Techniques for the CO_2 Laser Fabrication of Soft Glass Optical Fibre Devices and Measurement of their Optical and Physical Properties

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Abstract

This thesis presents an investigation into the direct CO_2 laser post processing of optical fibres, with a specific emphasis on soft glass compositions. It presents novel techniques for the fabrication of soft glass optical fibre based devices, novel techniques for the direct measurement of glass melt properties and the optical characterization of all fabricated devices, including a novel technique for measuring the evolution of ultra-short pulses along sub-wavelength tapered optical fibre.

New photonic devices fabricated from soft glass optical fibres are of scientific interest due to the high non-linearity and high refractive index. However for the increased understanding and controlled fabrication of such devices, measured values of the physical properties of the glass melts are required, and for many new materials this information is either unavailable or must be obtained for the exact conditions that the devices are produced.

This thesis presents new methods for the measurement of surface tension and viscosity at the same conditions as the fabrication of the optical devices presented, through the use of a scanning CO_2 laser. It also reports previously unpublished surface tension values for several glass compositions and investigates the effect the glass making environment had on the resulting surface tensions.

Novel fabrication techniques for new soft glass optical devices are also presented, including the pressurised tapering of Bismuth MOF using an elliptical CO_2 laser beam control the rate of microstructure collapse or expansion such as to produce a photonic crystal device whereby the zero dispersion wavelength varies as a function of displacement along the taper length.

The direct CO_2 laser tapering of silica and soft glass optical fibres to sub-wavelength diameters is also presented as well as the production of new high Q factor optical

microsphere’s resonators of diameters <10µm, fabricated from Er-Yb co-doped tellurite glass, and attached to tapers situated near the un-tapered optical fibre for mechanical stability.

Acknowledgements

Just before beginning my PhD my primary supervisor Jesper referred to me as an uncut diamond in terms of my experimental work. Now I'm finished I can't help but feel somewhat cut and polished, though I think I'm still a little sore from the process ;)

Firstly I would like to thank my extremely loving and understanding partner Beth and my mother Eleanor for putting up with me disappearing off to university at weird hours in the morning and all weekends to go work in the lab.

I've had the opportunity of working with some very good researchers who were pointed in my direction by my co-supervisor Tanya Monro. The first I encountered was Dominic Murphy, who lifted me out of a very major slump and helped get my first conference paper out, though on reflection I really should have pushed further and turned it into a journal article. The second is Heike, who helped me get my first journal paper out and set me to measuring just about every known composition of soft glass ;). Hopefully I get the opportunity of working with these people again.

Without the support of friends it is next to impossible survive a PHD. I can say this with absolute certainty: without the friendship of Miftar Ganija I would have given up on my PHD. Having friends to talk openly with about physics, politics and the pain and the suffering associated with research definitely has kept me moderately sane.

When you have been doing a PHD for as long as I have, you have you rely on a lot of people's help. Without the staff from the School of Chemistry and Physics and their friendly support I would be in deep water, as well as out of work!

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Statement of Originality

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SIGNED…………………………………...

DATE…………………………………......

Supervisors: Prof. Jesper Munch, Prof Tanya M. Monro.

Symbols

Symbol	Meaning
µm	Micrometre
c	Speed of light in vacuum 299,792,458 ms^{-1}
dBm	Power ratio in decibels of the measured power relative to 1mW
fs	femtosecond
I	Intensity of electromagnetic radiation
I_a	Absorbed intensity
I_i	Incident intensity of dielectric interface
I_r	Reflected intensity
I_t	Transmitted intensity
k	Nonlinear refractive index, extinction coefficient
n	Refractive index
ñ	Complex refractive index ñ=n+ik
nm	nanometre
Q	Quality factor of a resonator
R	Reflectance to I_i
$T_{10}{}^{7.6}$	Also commonly referred to as the softening point, defined as the glass temperature in Kelvin when the viscosity is $10^{7.6}$dPa.S
T_g	Glass transition temperature in Kelvin
γ	Surface tension
ε_0	Permittivity of free space: $8.854187817620 \times 10^{-12}$ Fm^{-1}
η_g	Geometric efficiency of absorption
η	Dynamic viscosity
λ	Wavelength of electromagnetic radiation
Λ	Pitch: Periodic spacing between the centre of holes in micro-structured optical fibre, or the periodic separation between induced effective refractive index changes in long period gratings
ρ	Density
ω and ω_0	Beam radius, and minimum beam radius.
α	Absorption coefficient
g	Acceleration due to gravity ~9.8ms^{-2}

Terms and Acronyms

Term or Acronym	Definition
CO_2	Carbon dioxide
BS	Beam Splitter
fused silica	amorphous SiO_2
FWHM	Full Width Half Maximum of a Gaussian distribution
HeNe laser	Helium-Neon laser in this thesis operating at 632.8nm
KLM	Kerr Lens Mode-locked
LP	Linear Polariser
MOF	Micro-structured Optical Fibre
OPL	Optical Path Length
OSA	Optical Spectrum Analyser
PWM	Pulse Width Modulation
SEM	Scanning Electron Microscope
Soft Glass	A glass with a low softening point relative to pure fused silica
SPM	Self-Phase Modulation
SPR	Surface Plasmon Resonance
Ti:sapphire	Ti-doped alumina, Al_2O_3:Ti
WLS	White Light Source, in the context of this thesis is either a super-continuum source, or tungsten filament based source.