Institution: University of Bath

Unit of Assessment: 9: Physics

Title of case study: Novel light sources and the economic success of Fianium Ltd

1. Summary of the impact

Research by Bath physicists into non-linear effects in optical fibres has led directly to the development of a new technology: bright white light ("supercontinuum") lasers which remove the need for multiple single wavelength laser systems in low power applications. Based on a successful collaboration with Bath, these lasers are marketed by Fianium Ltd (est. 2003). Since 2008 Fianium has expanded greatly TEXT REDACTED. In recognition of this success, Fianium received the Queen's Award for Enterprise in both 2009 and 2012. Bath physicists and Fianium continue to engage in knowledge exchange projects which has resulted in over £1M of DTI/TSB investment funding, TEXT REDACTED.

2. Underpinning research

The Bath research underpinning commercial supercontinuum began in 1998 with investigations into nonlinearity in new designs of optical fibres, informed by previous theoretical studies of fibre dispersion by members (Birks, Knight, Russell§) of Bath's Centre for Photonics and Photonic Materials (CPPM)[1]. Stimulated by CPPM's work on new nonlinear fibre designs, researchers elsewhere (Bell Laboratories, 1999) demonstrated that these fibres could be used to transform ultrashort laser pulses into a broad range of wavelengths covering the visible and near-infrared, known as a supercontinuum. Similar work was already underway at the CPPM and the first Bath paper on the subject appeared just weeks later [2].

These early supercontinuum sources were very much laboratory experiments requiring expensive and complex ultrashort pulse Ti:sapphire lasers. However, Wadsworth§ of the CPPM realised that far more applications and far greater impact would be possible if the same results could be obtained using the much simpler and cheaper technology of Nd or Yb based lasers. This required the design of new fibres with dispersion suited to the different laser wavelength, as well as an understanding of how the physics of the generation would change from the ultrashort pulses used originally, to longer (quasi-continuous) pulses [3].

In 2004, members of the CPPM (Wadsworth, Knight, Birks, Russell) published a paper demonstrating supercontinuum with compact, long pulse, Nd based lasers, which was also entirely compatible with the Yb based fibre lasers being developed by Fianium at the time [4]. TEXT REDACTED by 2005/06 Fianium were selling supercontinuum sources. With the potential for further commercialisation opportunities obvious to both parties, Fianium and CPPM researchers embarked on an enthusiastic and fruitful collaboration. By working closely with researchers in Bath's CPPM, Fianium Ltd. has been able to understand, influence and licence developments in supercontinuum laser technology to bring new products to market rapidly.

Further research on supercontinuum has followed in Bath, including extending the visible wavelength coverage across the blue [5] and then the ultraviolet (320nm) [6]. Complementary theoretical work by Skryabin§ of the CPPM [7] has elucidated the physical processes controlling the commercially important shortest wavelengths in the visible supercontinuum. A key aim is to exploit the findings of this fundamental research to develop routes to new technologies within the context of collaborative research funded by the Technology Strategy Board (TSB)[8], Knowledge Transfer Partnerships (KTP) and FP7.

§ T.A. Birks (Professor 1996-present), J.C. Knight (Professor 1996-present), P. S-J. Russell (Professor 1996-2005), Wadsworth (Reader 1999-present, and Skryabin (Professor 2000-present).

3. References to the research

[1] D. Mogilevtsev, T.A. Birks, and P.St.J. Russell, *Group-velocity dispersion in photonic crystal fibres*, Optics Letters, **23**, 1662-1664 (1998). 319 citations. http://dx.doi.org/10.1364/OL.23.001662

[2](*) W.J. Wadsworth, J.C. Knight, A. Ortigosa Blanch, J. Arriaga, E. Silvestre and P.St.J. Russell, *Soliton effects in photonic crystal fibres at 850 nm*, Electronics Letters, **36**, 53-55 (2000). 211 citations. DOI:10.1049/el.20000134

[3](*) S. Coen, A.H.L. Chau, R. Leonhardt, J.D. Harvey, J.C. Knight, W.J. Wadsworth, and P.St.J. Russell, *Supercontinuum generation by stimulated Raman scattering and parametric four-wave mixing in photonic crystal fibers*, J. Optical Society of America B, **19**, 753-764 (2002). 270 citations. http://dx.doi.org/10.1364/JOSAB.19.000753

[4](*) WJ Wadsworth, N Joly, JC Knight, TA Birks, F Biancalana and PSJ Russell, *Supercontinuum and four-wave mixing with Q-switched pulses in endlessly single-mode photonic crystal fibres*, Optics Express, **12**, 299-309 (2004). 365 citations. http://dx.doi.org/10.1364/OPEX.12.000299

[5] JM Stone and JC Knight, *Visibly "white" light generation in uniform photonic crystal fiber using a microchip laser*, Optics Express, **16**, 2670-2675 (2008). http://dx.doi.org/10.1364/OE.16.002670

[6] J.M. Stone and J.C. Knight *From zero dispersion to group index matching: How tapering fibers offers the best of both worlds for visible supercontinuum generation*, Optical Fiber Technology, 18, 315–321(2012). 10.1016/j.yofte.2012.06.004

[7] A.V. Gorbach, and D.V. Skryabin, *Light trapping in gravity-like potentials and expansion of supercontinuum spectra in photonic-crystal fibres*, Nature Photonics, **1**, 653-657 (2007). doi:10.1038/nphoton.2007.202

[8] Technology Strategy Board (TSB) Collaborative research project, Whitelase, TP11/LLD/6/I/AF052H (2008-2011). TEXT REDACTED; TSB Collaborative research project, Ultrafast, TP/4/NGL/6/I/22227 (2006-2008).

(*) Best indicators of research quality

4. Details of the impact

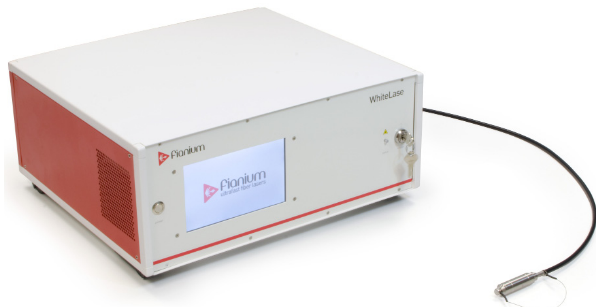
Traditional laser light sources operate at a single wavelength and consequently if a particular investigation requires multiple wavelengths, the user has to buy and install a separate laser system for each. By contrast, supercontinuum fibre lasers provide the directional beam and tight focus of standard lasers, but with an exceptionally broad spectral bandwidth. Although this comes at the cost of lower power compared to single wavelength lasers, there are nevertheless a myriad of applications requiring multiple wavelengths for which high power is not necessary. For these a supercontinuum source provides an effective all-in-one solution in which the wavelength is changed simply by inserting an appropriate filter. Applications are found across microscopy, medical imaging and spectroscopy, enabling experiments or analyses that would otherwise be impossible or prohibitively expensive [9]. As such, there is a large and rapidly expanding market for any company able to provide supercontinuum fibre lasers having the right price and performance.

As a result of its collaboration with Bath researchers, Fianium [10,11] is now firmly established as a world leader in supercontinuum sources, with a TEXT REDACTED. Following TEXT REDACTED and in recognition of their outstanding achievements in international trade and innovation, Fianium received the Queen's Award for Enterprise in both 2009 and 2012 – the UK's top award for business performance [13]. TEXT REDACTED. The 2012 award specifically recognises the innovation associated with Fianium's supercontinuum sources. Since 2008, TEXT REDACTED representing a significant economic gain [12] (the R&D employment multiplier is 1.23, while the output multiplier is 1.44 [14]).

Bath's CPPM is a world leader in fibre supercontinuum research, and although not the only research team in this active field TEXT REDACTED.

The success of the early interaction with CPPM led to a joint DTI/TSB project with Fianium between 2006 and 2008 [15]. The strengthened links that ensued provided CPPM researchers with improved insight into the commercial possibilities of supercontinuum fibres. In particular, Knight and Wadsworth initiated research on how to extend the short wavelength cut-off of the supercontinuum further into the blue end of the spectrum. TEXT REDACTED. An improved understanding of the non-linear optical physics that underlies supercontinuum generation resulting from theoretical work at CPPM (Skryabin [7]) led Knight in 2007/8 to design a new fibre that reduced the short wavelength cut-off to 420 nm (ultraviolet) [5]. TEXT REDACTED.

Another TSB-funded project, *Whitelase*, between Fianium and the CPPM (Knight, Wadsworth; 2008-2011 [8,15]) further extended the supercontinuum into the deep ultraviolet (320 nm)[6] TEXT REDACTED. Knowledge transfer into engineered products has been facilitated by two KTP projects (Knight, Wadsworth; 2011-2013) TEXT REDACTED. In total, this investment revenue amounts to TEXT REDACTED. The on-going relationship between Fianium and the CPPM has also been supported by licensing and consultancy agreements with Knight and Wadsworth. A number of US and EU patents protect Bath's methods for supercontinuum generation [16] . TEXT REDACTED.



The SC390 supercontinuum source "Whitelase"

The principal impact claimed in this case study is

- Development of a world loading new technology: Supercontinuum light sources
- Sales of supercontinuum products since 2008 total TEXT REDACTED.
- TEXT REDACTED.
- TEXT REDACTED.
- Fianium received the Queen's Award for Enterprise in both 2009 and 2012 [13]
- The collaboration between Bath physicists and Fianium has resulted in over £1M of DTI/TSB investment funding [15].

5. Sources to corroborate the impact

[9] http://en.wikipedia.org/wiki/Supercontinuum (accessed 15/3/2013).

[10] Fianium website: http://www.fianium.com/ (accessed 16/6/2013)

[11] Fianium contacts: Chief Executive Officer, Fianium Ltd.; Vice President of Business

Development, Fianium Ltd.

[12] Data from Vice President of Business Development, Fianium Ltd (September 2013).

[13] http://www.queensawardsmagazine.com/home (accessed 15/4/2013).

[14] *The Economic Impact of UK higher education institutions*, report by Universities UK. (2007). http://www.universitiesuk.ac.uk/highereducation/Pages/EconomicImpact3.aspx (accessed 15/4/2013)

[15] TEXT REDACTED.

[16] Patents: US 8,467,42; US 8,422,519, EP 22505529, GB20080002356