfluidic devices.

The design of silica sol-gel based monoliths for use in disposable PDMS microfluidic devices required the optimization of a number of process variables. Methacryloxypropyltrimethoxysilane (MPTMOS) was selected as the primary monomer precursor and was combined with varying amounts of an epoxide containing monomer, glycidyloxypropyltrimethoxysilane (GPTMOS). Various design challenges existed to develop this system for use in PDMS devices. They related to obtaining: a homogenous gel within the channel, an appropriate pore structure, a suitably high ligand density, good attachment of the monolith to the channel walls, and low non-specific binding. Process variables were optimized including: the selection of a proper porogen, determination of an optimum monomer to porogen ratio and channel aspect ratio, selection of appropriate phase separation additives, ensuring proper attachment of the monolith to channel walls, and identifying conditions whereby non-specific binding was mitigated. Results are presented on the optimization of these processing conditions. The resulting monoliths were evaluated using SEM, pore size characterization techniques, batch experiments, and chip experiments.

Boronic acid was used as a model ligand to investigate the ability of the silica sol-gel monolith system to show specificity of binding. Three different approaches were employed to functionalize the base monolith with boronic acid. Boronic acid was covalently attached to the monolith using either the epoxide functionality or the sol-gel functionality present in the monolith chemistry. Alternatively, boronic acid was combined with the reactants prior to polymerization which served to entrap the ligand within the monolith network. The specificity of binding was demonstrated using small molecules, proteins, and peptides in both batch and chip experiments. Detection of analytes was performed using fluorescence microscopy for protein samples and MALDI-MS detection for peptide samples.

Finally, preliminary work was also conducted whereby miniature diodes were embedded in microfluidic loops formulated in PDMS. Using a combination of applied AC and DC fields, the focusing of charged biomolecules within the microfluidic loop was investigated.