INVESTIGATION OF IRREVERSIBLE BONDING BETWEEN POLYDIMETHYLSILOXANE AND PRINTED CIRCUIT BOARD FOR DESIGNING LEAKAGE-FREE DNA BIOCHIP

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by

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LIST OF SYMBOLS

α_i	Degree of ionization (or dissociation) of a molecule
μ_{eo}	Electroosmotic mobility
ε	Dielectric constant of a medium
ζ	Zeta potential
μ_{ep}	Electrophoretic mobility
η	Viscosity of a medium
μ_{eff}	Effective mobility
E	Electric field strength
F_E	Force imparted by electric field
F_F	Retarding frictional force
f	Friction coefficient
$\mathrm{pK_a}$	pH value
q	Effective charge
r	Hydrodynamic radius of ion
v_{ep}	Velocity of ion/ charge species
v_{eo}	Electroosmotic velocity
Z	Charge to mass ratio

LIST OF ABBREVIATIONS

μTAS	Micro Total Analysis Systems
3D	Three-Dimensional
AC	Alternating Current
ADDITOL HDMAP	2-hydroxy-2-methyl-1-phenyl propanone
AE	Counter Electrode or Auxiliary Electrode
CAD	Computer Aided Design
CE	Capillary Electrophoresis
CEC	Capillary ElectroChromatography
CGE	Capillary Gel Electrophoresis
CIEC	Capillary Isoelectric Focussing
CITP	Capillary Isotachophoresis
CMOS	Complementary Metal–Oxide Semiconductor
CNC	Computerised Numerical Controlled
CPW	Coplanar Waveguide
CV	Cyclic voltammetry
CZE	Capillary Zone Electrophoresis
D.C.	Direct Current
DABA	Diacrylate bisphenol A based photopolymer
dGTP	Deoxyguanosine triphosphate
DNA	Deoxyribonucleic Acid
EB	Electron Beam
EC	Electrochemical
EDTA	Ethylenediaminetetraacetic acid

EOCB	Electrical–Optical Circuit Board
EOF	Electroosmostic Flow or Electroendoosmotic Flow
FR-4	Flame Retardant 4 (compliance with UL94V-0)
GBIP	General Purpose Interface Bus
GB	Gigabyte
HDDA	1,6-Hexanediol Diacrylate
HF	hydrogen fluoride
HPLC	High-Performance Liquid Chromatography
HVPS	High Voltage Power Supply
IC	Integrated Circuit
ID	Internal Diameter
ISFET	Ion-sensitive Field-effect Transistor
isMEA	Integrated Stretchable Microelectrode Array
LC	Liquid Chromatography
LIF	Laser-induced Fluorescence
LOC	Lab-on-a-chip
LOD	Limits of Detection
MCE	Microchip Capillary Electrophoresis
MCE-AD	Microchip Capillary Electrophoresis with Amperometric Detection
MEA	Microelectrode Array
MEKC	Micellar ElectroKinetic Chromatography
MEMS	Microelectromechanical Systems
MMRA	Modified Mould Release Agent
MS	Mass Spectrometry

PC	Personal Computer
PCB	Printed Circuit Board
PCR	Polymerase Chain Reaction
PDMS	Polydimethylsiloxane
PET	Polyethylene terephthalate
POC	Point-of-care
PRAA	largest percentage of residual adhesion area
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
RAM	Random-access memory
RE	Reference Electrode
rpm	Revolutions per minute
SAP	Surface Adhesion Promoter
SEM	Standard error of the mean
SMU	Source Measure Unit
UTM	Universal Testing Machine
UV	Ultraviolet
WE	Working Electrode
XB	Expandable microspheres
X-rays	X-Radiation

KAJIAN KEATAS PENGIKATAN TAK BOLEH BALIK ANTARA *POLYDIMETHYLSILOXANE* DAN PAPAN LITAR TERCETAK BAGI REKAAN BIOCIP DNA YANG BEBAS BOCOR

ABSTRAK

Salah satu isu dalam merekabentuk biocip DNA pakai buang berasaskan teknologi kapilari elektroforesis adalah kebocoran bendalir dalam saluran mikro melalui ruang-ruang kecil antara elektrod-elektrod. Dalam kajian ini biocip yang bebas bocor dan boleh diguna semula direka untuk aplikasi pemisahan dan pengesanan DNA. Biocip ini terdiri daripada struktur microfluidic PDMS yang dibina dengan kaedah soft-litografi dan elektrod-elektrod tembaga yang diukir pada papan FR-4 menggunakan proses pembuatan lazim separa automatik. Lapisan halangan yang dibuat daripada bahan pembekuan dengan cahaya (photocurable) polimer diacrylate bisphenol A (DABA), digunakan untuk mewujudkan ikatan tak boleh balik antara substrat PDMS dan substrat PCB. Ujian tarikan telah menghasilkan purata kekuatan tegangan setinggi 287.357 kPa dan sisihan piawai ± 23.793 kPa. Keputusan ini adalah setanding dengan ikatan PDMS-PDMS melalui proses konvensional plasma oksigen dan melalui pengecajan korona. Sementara itu, ujian kebocoran menunjukkan bahawa saluran mikro boleh bertahan dengan tekanan lebih daripada 189 kPa dimana ianya cukup tinggi bagi kebanyakan aplikasi biocip. Akhirnya, eksperimen-eksperimen yang telah dilaksanakan pada DNA band tunggal yang dihasilkan dari proses PCR dan juga pada DNA band pelbagai daripada piawaian DNA ladder telah menunjukkan bahawa reka bentuk yang dicadangkan dengan jitu dapat

mengasingkan cebisan-cebisan DNA dengan sensitiviti arus elektrik secara konsisten lebih tinggi daripada 100 nA dan pada kekuatan medan elektrik 20V/cm. Berbanding dengan reka bentuk sebelumnya yang menggunakan klip untuk mengapit secara mekanikal substrat PDMS dan PCB, pendekatan baru dengan berkesan melekatkan peranti tersebut, dengan itu menghalang kebocoran cecair dari kawasan sensor. Pencapaian ini bersama dengan sifat-sifat lengai elektrokimia pada lapisan penghalang fotopolimer tersebut, membuka peluang dalam mereka bentuk peranti yang benar-benar mudah alih dan pakai buang untuk pengesanan biologi di masa hadapan.

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ABSTRACT

One of the issues in designing a disposable DNA biochip based on capillary electrophoresis technology is the leakage of fluid in the microchannel though small gaps between electrodes. In this work a leakage-free and reusable biochip is designed for DNA separation and detection applications. The biochip comprises PDMS microfluidic structure fabricated with soft-lithography and copper electrodes which are engraved on FR-4 board with standard semi-automatic processes. An inhibitive layer made from photocurable diacrylate bisphenol A polymer (DABA) is used to establish irreversible bonding between PDMS and PCB substrates. Pull-off tests resulted in an average tensile strength of 287.357 kPa and standard deviation ± 23.793 kPa. These results are comparable to PDMS–PDMS bonding via conventional oxygen plasma and corona discharge. Meanwhile the leakage test showed that the microchannel could withstand pressure of more than 189 kPa which is sufficiently high for most biochip applications. Finally experiments performed on single DNA band produced by using PCR and multiple bands from standard DNA ladders indicated that the proposed design can accurately separate DNA fragments with current sensitivity consistently higher than 100 nA and at electric field strength of 20V/cm. Comparing to the previous design that used clips to mechanically clamp PDMS and PCB substrates, the new approach effectively seals the device,

thus preventing leakage of liquid from the sensor matrix. This together with the electrochemically inert characteristics of the photopolymer inhibitor, open up possibilities in designing a truly portable bio-sensing device.

CHAPTER ONE
INTRODUCTION

1.1 Overview

The vast applications of electrophoresis are most evident in the health or medical industry, including protein, antibiotic and vaccine analysis. DNA analysis to date being the most important electrophoresis applications. It allows researchers to map and see the differences in the genetic code of species on earth, and also provides a reliable root in forensic investigations. Currently, there are two common applications of DNA analysis, which are the DNA fingerprinting (or also called DNA profiling) and the genome sequencing. DNA fingerprinting of individuals takes place by sampling their DNA and comparing it with a sample found at a crime scene. On the other hand, the DNA sequencing, determines the sequence of a stretch of DNA. Although DNA sequencing and DNA fingerprinting involve similar techniques, the ultimate aim of each is different and they have different applications.

Figure 1.1: Rapid HIT Human DNA Identification System, developed by IntegenX in the US and Key Forensic Services in the UK [1, 2].