Chapter 1 – INTRODUCTION

1.1 BACKGROUND

A laser is only a relatively sophisticated light source with many special optical properties, such as high directionality and coherence within the beam, which have been applied over the last five decades to a vast range of military as well as civilian applications. As the laser technology continues to develop, so the number of military applications increases. Hence, the “laser” can no longer be considered to be a technical solution looking for a problem.

In the decades since 1960, the developments in general with laser technology have revolutionised the performance of many military systems, providing the operators and war fighters with significant enhancements in performance particularly in remote sensing, countermeasure techniques (hard- and soft-kill options), guidance and navigation systems, as well as a valuable training aid. Consequently, there have been many military projects aimed at exploiting one or more of these special optical properties of the laser, or its fundamental characteristics, since the first reported practical demonstration of laser action in May 1960 by Theodore Maiman.

The first reported application of laser technology concerned sensing and targeting, and in particular, the use of a pulsed source to measure the distance to distant or remote objects. This provided unprecedented measurements of accuracy to a target from the remote “spotter’s position”. More recent examples of the use of the laser in the sensing function have included gated-imaging and laser-radar applications. There are a number of projects that exploit the high radiant-intensity characteristics of the laser beam for directed-energy applications, particularly for countermeasure systems used for platform protection or anti-air applications.

One of the most significant developments in laser technology over the last decade has been with the fiber laser. The initial catalyst for its development was the so-called telecommunications boom, but as often happens, the techniques developed for that application were relevant to other applications; moreover, the fiber-laser concept has proved to be extremely versatile.

A fiber laser is a solid-state rod laser with a long and very thin gain medium surrounded by an undoped host, such as “glass”, which has many advantages for the efficient extraction of waste heat, which can be one of the limiting features of solid-state lasers, leading to very undesirable beam characteristics. The inefficiencies in the generation of photons leading to heat generation within the laser gain medium are usually the fundamental cause of aberrations in the emitted beam intensity profile produced by a conventional solid-state laser.

The operation of a fiber laser can be considered to be a brightness converter, owing to the very high optical-to-optical conversion efficiency, as well as a wavelength changer. The device takes the highly divergent laser light from the pump diodes and usually emits light at a slightly different wavelength in a much brighter beam, i.e. a beam with more optical power and very small divergence. Beam brightness is a fundamental requirement of all directed-energy applications; additionally, beam brightness is important for many sensing applications. Moreover, fiber-laser technology can be configured to control the mode and polarisation of the emission from each fiber laser device. Mode control is normally a fundamental requirement for higher-power devices intending to combine the emission from several lasers in order to create a higher power output. However, not all directed-energy applications require high-power emission, but normally stable and high beam-quality characteristics are necessary.

The basic design of a conventional fiber laser is a doped core surrounded by a so-called cladding region of similar material to the core but not doped and with a slightly reduced refractive index compared with the core. This optical arrangement, with the differing refractive indices, provides the confinement of the light along the length of the optical fiber core. This core region is often a few microns in diameter and the cladding several orders of magnitude greater, although so-called large-mode area devices have been demonstrated for high-power applications; these fibers have a core diameter of the order of 10 – 50 µm.

Until recently, the main thrust with fiber-laser technology has been with devices that emit in the near and short-wave infrared (up to about 2 µm). These devices have been shown to be highly efficient and robust, so that very small and compact systems can be realised.

The mid-wave infrared (2 – 5 µm), coinciding with an atmospheric window that generally has high beam transmission, is a very important part of the electromagnetic spectrum for many military applications, especially for sensing and countermeasure systems. Other laser technologies are available for operation in this part of the spectrum, but most lack the advantages of fiber-laser sources; moreover, many of these sources are reliant on non-linear techniques using bulk crystals, which tend to make the source more complex and reduce efficiency, leading to a larger system "package".

An Exploratory Team was formed during 2009 under the auspices of the NATO Sensors and Electronic Technologies (SET) Panel to consider the prospects for the application of fiber laser technology, and associated techniques, to generate emission in the mid-wave infrared. This short study identified the following research areas where progress was needed for mid-IR fiber laser technology to advance:

- Fiber gain media based upon materials other than silica, for low-loss transmission through the mid-IR spectral region;
- For writing gratings into non-silica fibers to form resonators to enable monolithic structures to be realised; and
- Optical components such as isolators, modulators, and switches designed for mid-IR operation.

The latter topic was not included in the scope of the planned study group because development of such components entails significant expense and is best left for industry. However, given the growing use of shorter-wavelength fiber lasers as pumps for $\chi^{(2)}$ frequency conversion into the mid-IR, a comparative assessment of fiber-based pumping strategies and architectures was added to the scope of the study group.

The recommendation from the ET to the SET Panel was that the technology base was sufficiently well developed to warrant an investigation of mid-wave IR generation in solid-state devices for military applications. This recommendation was accepted and a technology group was formed to plan and implement a programme of research to investigate these topics. Moreover, the proposed research topic to investigate *fiber gain media based upon materials other than silica, for transmission through the mid-IR*, was expanded and differentiated to include non-linear fibers (Raman, super-continuum), for example, in addition to laser gain media, to reflect existing interest and progress in these techniques.

1.2 OBJECTIVES

The principal objective of this Research Task Group (RTG) was to advance the state-of-the-art in mid-IR fiber laser technology through collaboration involving leading researchers in participating Nations, focusing on the technical areas listed below. Whilst the mid-IR spectral region is often defined as 2 – 5 µm to correspond with the atmospheric transmission window at these wavelengths, the technical challenges of producing coherent output at 3 µm and beyond are more significant and often distinct from those associated with the 2 – 3 µm region. This is demonstrated by the increasing availability of lasers, both fiber and bulk, operating in this region. To extend coverage through the entire mid-IR region, the RTG decided to focus on sources that can emit at 3 µm and longer wavelengths. This, of course, does not exclude sources that can operate at shorter wavelengths in addition to the 3 – 5 µm region.

1.3 GOALS

The specific goals of the TG programme were:

- To investigate direct lasing in fiber gain media at wavelengths longer than 3 µm:
  - Spectroscopic characterisation of doped IR glasses and fibers to augment existing data;
  - Modelling of lasing in candidate fibers using spectroscopic data;
  - Development of specifications for fabrication of promising candidate fiber(s);
  - Exchange of data among panel members; and
  - Demonstration of gain/lasing in IR glass preform, and experimental fiber.
- To investigate non-linear frequency conversion in fibers at wavelengths longer than 3 µm:
  - Measurement non-linearity and dispersion in candidate fibers;
  - Exchange of data among Task Group members;
  - Modelling of frequency conversion behaviour using resulting data;
  - Demonstration of super-continuum generation in suitable fiber(s) using streamlined pump architecture; and
  - Investigation of Raman conversion, if suitable fiber is available.
- Comparison of fiber-based pump techniques for frequency conversion into the mid-IR:
  - Identification and assembly of a standard set of non-linear frequency conversion samples;
  - Development of an experimental protocol for frequency conversion experiments;
  - Evaluation of diverse pumping schemes using the standard sample set and measurement protocol; and
  - Exchange, analysis, and comparison of results.

1.4 RTG MEMBERSHIP

It was decided by consensus that Task Group members should be government or government on-site contractors, to include on-site support contractor scientists involved in national research programmes related to the activities of the Group. The countries that participated in this activity were: Canada, Denmark, France, Germany, Norway, Poland, the United Kingdom and the United States. The lead Nation was the United States and technical team leader was Dr. Rita Peterson of the Air Force Research Laboratory (AFRL).