Photoswitchable Sensors:
Reversible Ion Detection Using Optical Fibres

by
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Contents

Abstract

In studying and diagnosing cellular systems and diseases, the ability to accurately detect and monitor the concentrations and fluctuations of metal ions is of particular importance. Fluorescent photoswitchable sensors provide a means to reversibly detect metal ions in solution. This class of sensors uses a light stimulus to chemically switch between two distinct species, one that can bind to an analyte of choice and one that cannot bind. This then provides sensors that can be turned off at will, allowing the sensor to be reset and used again at a different time point. This thesis investigates the design, synthesis and metal ion selectivity of a series of photoswitchable sensors. These sensors contain a spiropyran core unit with differing ion binding domains, such as an aza-crown ether, providing ion specificity, as well as a free carboxyl group that allows for attachment to a solid support. A discussion on the choice of this photoswitchable moiety and subsequent design and synthesis as a new metal ion sensor is presented in Chapters 2, and 3 and 4, respectively.

These photoswitchable sensor molecules were then used within a microstructured optical fibre (MOF) sensing platform. Suspended core microstructured optical fibres provide a biologically suitable platform that provides a very sensitive means to sense in nanolitre volumes of sample. Covalently attaching these photoswitchable sensors to the light guiding core, via APTES silanization, provided a reversible sensing system capable of detecting picomolar concentrations of metal ions, such as Ca^{2+} in a biological sample while not contaminating the sample. The MOF not only provided a means to detect a fluorescence signal, it also allowed for repetitive on/off photocycling of the photoswitch, both in solution and attached to the surface.

Declaration

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Publications During Candidature

Stubing, D. B.; Heng, S.; Monro, T. M.; Abell, A. D. A comparative study of the fluorescence and photostability of common photoswitches in microstructured optical fibre. *Sensors and Actuators B: Chemical* 2017, *239*, 474-480.

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Contributions relating to specific work presented in published work are addressed in the relevant sections.

Abbreviations

^{13}C NMR	–	carbon nuclear magnetic resonance spectroscopy
^{19}F NMR	–	fluorine nuclear magnetic resonance spectroscopy
^{1}H NMR	–	proton nuclear magnetic resonance spectroscopy
AAS	–	atomic absorption spectroscopy
ACN	–	acetonitrile
AFM	–	atomic force microscopy
APTES	–	aminopropyl triethoxysilane
Azo1	–	azobenzene lumogallion derivative (Chapter 2 and 5)
$CDCl_3$	–	deuterated chloroform
CF_3-Fulgide	–	trifluromethyl indolylfulgide (Chapter 2)
CTES	–	carboxy triethoxysilane
DA1	–	diphenythienyl perfluoropentene (Chapter 2)
DASAs	–	donor acceptor Stenhouse abducts (furfural based photoswitch)
DIPEA	–	diisopropylethylamine
DMF	–	dimethyl formamide
DMSO	–	dimethyl sulfoxide
DMSO-d_6	–	hexa-deuterated dimethyl sulfoxide (DMSO)
EDC	–	N-Ethyl-N′-(3-dimethylaminopropyl)carbodiimide hydrochloride
EDTA	–	ethylenediaminetetraacetic acid
F2	–	a type of lead silicate glass
F300	–	high purity silica glass produced by Heraeus Quartzglas
FCF	–	fluorescence capture fraction
FRET	–	Förster (fluorescence) resonance electron transfer
FT-IR	–	Fourier transform infrared
HATU	–	1-[Bis(dimethylamino)methylene]-1H-1,2,3-triazolo[4,5-b]pyridinium 3-oxid hexafluorophosphate
HBDI	–	4-hydroxybenzylidene-1,2 dimethylimidazolinone
HOMO	–	highest occupied molecular orbital
HPLC	–	high pressure liquid chromatography
ICP-MS	–	inducted coupled plasma mass spectroscopy

IR	–	infra-red
IVF	–	*in vitro* fertilisation
LDA	–	lithium diisopropylamide
MC	–	merocyanine isomer of spiropyran
MCT	–	mercury cadmium telluride
MOF	–	microstructured optical fibre
MS	–	mass spectrometry
n-BuLi	–	n-Butyllithium
ND	–	neutral-density filter
NHS	–	N-Hydroxysuccinimide
PAINT	–	point accumulation for imaging in nanoscale topography
PALM	–	photo-activated localisation microscopy
Piranha	–	a 7:3 solution of H_2SO_4 and 30 % $H_2O_{2(aq)}$
PMMA	–	poly (methyl methacrylate)
PMT	–	photomultiplier tube
PSS	–	photo-stationary state
RFU	–	relative fluorescence units
RP-HPLC	–	reverse-phase high pressure liquid chromatography
SAM	–	self-assembled monolayer
SCF (SC-MOF)	–	suspended core fibre
SP	–	spiropyran
SP1	–	zinc selective spiropyran (Chapter 2 and 5)
SP-1	–	spiropyran with methyl-1-aza-12-crown-4 (Chapter 3 and 4)
SP-2	–	spiropyran with methyl-1-aza-15-crown-5 (Chapter 3 and 4)
SP-3	–	spiropyran with methyl-1-aza-18-crown-6 (Chapter 3, 4, and 5)
SP-4	–	spiropyran with N-ethoxy and methyl-1-aza-18-crown-6 (Chapter 4)
SP-5	–	spiropyran with N-ethoxy and methyl-(tetrahydro-2H-pyran-2-ylmethoxy) (Chapter 5)
SP-6	–	spiropyran with N-butanoic acid and diether alkyl chain (Chapter 5)
SP-7	–	spiropyran with N-ethoxy and diether alkyl chain (Chapter 5)
STED	–	stimulated emission depletion microscopy
STORM	–	stochastic optical reconstruction microscopy
TOF-SIM	–	time-of-fight secondary ion mass spectrometry
UV	–	ultra-violet

UV254nm	–	irradiation from a germicidal UV source (Hg 254 nm emission band)
UV352nm	–	irradiation from a UV blacklight source (Hg 352 nm emission band)
UV-vis	–	ultra-violet to visible absorption spectroscopy
XPS	–	x-ray photoelectron spectroscopy
λ_{em}	–	peak emission wavelength
λ_{ex}	–	excitation wavelength
λ_{max}	–	peak absorption wavelength