Soft glass optical fibres for telecommunications applications

by

H. Tilanka Munasinghe

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degree of Doctor of Philosophy

in the
Faculty of Sciences
School of Physical Sciences

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Abstract

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As the appetite for data use across telecommunications networks is predicted to continue to grow rapidly in the coming years, there is an increasing need to address the bandwidth gap that exists between the optical links that underpin high speed networks and the electronic layer typically used for processing signals at the endpoints. Nonlinear fibre optics is a potential avenue to addressing this bandwidth bottleneck, where nonlinear optical phenomena can be exploited to perform signal processing tasks, thereby allowing the broad bandwidth of optical media to be used for signal processing as well as transmission. Indeed the development of such optical signal processing devices is crucial to moving towards the next generation of communications technology – where ultra fast telecommunication networks with speeds approaching 1 Tb/s are required.

This work explored the use of the enhanced optical nonlinearity and dispersion engineering possible in soft glass microstructured fibres as a basis for developing devices for broadband telecommunications applications at 1.55 µm. Two applications were considered in this research, namely multicasting and phase sensitive amplification – both of which are signal processing applications that are important to the realisation of all optical networks.

A number of soft glass materials were studied in this research, primarily those with high nonlinear refractive indices such as chalcogenides, tellurites, bismuth oxide based glasses and germanates. During the course of this work a novel lead germanate glass was also developed. This glass was shown to have a high nonlinear index and relatively high mechanical strength when compared to tellurite glasses of similar refractive indices.

Dispersion tailored, soft glass fibre designs were developed for both multicasting and phase sensitive amplification. The design geometry, referred to as a 'hexagonal wagon wheel design', was a hybrid model combining a hexagonal array geometry for dispersion engineering with a suspended core or 'wagon wheel' geometry for high nonlinearity. The fibre designs were optimised for each application by using a genetic algorithm

based optimisation technique to achieve high and broad gain suitable for efficient signal processing at extremely high bit rates.

Each fibre design was modelled for its intended application to demonstrate, numerically, that the designs were indeed capable of performing their intended application over a broad band. The modelling work used a numerical beam propagation model and demonstrated that the designs were capable of operating at the extremely high bit rate of 640 Gb/s.

Advances were made to fabrication techniques during the fabrication trials of these novel designs due to the complex nature of the designs and, in some cases, the use of novel materials. A first generation, simplified hexagonal wagon wheel fibre was fabricated in the novel germanate glass developed earlier. A number of characterisation experiments were also performed on fabricated microstructured fibres, including a measurement of the dispersion profile for a tellurite fibre (that was shown to be in good agreement with modelling results) and the measurement of the nonlinear index for a fibre fabricated with the novel germanate glass – one of the few such measurements in the literature for this family of glasses.

In addition to these fabrication advances and characterisation experiments, a study of dispersive waves was performed on previously fabricated hexagonal wagon wheel fibres in collaboration with colleagues at the University of California, Merced. These experiments were used to study soliton propagation in these fibres at near infrared wavelengths. Comparison of experimental data to theoretical models is shown to have good agreement – an important validation of the modelling technique.

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This thesis would not be possible without the contributions of many others throughout my research journey. First and foremost, I would like to thank my supervisors, Prof. Tanya Monro and A/Prof. Shahraam Afshar Vahid, for their continuous guidance and commitment throughout my candidature. I would also like to thank A/Prof. Heike Ebendorff-Heidepriem for taking the time to provide valuable input and guidance on the glass and fibre fabrication aspects of this work.

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Contents

Declaration of Authorship iii

Abstract iii

Acknowledgements vi

Abbreviations xi

List of Figures 1

List of Tables 9

1 Introduction 11
- 1.1 Background and motivation . . . 12
- 1.2 Thesis aims and methodology . . . 16
- 1.3 Thesis outline . . . 18
- 1.4 Statement of Original Work and Author Contribution . . . 21
- 1.5 List of publications . . . 24

2 Nonlinear telecommunications applications 27
- 2.1 Introduction . . . 27
- 2.2 Theoretical fundamentals . . . 29
  - 2.2.1 Optical nonlinearity . . . 29
    - 2.2.1.1 Nonlinear refractive index . . . 32
  - 2.2.2 Wave propagation . . . 34
  - 2.2.3 Fibre nonlinearity and dispersion . . . 36
    - 2.2.3.1 Nonlinear pulse propagation . . . 39
- 2.3 Four wave mixing . . . 41
  - 2.3.1 Theory of FWM . . . 43
- 2.4 Signal processing applications based on FWM . . . 46
  - 2.4.1 Multicasting . . . 47
    - 2.4.1.1 Theory . . . 48
    - 2.4.1.2 Design considerations . . . 50
  - 2.4.2 Phase sensitive application . . . 50
    - 2.4.2.1 Theory of phase sensitive amplification . . . 53

2.4.2.2 Design considerations . . . 56
2.5 Conclusion . . . 56

3 Soft glass **59**
3.1 Introduction . . . 59
3.2 Glass fundamentals . . . 60
3.2.1 Optical properties . . . 63
3.2.2 Fabrication procedure . . . 65
3.3 Characteristics of soft glasses . . . 67
3.4 Families of soft glasses . . . 69
3.4.1 Chalcogenide . . . 70
3.4.2 Lead silicate . . . 71
3.4.3 Bismuth silicate . . . 71
3.4.4 Tellurite . . . 72
3.4.5 Germanate . . . 72
3.5 Development and characterisation of new germanate glasses . . . 73
3.5.1 Glass fabrication . . . 75
3.5.2 Density and thermal properties . . . 77
3.5.3 Refractive index measurements via ellipsometry . . . 80
3.5.4 Nonlinearity . . . 85
3.5.5 Loss . . . 87
3.5.5.1 Visible and near-IR loss of unstructured fibres . . . 88
3.5.6 Raman characteristics . . . 89
3.5.7 Summary . . . 91
3.6 Conclusion . . . 92

4 Fibre design **93**
4.1 Introduction . . . 93
4.2 Design considerations . . . 94
4.3 Finite element method . . . 98
4.4 Dispersion engineered fibre types . . . 101
4.4.1 Microstructured optical fibres . . . 101
4.4.1.1 Simple MOFs – the suspended core fibre . . . 102
4.4.1.2 Complex MOFs . . . 103
4.4.2 All solid fibres . . . 105
4.5 Design approach . . . 106
4.5.1 The hexagonal wagon wheel fibre . . . 106
4.5.2 Genetic algorithm optimisation . . . 108
4.5.3 Tellurite HWW for multicasting . . . 112
4.5.4 Bismuth HWW for PSA . . . 115
4.6 Evaluation of optimisation procedure . . . 119
4.7 Simplified germanate HWW . . . 121
4.8 Conclusion . . . 124

5 Modelling of fibre designs **125**
5.1 Introduction . . . 125
5.2 Pulse propagation model . . . 126

5.3 Tellurite HWW for for multicasting . . . 132
  5.3.1 Simulation results . . . 133
  5.3.2 Analysis of structural deviations . . . 135
  5.3.3 Summary of Tellurite HWW modelling . . . 136
5.4 Bismuth HWW for phase sensitive amplification . . . 138
  5.4.1 Simulation results . . . 138
  5.4.2 Analysis of structural deviations . . . 140
  5.4.3 Summary of Bismuth HWW modelling . . . 143
5.5 Conclusion . . . 144

6 Fibre fabrication **145**
6.1 Introduction . . . 145
6.2 Background . . . 146
6.3 Preliminary work – composite fibre fabrication . . . 153
  6.3.1 Background and motivation . . . 153
  6.3.2 Results and discussion . . . 154
  6.3.3 Summary . . . 160
6.4 Tellurite HWW fabrication trials . . . 161
  6.4.1 First iteration . . . 162
    6.4.1.1 Die design – v1 . . . 162
    6.4.1.2 Extrusion results . . . 163
  6.4.2 Second iteration . . . 166
    6.4.2.1 Die design – v1.1 . . . 167
    6.4.2.2 Extrusion results . . . 167
  6.4.3 Summary of tellurite HWW extrusions . . . 169
6.5 Germanate HWW fabrication trials . . . 170
  6.5.1 First iteration . . . 170
    6.5.1.1 Die design – v2 . . . 170
    6.5.1.2 Extrusions . . . 171
  6.5.2 Second iteration – the simplified HWW . . . 172
    6.5.2.1 Die design – v3 . . . 173
    6.5.2.2 Extrusions . . . 174
  6.5.3 Summary of germanate HWW extrusions . . . 175
6.6 Fibre draws . . . 177
  6.6.1 Initial trials – self pressurisation . . . 177
  6.6.2 Inflation trials . . . 178
  6.6.3 Active pressurisation trials . . . 179
6.7 Conclusion . . . 182

7 Fibre characterisation **185**
7.1 Introduction . . . 185
7.2 Dispersion measurement . . . 186
  7.2.1 Background . . . 186
  7.2.2 Experimental details . . . 191
  7.2.3 Results . . . 193
  7.2.4 Summary of dispersion measurements . . . 194
7.3 Nonlinearity measurement . . . 196

- 7.3.1 Background . . . 196
- 7.3.2 Experimental details . . . 199
- 7.3.3 Results . . . 200
- 7.3.4 Summary of nonlinearity measurements . . . 204
- 7.4 Ge HWW loss measurement . . . 204
  - 7.4.1 Background . . . 204
  - 7.4.2 Experimental details . . . 205
  - 7.4.3 Results . . . 206
  - 7.4.4 Summary of germanate HWW loss measurements . . . 206
- 7.5 Conclusion . . . 207

8 Dispersive wave generation **209**

- 8.1 Introduction . . . 209
- 8.2 Background . . . 210
  - 8.2.1 Solitons . . . 212
  - 8.2.2 Dispersive wave generation . . . 214
- 8.3 Experimental details . . . 217
- 8.4 Results . . . 223
- 8.5 Comparison to theory and simulations . . . 225
- 8.6 Conclusion . . . 230

9 Conclusion **233**

- 9.1 Future work . . . 236

Bibliography **237**

Abbreviations

CW	**C**ontinuous **W**ave
DPSK	**D**ifferential **P**hase **S**hift **K**eying
DSC	**D**ifferential **S**canning **C**alorimetry
EDFA	**E**rbium **D**oped **F**ibre **A**mplifier
ETDM	**E**lectrical **T**ime **D**omain **M**ultiplexing
FFT	**F**ast **F**ourier **T**ransform
FEM	**F**inite **E**lement **M**ethod
FWM	**F**our **W**ave **M**ixing
FWHM	**F**ull **W**idth at **H**alf **M**aximum
HWW	**H**exagonal **W**agon **W**heel
HNLF	**H**ighly **N**on**L**inear **F**ibre
MOF	**M**icrostructured **O**ptical **F**ibre
MPASS	**M**ulticast **P**arametric **S**ynchronous **S**ampling
NSE	**N**onlinear **S**chrödinger **E**quation
OOK	**O**n **O**ff **K**eyed
OPO	**O**ptical **P**arametric **O**scillator
OSA	**O**ptical **S**pectrum **A**nalyser
OTD	**O**ptical **T**ime **D**ivision
PCF	**P**hotonic **C**rystal **F**ibre
PSA	**P**hase **S**ensitive **A**mplification
PPM	**P**ulse **P**ropagation **M**odel
SEM	**S**canning **E**lectron **M**icrograph
SPM	**S**elf **P**hase **M**odulation
SBS	**S**timulated **B**rillouin **S**cattering
SRS	**S**timulated **R**aman **S**cattering

VASE	**V**ariable **A**ngle **S**pectroscopic **E**llipsometry
WDM	**W**avelength **D**ivision **M**ultiplexing
XPM	**C**ross **P**hase **M**odulation
ZDW	**Z**ero **D**ispersion **W**avelength

List of Figures

1.1 An example of the suspended core or ‘wagon wheel’ type fibre design is shown on the left in (a) [1], while the hexagonal array design is shown on the right in (b) [2]. The approach used in this work was to combine the two design types to create a hybrid geometry termed the ‘hexagonal wagon wheel’ design (Section 4.5 describes the design process in detail). . 18

2.1 This schematic shows the difference between non-degenerate FWM (on the left) and degenerate FWM (on the right). In the degenerate case two photons from a pump at a single wavelength interact to give the side bands, whereas in the non-degenerate case the two pump photons are at different frequencies. 42
2.2 The top left diagram shows a 1-to-2 scheme that uses degenerate FWM to generate an idler wave from a signal, and thus a total of two versions of the signal. The scheme can be cascaded by adding a secondary pump which may then be used for 1-to-4 multicasting (top right). Further FWM can create more pump waves naturally, leading to further cascading of the process to 1-to-8 multicasting (bottom) and so on provided the gain bandwidth and transmission window of the device are wide enough. . . . 49
2.3 Phasor schematic of phase insensitive amplification (PIA, left) versus phase sensitive amplification (PSA, right). In PIA the input signal is amplified by the same amount regardless of its phase, which is also unchanged. In PSA the signal amplification depends on its phase which is squeezed to the gain axis – in this case this is the real axis. Meanwhile, quadrature components along the imaginary axis are attenuated. 51

3.1 A typical volume–temperature diagram for a glass material [3]. This diagram shows how the volume changes with temperature as the material is cooled from the liquid to the glassy state. $T_{g,f}$ is the characteristic temperature of the glass transition region for the slow cooled glass – this temperature is interchangeably referred to as the fictive temperature T_f or the glass transition temperature T_g. The transition temperature for the fast cooled glass can also be derived in a similar fashion. 61
3.2 Glass being poured from a gold crucible into a rectangular brass mould. The relatively small rectangular blocks produced from this type of mould is used for characterisation of the bulk material. 65
3.3 A cylindrical mould of the type in this picture is used to produce glass billets (seen at the bottom of the picture) for extrusion. 66
3.4 DSC data for the GPNL2 germanate glass shows the glass relaxation peak, centred at approximately 667 °C, and the crystallisation peak, centred at approximately 741 °C. 79

3.5 Glass transition temperature (T_g) as a function of the $(La,Tm)_2O_3$ content of Na-free germanate glasses (GPL) and Na-containing germanate glasses (GPNL). 80
3.6 Schematic for a typical ellipsometry measurement. Linearly polarised light of a known polarisation is reflected off a sample and then the output polarisation is measured via a rotating analyser. This figure was taken from the J.A. Woollam Co. Inc. website [4]. 81
3.7 This figure highlights the difference between having a smooth back surface, versus a rough one. For the smooth surface on the left, back reflections may be in parallel with those beams reflected from the front surface. However if the back surface is rough the light is scattered and does not interfere with reflections from the front surface. 82
3.8 Analysis of the surface roughness of one of the germanate samples. (a) and (b) show the top surface before and after polishing, respectively. Similarly (c) and (d) show the bottom surface, before and after polishing. The roughness of the any particular point in the plots is given by its colour bar on the right of each plot. 84
3.9 Refractive indices of of GPL5, GPNL2 and GPNL5 germanate glasses and TZNL tellurite glass. Circles are measured points; the line shows the Sellmeier fit. 85
3.10 Nonlinear index of GPNL5 compared with other soft glasses. The solid line represents the Miller's rule, as per Reference [5]. 86
3.11 Loss spectra of unstructured fibres. 89
3.12 Raman spectra of germanate glasses (GPL5, GPNL5) and tellurite glass (TZNL). 90

4.1 The stages involved in modelling a given fibre geometry. The fibre geometry is first defined as in (a); a mesh of finite elements is then defined within this geometry as in (b); the wave equation is then solved over these elements to calculate the fibre modes, including the fundamental mode solution shown in (c). 99
4.2 A suspended core fibre fabricated in a fluoride glass. This fibre was fabricated as part of research into fibre based optical sensing [1]. 102
4.3 Dispersion and nonlinearity of a various soft glass suspended core fibres, as a function of core diameter d and wavelength λ. The dark region on the graph on the left hand side is the zero dispersion plane – the intersection of this plane and the dispersion curves gives the ZDW. The graphs show that, for all the glasses, the ZDW moves to shorter wavelengths as the core diameter increases. Meanwhile, the nonlinear coefficient increases of smaller core diameters due to the increased confinement. 104
4.4 A hexagonal array MOF fabricated in a bismuth glass [2] 105
4.5 Dispersion and nonlinearity, as a function of core diameter d and wavelengths λ, for a solid fibre consisting of two commercial lead silicate glasses – SF57 for the core and SF6 for the cladding. The dark region on the graph on the left shows the zero dispersion plane. We can see that by combining two glasses it is possible to obtain a zero dispersion wavelength with a much lower dispersion slope compared to Figure 4.3. 106
4.6 Initial fibre geometry. The fibre parameters shown above were used to optimise the design for low dispersion and high nonlinearity 107

4.7 A simple flowchart summarising a typical genetic algorithm optimisation procedure. . . . 112

4.8 Evolution of mean fitness for tellurite HWW. After an initial fluctuation in the mean fitness, it steadily increases before converging at around the 21st generation. . . . 113

4.9 The geometry of HWW fibre designed in tellurite for multicasting. The shape of the fundamental mode at 1550 nm is shown in the figure inset. This geometry corresponds to the fibre parameters in Table 4.1. . . . 115

4.10 Dispersion and nonlinearity for the tellurite HWW design shown in Figure 4.9. At 1550 nm the nonlinear coefficient of this fibre design $\gamma = 1789$ $\mathrm{W^{-1}km^{-1}}$, while the dispersion $D = 1.8$ $\mathrm{ps^{-1}nm^{-1}km^{-1}}$ and the dispersion slope (evaluated from 1540 nm to 1560 nm) is 0.010 $\mathrm{ps^{-1}nm^{-2}km^{-1}}$. 115

4.11 Evolution of mean fitness for bismuth HWW. After an initial fluctuation in the mean fitness it increases steadily before converging at around the 15th generation. . . . 117

4.12 Convergence of population parameters R1 and R3 118

4.13 The geometry of HWW fibre designed in bismuth for PSA. The shape of the fundamental mode at 1550 nm is shown in the figure inset. This geometry corresponds to the fibre parameters in Table 4.2. . . . 119

4.14 Dispersion and nonlinearity for bismuth HWW shown in Figure 4.13. At 1550 nm the nonlinear coefficient of this fibre $\gamma = 1099$ $\mathrm{W^{-1}km^{-1}}$, while the dispersion $D = 0.14$ $\mathrm{ps^{-1}nm^{-1}km^{-1}}$ and the dispersion slope is 0.246 $\mathrm{ps^{-1}nm^{-2}km^{-1}}$ 119

4.15 Gain bandwidth for dispersion engineered fibre MOF compared to other highly nonlinear fibres. In the figures above P represents the power in either pump and the gain is defined as in Equation 2.73. In all plots the ZDW is at 1550 nm. . . . 121

4.16 The geometry of the HWW with no inner holes at a core radius of 3.4 µm. This geometry was obtained by taking the HWW design shown in Figure 4.13, removing the inner holes and scaling the core radius to move the ZDW to 1.55 µm. The shape of the fundamental mode at 1550 nm is shown in the figure inset. . . . 122

4.17 Dispersion and nonlinearity for the simplified germanate HWW, with no inner holes and a core diameter of 3.4 µm (as shown in Figure 4.16). At 1550 nm the nonlinear coefficient of this fibre $\gamma = 344$ $\mathrm{W^{-1}km^{-1}}$, while the dispersion $D = -1.47$ $\mathrm{ps^{-1}nm^{-1}km^{-1}}$ and the dispersion slope is 0.237 $\mathrm{ps^{-1}nm^{-2}km^{-1}}$ 123

4.18 Evaluation of the dispersion at 1550 nm and the dispersion slope for a germanate HWW with no inner holes. A core diameter of 3.4 µm gives the best result 123

5.1 Raman gain for BiAB061 glass. This data is reproduced from [6] which is, to the best of our knowledge, the only known measurement of Raman gain for bismuth oxide glasses. . . . 128

5.2 Raman gain for TZN glass of composition $70\cdot\mathrm{TeO_2}$ — $20\cdot\mathrm{ZnO}$ — $10\cdot\mathrm{Na_2O}$ from Reference [7]. This glass has a very similar composition to the TZNL glass ($73\cdot\mathrm{TeO_2}$ — $20\cdot\mathrm{ZnO}$ — $5\cdot\mathrm{Na_2O}$ — $2\cdot\mathrm{La_2O_3}$) considered in this work. 129

5.3 Dispersion and nonlinearity for the tellurite HWW design modelled for multicasting (see Figure 4.9 for the fibre geometry). . . . 132

5.4 Power spectrum at various fibre lengths in the propagation model. The cascaded FWM process has already started by 10 cm. At 48 cm, 16 signal copies have been generated with $<$ 5 dB noise ripple. 134
5.5 The effect, on dispersion and nonlinearity, of scaling the fibre design. . . . 135
5.6 Power spectrum at 48 cm for the non ideal fibre cases. This spectrum has much poorer signal equalisation compared to the spectrum for the ideal case at the same length [Figure 5.4(c)]. 136
5.7 Dispersion and nonlinearity for bismuth HWW design modelled for PSA (see Figure 4.13 for the fibre geometry). 138
5.8 Simultaneous reduction in amplitude noise ripple and amplification for a train of 640 Gb/s pulses. The red bars show the spread in amplitude noise. 139
5.9 Squeezing performance for 640 Gb/s pulses at different propagation distances – from near the start of the model (fibre length $L = 1$ cm, top left), in steps of 10 cm to the end of the model ($L = 53$ cm, bottom right). The initial signal had approximately 90° of noise, which is squeezed to less than 20° after 53 cm of propagation. The input signal for this simulation was set to 0.35 W, while each pump was set to 0.8 W. 141
5.10 The effect, on dispersion and nonlinearity, of scaling the fibre design. 142
5.11 Phase response for deviations from the ideal fibre structure: -10% deviation from ideal structure (top left), ideal structure (top right), $+10\%$ deviation from ideal structure (bottom left), $+20\%$ deviation from ideal structure (bottom right) 143

6.1 Examples of various microstructured fibre geometries fabricated at the Institute for Photonics and Advanced Sensing, University of Adelaide. The fibre in (a) is a photonic band gap fibre; (b) is a suspended core fibre (alternatively known as a 'wagon wheel' fibre); (c) is a large mode area fibre. 147
6.2 A schematic of the extrusion process. The billet is placed in a metal body within a chamber (not pictured) where it is heated to a point where the glass softens. Pressure is then applied via a piston acting on the top of the glass to force the glass through a die. The result is an extrudate which has the inverse shape of the die – for example, as pictured here, if the glass is extruded through a die with a single central pin the extrudate will take the shape of a tube. 149
6.3 To start the fibre draw or caning process, heat is applied to the bottom of the preform such that a section starts to soften. The weight of the glass beneath the softened section then starts to pull the glass through under gravity forming what is known as the drop. The drop is allowed to continue under its own weight until a suitably long section has been drawn out. If a cane is to be drawn this section is then softly clamped between rollers to continue drawing out the glass (see Figure 6.4), otherwise the end is fixed to a rolling fibre drum which pulls the glass through. 150
6.4 Once the drop has formed and drawn down some cane, tractor wheels are applied to the side to enable more cane to be drawn. Sections of cane are cleaved off below the rolling wheels once they are long enough and the process continues until all the glass from the preform has been drawn out. The fibre drawing process is very similar to this schematic where instead of pulling the glass via the rollers the (much narrower) fibre end is attached to a rolling drum that pulls the glass through as it rotates. . 151

6.5 Dispersion variation of chalcogenide and tellurite composite fibre with core diameter. The graph shows that a ZDW of 1550 nm can be obtained for a core diameter around 0.75 µm. 154
6.6 Chalcogenide rods obtained after extruding the glass through a 1 mm rod die. 155
6.7 The measured loss for the chalcogenide–tellurite composite fibre fabricated via the rod–in–tube technique. The loss for this fibre was measured to be 25.1 ± 1.0 dB/m for a core diameter of 9.1 ± 0.4 µm at 1.55 µm. . . 156
6.8 The core diameter of the composite fibre was measured using an image such as (a) from a calibrated optical microscope. The guidance in the core was confirmed by imaging the output face of the fibre onto an IR camera to produce an image such as that in (b). 157
6.9 SEM images showing defects at the core–cladding interface of the composite chalcogenide–tellurite fibre. 158
6.10 A schematic of the billet stack extrusion process. Individual glass billets are vertically stacked and then extruded together. The resulting preform is a composite structure with alternating layers of glass. 159
6.11 Cross sectional samples of composite preform created by a billet stack extrusion. We see the amount of the core material (chalcogenide) increasing through the preform. Note the cracks through the glass seen in (a). These seem to indicate physical stresses in the preform. 160
6.12 The die plate and jacket used in the v1 design. 162
6.13 The die design for the sieve plate, which consists of six cylindrical pins for the inner hoes and six wedge shaped pins for the outer holes. 163
6.14 The preform obtained from the Te-126 extrusion. Unfused glass strands around the outer part of the preform are observed along the length of the preform in (a), and at the start of the preform in (b). 164
6.15 Cross-section from the Te-126 extrusion result. This extrusion was not successful due to the clear lack of fusion in the glass, and the distortion of the inner holes. The red circle highlights one of the inner holes, which has drifted out toward the edge of the core region. 165
6.16 Preform obtained from second tellurite extrusion (Te-127). The preform is again mostly unfused with some partial fusion around the core region. . 166
6.17 The v1.1 die. This die was made by taking the v1 die (pictured in Figure 6.12) and adding some modifications to block some of the outer feed holes and thus reduce the amount of glass flow in this region. 167
6.18 Results from Te-128 extrusion showing the preform fused into a solid block. 168
6.19 The cane obtained from the Te-128 preform. While the shape of the core is close to the design, some of the inner holes have drifted out into the struts. 169
6.20 Change in shape of outer pins from the v1.1 die (left) to the v2 die. The red circles highlight the inner edges of one of the outer pins showing how it changed from a sharp edge on the v1.1 die (left) to a rounded edge on the v2 die (right). 171
6.21 The v2 design of the die. This major revision to the design has a much smaller die plate due to the reduced number of outer feed holes. 172
6.22 Results from Ge-15 extrusion 172
6.23 Cross section of Ge-15 cane showing no inner holes 173
6.24 The v3 version of the die design for the simplified germanate HWW . . . 174

6.25 Results of Ge-21 extrusion. A cross section of the preform is shown in (a) and again in (b) with the die structure overlaid 174
6.26 The effect of active pressure on the caning of the Ge-21 preform. The applied pressure was increased from 0 mbar to 35 mbar to open out the holes. 176
6.27 Example of a tube extrusion. The cross section shown in (b) has an outer diameter of 10.4 mm and an inner diameter of 0.8 mm. 177
6.28 Inflation ratio (as defined in Equation 6.2) plotted as a function of applied pressure for GPL (blue) and GPNL5 (black) capillaries. 179
6.29 The effect of pressure and temperature on fibre inflation. For the fibre shown in (a) the pressure is too low and consequently the cane has not fully inflated into the space of the tube. In (b) the pressure is too high leading to some of the holes blowing out. 180
6.30 Ge-f19 draw – the first successful HWW fibre draw using the GPNL5 germanate glass. The image in (a) is from an optical microscope while (b) shown a scanning electron micrograph (SEM) image of the core region. 181
6.31 Ge-f23 draw – SEM images of second successful HWW fibre draw. This structure is more symmetric than the previous one. 182

7.1 Experimental setup used when measuring the dispersion of a fibre via the interferometric method. The interferometer is setup into a Mach-Zender configuration, with the test fibre being placed in the fibre arm and the variable length air arm used to match the optical path length. 188
7.2 Example of interferogram obtained for an imaginary 0.2 m fibre, path length matched at a central wavelength of 1550 nm. Figure (a) shows the case of a relatively high normal dispersion ($D = -80$ ps^{-1}nm^{-1}km^{-1})while Figure (b) corresponds to a relatively low normal dispersion ($D = -10$ ps^{-1}nm^{-1}km^{-1}). The greater number of fringes available when the dispersion is high makes the error of the fit lower. 191
7.3 Experimental setup for interferometric measurement. In the diagram above WLS refers to the white light source; OSA to the optical spectrum analyser; M1 to M7 are mirrors; and BS1 and BS2 are 50:50 beam splitters. The dotted lines show the path of the beam. 192
7.4 Interferogram obtained for the bismuth suspended core fibre. The central peak in this spectrum is at approximately 897 nm, as highlighted by the vertical red line. 193
7.5 Dispersion results for (a) bismuth and (b) tellurite suspended core fibres. The solid line shows the dispersion as evaluated by modelling a SEM image of the fibre geometry (shown in the insets of each figure) while the dots correspond to experimentally measured points. 195
7.6 An example of a FWM spectrum that may be used to calculate the SMP induced phase shift and consequently the fibre nonlinearity. The pump waves that comprise the beat signal are labelled $P1$ and $P2$, while the FWM side bands are labelled $S1$ and $S2$. 198
7.7 Experimental setup for nonlinearity measurement. In the diagram above EDFA refers to the erbium doped fibre amplifier; OSA to the optical spectrum analyser; PC1, PC2 are polarisation controllers; and L1, L2, L3, L4 are coupling lenses. 199

7.8 FWM spectrum for silica HNLF, with power specified as a dB ratio with an arbitrary reference. The pump peaks are visible at 1554 nm and 1555 nm while primary side bands are visible at 1553 nm and 1556 nm. For higher powers, a second set of side bands starts to appear at 1552.5 nm and 1557.5 nm. Note that, for clarity, the average power for each spectrum has not been labelled on this graph; these values are found on the x axis in Figure 7.9. 201

7.9 Phase shift measurement for silica HNLF. For this fibre length and loss were quoted by the manufacturer to be 302 m and 0.16 dB/m, respectively. This results in a nonlinearity value of $\gamma = 10.3 \pm 128$ W^{-1}km^{-1}. Note that the error bars for ϕ are too small to be seen on this graph. 202

7.10 SEM images of GPNL5 suspended core fibre cross section. This fibre was used to measure the nonlinear index of this glass, via a nonlinearity measurement. 202

7.11 FWM spectrum for germanate suspended core fibre, with power specified as a dB ratio with an arbitrary reference. The pump peaks are visible at 1552.8 nm and 1553.5 nm while the side bands are visible at 1552.2 nm and 1554.1 nm. Note that, for clarity, the average power for each spectrum has not been labelled on this graph; these values are found on the x axis in Figure 7.12. 203

7.12 Phase shift measurement for germanate suspended core fibre. For this fibre, the length was measured to be 56.6 cm and the loss, α, to be 8.0 ± 0.8 dB/m. This results in a nonlinearity value of $\gamma = 1177 \pm 128$ W^{-1}km^{-1}. 203

7.13 Experimental setup for loss measurement. The points marked P_{in} and P_{out} show where the input and output powers were measured. 206

7.14 Loss curve for Ge-f23 HWW fibre, with power specified as a dB ratio with an arbitrary reference. The black line represents a linear fit of the data; its slope gives the loss as 10.8 ± 1.3 dB/m 207

8.1 Experimental setup for dispersive wave generation. An OPO was used to pump a 500 m length of silica SMF to generate a Raman soliton which was then injected into a soft glass MOF test fibre to generate dispersive waves. The OPO beam is coupled into the SMF at the point A, the Raman soliton is coupled into the test fibre at the point B and the final spectra with the dispersive waves are measured by coupling the light into an OSA at point C. 218

8.2 Raman gain spectrum for fused silica, normalised to the maximum gain [8]. Note that the pump and Stokes are polarised along the same axis for this measurement and thus this represents the maximum Raman gain possible for this material. 219

8.3 The spectrum obtained from the SMF spool, i.e. measured at the point B in Figure 8.1, with power specified as a dB ratio with an arbitrary reference. The generated Raman soliton is seen at approximately 1650 nm. This soliton (along with the residual pump) was used as input to the MOF to generate dispersive waves. 220

8.4 The dispersion profile of the SF57 HWW fibre used in the experiment. The zero dispersion wavelength is at 1614 nm. The inset shows a cross section of the fibre core region. 221

8.5 The effect of varying both pump power and wavelength (simultaneously) on the position of the Raman soliton, with power specified as a dB ratio with an arbitrary reference. The inset shows a zoomed-in version of the pump peak, highlighting how relatively small changes to the pump wavelength λ_P and power were used to tune the soliton peak over a 50 nm range. The cut-off in the spectrum at 1768 nm is due to the detection limit of the OSA. 223

8.6 Results from the experiment showing dispersive waves generated in the soft glass MOF in the wavelength region from 1350 nm to 1450 nm when pumped with solitons in the 1680 nm to 1780 nm range. The spectral power is specified as a dB ratio with an arbitrary reference. The central peak of the soliton λ_S is given in the legend. The residue of the OPO pump that was used to generate the soliton is also seen at around 1560 nm, as equipment to filter this residue was unavailable at the time. 224

8.7 The power spectrum measured after the SMF. The red dotted lines indicate the spectral edges of the soliton. 226

8.8 Normalised soliton spectrum along with the theoretical pulse fit used to calculate the pulse width. The fitted pulse may be transformed back to the time domain to obtain the pulse width, calculated to be 131 fs for this pulse. 227

8.9 Comparison of experimental spectra to simulations. For each soliton wavelength λ_S the corresponding spectrum from Figure 8.6 is overlaid with a spectrum obtained by running a pulse propagation model for a soliton at the same wavelength, with the input pulse parameters from Table 8.1. 229

8.10 Comparison of the dispersive wave peaks observed experimentally, to those predicted by Equation 8.7 (black line) and those from a numerical model of the NSE (blue line). 231

List of Tables

3.1 Figures of merit (FOMs) for various nonlinear optical fibres. The silica HNLF is a commercially available fibre used in our lab, while the rest are taken from the literature. The FOMs show that although the soft glass fibres have a higher loss, they score highly when considering nonlinear fibres for compact devices. 69

3.2 Refractive indices, both linear and nonlinear, for various soft glasses and, for reference, conventional fused silica glass. In this table λ_n refers to the wavelength at which the refractive index n is obtained; n_2 is the nonlinear component of the refractive index. 73

3.3 Nominal glass composition (in mol%), density, glass transition temperature (T_g), onset of glass crystallization (T_x), glass stability ($T_x - T_g$), linear (n_0) and nonlinear (n_2) indices of germanate glasses made and tellurite glass TZNL published in Reference [9]^f. 76

3.4 Sellmeier coefficients for germanate and tellurite glasses 84

4.1 Fibre parameters for the 23rd generation. 114

4.2 Fibre parameters for the 20th generation. 116

6.1 Summary of results from tellurite HWW fabrication trials. The columns labelled T and v refer to the extrusion temperature and ram speed, respectively. 169

6.2 Summary of results from germanate HWW fabrication trials. The columns labelled T and v refer to the extrusion temperature and ram speed, respectively. 175

8.1 This table shows the measured peak wavelength for the soliton (first column) and dispersive wave (last column) for the experimental dataset shown in Figure 8.6. The table also shows the calculated power values for the soliton. These values for the input peak power, $P_{peak,in}$, were used in a pulse propagation model to match numerical data to the experiment. . . 227