Applications of Microstructured Fibre Technology in Aerospace and Defence

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Abstract

The EMRS DTC project "Photonic Fibres for Active Sensor Systems" aimed to assess the potential impact of microstructured fibres for security and defence applications. Results achieved have suggested enormous potential for these novel fibre types to influence the next generation of photonic systems for security and defence applications. However, it is important to establish where the fibres can offer the greatest advantages and what research still needs to be done to drive the technology towards real platform solutions.

Keywords: Holey Fibre, Photonic Bandgap Fibre, Optical Parametric Oscillator

Introduction

Fibre delivery of intense laser radiation is important in numerous application areas, from medicine through to industrial processing and aerospace. Fibres for high power transmission must offer low values of optical nonlinearity and high damage thresholds. In addition, singlemode operation is a fundamental requirement for the many applications in which good beam quality is essential.

"Photonic Fibres for Active Sensor Systems" addresses the problem of integrating laser systems into sensors on-board aircraft platforms. The use of Photonic Fibres, a.k.a. Microstructured Fibres (MFs), offers the potential for delivery of high power laser radiation with diffraction-limited performance. Over the course of the project, BAE SYSTEMS have investigated the suitability and performance of MF, which has been designed and fabricated at the ORC. In this paper we summarise the technology assessed and discuss the potential impact that MF can have on defence applications.

Microstructured Fibres

In recent years MF technology has revolutionised the field of optical fibres, enabling a wide range of novel optical properties to be realised. These fibres, in which the cladding region is peppered with many small air holes, are separated into two categories, defined by the way in which they guide light: (1) index-guiding holey fibres (HFs), in which the core is solid and light is guided by a modified form of total internal reflection, and (2) photonic band-gap fibres (PBGFs), in which guidance in a hollow core can be achieved via photonic band-gap effects. Both of these MF types offer attractive qualities for beam delivery applications. For example, using HF technology, large-mode-area, pure silica fibres with robust single-mode guidance over broad wavelength ranges can be routinely fabricated. In addition, the ability to guide light in the air-core within a PBGF presents obvious power handling advantages.

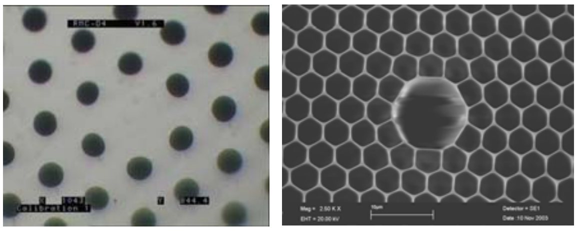

Figure 1. *Cross section of fibres observed in the project: (Left) Holey Fibre; (Right) Photonic Bandgap Fibre*

PBGFs exploit the occurrence of optical bandgaps in a perfectly periodic dielectric structure (i.e., the array of holes shown in Fig.1). In these structures the transverse propagation of certain wavelengths is suppressed, and light is therefore effectively confined in the central core [1]. As bandgaps can only exist at defined optical wavelengths, PBGFs have the potential to be fabricated to support transmission in specific, distinct regions of the spectrum. PBGFs also offer the possibility to allow transmission beyond the transparency window of the host glass (e.g. silica). Low loss bandgap fibres are feasible using materials that are not transparent at the operating wavelength. This was demonstrated in the so-called omniguide fibres for CO_2 laser transmission at 10.6µm [2].

Technology Demonstrations

A demonstrator system was defined within the project in order to practically demonstrate that microstructured fibres have the potential to make an impact as a light delivery technology. The remit of the demonstrator system was to use MFs to deliver high-energy pump power to an optical parametric oscillator (OPO). This OPO would then be used to provide a 3-5µm wavelength source for applications such as biological sensing, targeting and threat detection.

Typically, OPOs are pumped using bulk optics and free-space beams. The insertion of a microstructured fibre to 'pipe' the pump source to the OPO crystal is the first known example of such a pumping scheme. The OPO used for the demonstrator was a simple laboratory-assembled device using a periodically poled lithium niobate (PPLN) crystal.

The experiment was performed with both HF and PBGF samples (Fig. 2). It was shown that the performance of both systems compared extremely well to an equivalent free-space system, and therefore both fibre types can be successfully used to deliver pump radiation to an OPO and hence to provide a suitable light delivery technology on platform [3].

The use of PBGFs has been assessed not only for beam delivery at 1 µm (alongside the HF structures) but also investigated for transmission at other wavelengths of interest, specifically in the mid-IR region, and assessed to determine the maximum attainable bandwidth of the supported wavelengths.

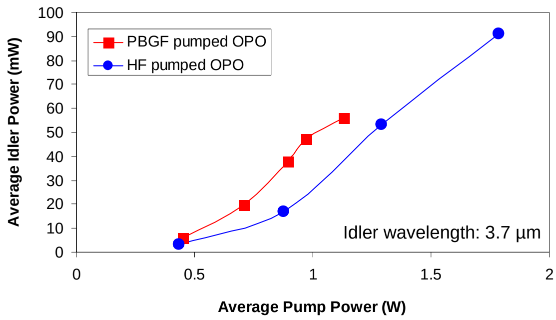

Figure 2. *Generated idler power vs. input pump power for MF pumped OPO systems.*

In [4] the ORC presented details of a silica PBGF designed and fabricated to support transmission of wavelengths from 2.07µm to 2.49µm (beyond the transmission window of silica), demonstrating a band-gap width of more than 400nm (see Fig. 3).

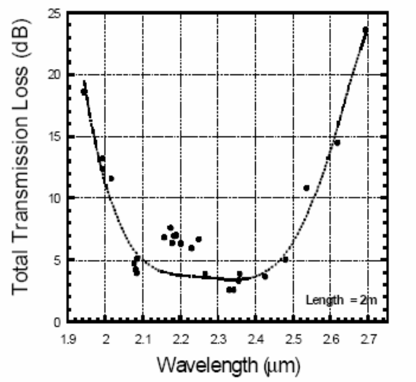

Figure 3. *Measured band-gap of 2m length of fibre*

In addition, PBGFs have recently been designed with optimised structures to achieve bandwidths in excess of 600 nm. These results will be presented at this conference [5]. This paper deals with the potential for the fibres to impact the defence industry rather than discussing the design and fabrication of the fibres. The reader is pointed to the references for further information on the fibre structures.

The transmission tests performed within the project have been made using an Q-switched mode locked (QSML) Nd:YAG system operating at λ = 1064 nm. The input QSML signal had an average power of 6.7W, a mode locked pulse length of ~ 150 ps and a Q-switch pulse repetition frequency (prf) of 15kHz.

For the HF pumped OPO experiment, peak energy of $\approx$ 2.6 Jcm^{-2} was focussed onto the fibre face, (mode area $\approx$ 350 μm^2). No damage occurred; however, a very small amount of power was also observed at a wavelength of 1120 nm. This is consistent with a spontaneous Raman shift in the fibre [6]. Transmission experiments have been conducted at higher powers in order to try to determine the maximum power that the HF can support and where the nonlinear effects become intolerable. At the maximum pulse energies available from the laser system (corresponding to ~ 35 Jcm^{-2} and peak pulse powers of ~103kW) a measurement of the spectral output shows that at this power density significant nonlinear effects are present and visible red is generated using the 1 µm pump source. The power density is still below the damage threshold of the fibre material.

PBGFs have much smaller mode areas than HFs (~20 – 30 μm^2), and the intensities within the fibre are significantly higher than in the HF. In the OPO pumping experiments power densities of up to 62 Jcm^{-2} are present in the PBGF. However, due to the fact that the majority of this energy is confined within the air core, no nonlinear effects are observed for transmission along a 10.5m length. Furthermore, no damage is observed to this fibre for optimal coupling conditions.

PBGFs have the potential to transmit far higher optical powers than is possible in any solid silica core. The maximum power density that BAE SYSTEMS have observed through a PBGF is 117Jcm^{-2} (in ps regime, limited by available source). Literature reports transmission of radiation from a Nd:YAG source (30 ns, 10 kHz) with damage occurring for pulse energies of ~ 1 mJ, equivalent to a fluence > 1 $kJcm^{-2}$ [7].

MF in Defence and Aerospace Applications

In the defence and aerospace sector, fibre delivery of high brightness sources offers many practical advantages over free-space solutions and has the potential to revolutionise next generation platform based laser sources. Fibre delivery allows complete flexibility in positioning and integrating high power lasers into air or land platforms. A suitable delivery fibre would enable a laser to be sited remotely from the sensor head and open up the possibility of several sensor types or several display units sharing the same multi-functional laser (Fig. 4). This could reduce the complexity and hence the cost of such systems leading to the potential for more affordable, robust systems.

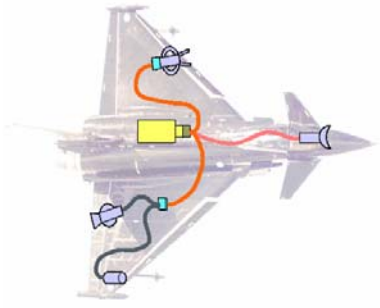

Figure 4. *Concept diagram showing remote location of sensors served from a single source*

During this project the ATC have made a speculative examination of MF technology and demonstrated that MF has the potential to impact onboard systems as a delivery technology. However it is important to establish where the technology 'fits' in current and future sensor systems. During the evaluation the ATC have attempted to align the programme of work to meet application requirements and drivers from SELEX, Thales and other potential end users.

The wavelengths of interest are considered to be 1 µm, 1.5 µm, 2 µm and mid-IR (3-5 µm) and the majority of these have been investigated during this project. It is clear that fibre delivery of high brightness pulsed sources offers practical advantages over free-space solutions for laser systems across a number of defence application areas. These potential applications include:

1. LIDAR, near earth observation and tracking
2. Target illumination (e.g. for active hyperspectral imaging, enabling 24-hr illumination capability)
3. Illumination sources for helmet mounted displays and HUDs
4. Range finding, infrared countermeasures (IRCM) and DEW
5. Delivery of high power radiation for Power-by-Light applications

The 'light piping' application is perhaps seen as the most likely application area for microstructured fibres. As well as the sensing applications in the mid-IR region, microstructured fibres may also be seen as a future technology for diode pump delivery systems (800 nm) allowing remote location of the laser head, target designation and countermeasures.

HF is likely to offer suitable performance for delivering radiation for remote sensing, target illumination (active imaging), power-by-light and DIRCM. The limitation of HF is likely to be governed by the generation of nonlinear effects at high powers rather than the damage limit of the material. Nonlinear effects have been observed at power densities below the damage threshold of silica and for some applications the resulting degradation in pure spectral content may comprise the functionality of the system.

The PBGF offers an alternative solution to avoid this. The air guidance presents obvious power handling advantages and indeed we have seen above that the powers observed through the PBGF are considerably higher than that of its HF counterpart. PBGFs are suitable for all the applications above and in addition may also become a potential technology for applications requiring extremely high powers e.g. DEW and target designation.

Potential platforms envisaged for microstructured fibre technology are UAVs, fast jets and rotary wing craft. Reduction in weight and ease of installation is of vital importance for laser based systems installed on platforms, particularly for autonomous vehicles, unmanned aircraft and any vehicle where positioning the laser becomes a critical design challenge. The use of fibre delivery has the potential to bring about not only flexibility in locating sensors but also a significant reduction in system cost in terms of installation, weight, and maintenance. For example, in a UAV used for target tracking / observation a minimum of four sensor systems may be required to provide a full overview of the bottom hemisphere. In a laser based system each of these sensors would require an independent laser source with associated drive electronics and cooling. This not only adds to the weight of the system but also has the potential to compromise optimal sensor positioning as the laser source and sensor head would need to be collocated.

In contrast, a fibre delivered laser source would allow complete flexibility in positioning the sensors on any part of the platform. With the radiation from the laser "piped" to each sensor it is possible to envisage all the sensors being served by a single centrally located laser source. This would result in a weight reduction of up to 75% over using four sources and an associated reduction in costs due to weight, heat dissipation and maintenance requirements.

Fibre delivery of radiation also opens up the potential for power-by-light applications with "all-fibre" network systems allowing command, control (actuation) and communications signals to flow through the same installation cables.

Route Map for Technology Exploitation

Many pre-installed systems are not looking for upgrade requirements at present and indeed the microstructured fibre technology is not at a technology readiness level (TRL) sufficient to be seen as an immediate solution for an upgrade.

It is more likely that microstructured fibres will be looked to as a technology for future applications requirements. Fibre delivery will become increasing important in order to assist with integration of several systems onto a single platform. The concept of the multifunctional laser system, which would be enabled by microstructured fibre technology, has the potential to revolutionise platform based laser systems.

In order to ensure that this technology is at sufficient readiness level to provide a viable solution for integration technology, a designated programme of development is required. The end preparation of the fibres is a critical factor to address. This is because the ends of the fibres degrade over time due to contaminants in the laboratory and air. This causes intolerable distortion to the mode profiles, losing the quality of the radiation. Contamination may also act as a damage site when the fibres are used for high power applications, resulting in a reduced capability for transmission. Since even a small degree of contamination may significantly degrade fibre performance, the issues surrounding end-face termination of MF fibres are of utmost concern if this technology is to move forward into commercial applications.

In addition the fibres will need to undergo a programme of development in terms of buffering, cabling and shielding in order to ensure that they are sufficiently ruggedised for aerospace installation. A full programme of environmental testing is then required in order to fully test the fibres for the demanding aerospace installation specifications. For example, the fibre should be able to withstand the same conditions as for communications fibres and withstand temperature cycles from –65° to 125°C without degradation in terms of strength or reduction in performance. It is anticipated that the fibres will perform to these standards; indeed, preliminary tests at BAE SYSTEMS have already shown that the strength performance of MF is comparable to that of standard step index fibres as installed on platform.

Industries outside aerospace and defence have also expressed broad interest for microstructured fibre technology. The delivery of high power radiation in a lightweight, flexible and cost effective medium is of great significance to the printing and marking industries, for Direct Write and for medical and automotive industries [8]. Furthermore, constant improvements in fibre laser technology are likely to drive the development of fully “fiberised” systems. However, it is important for the aerospace and defence industry that the programmes of development and testing are aligned with its own stringent requirements. The end preparation and cabling developed for industry may not provide a suitable solution to meet the required standard for platform installation.

Once these design challenges have been met, the next step would be to deploy the fibre into a large scale technology demonstration program, e.g. a UAV system or fast jet programme, and allow the customers to determine how much more freedom they have in terms of platform design when all sensors and onboard EO systems can be served by a single laser source delivered by fibre. Only then will the true benefits of microstructured fibres be realised.

Conclusions

The results obtained with the “Photonic Fibres for Active Sensor Systems” project suggest enormous potential for these novel fibre types to influence the next generation of photonic systems for security and defence applications.

It has been demonstrated through a representative demonstration (OPO pumping) and through laboratory based transmission trials that microstructured fibres have the wavelength flexibility and the power handling capability to deliver the powers required for onboard systems such as target illumination, LIDAR, near earth observation, DIRCM, and other EO based sensor activities. Microstructured fibres have been shown to support wavelengths of interest for all potential EO sensing applications: ~1 µm, 1.5 – 2.5 µm (SWIR) and mid IR.

There are a number of applications beyond aerospace and defence that will also benefit from this type of fibre delivery technology; printing and marking, direct write, fibre laser systems etc. These “industry pulls” are envisaged to help drive the technology and determine a suitable commercial cost.

It is clear that a further programme of work is now required to specifically focus on the development of the fibre technology to ensure that it will be suitable for the aerospace environment.

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