REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
19-06-2006	Final Report	1 July 2005 - 19-Dec-06

4. TITLE AND SUBTITLE

Final Report Item 0006

5a. CONTRACT NUMBER
FA8655-05-1-3046

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Dr. René E Kristiansen

5d. PROJECT NUMBER

5d. TASK NUMBER

5e. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Crystal Fibre A/S
Blokken 84
Birkerod 3460
Denmark

8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

EOARD
PSC 821 BOX 14
FPO AE 09421-0014

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
Grant 05-3046

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report results from a contract tasking Crystal Fibre A/S as follows: Crystal Fibre will conduct research and development of large mode area, dual clad multi-core Yb-doped photonic crystal fiber. The fiber may be polarization maintaining (PM). Nominal fiber designs will include six and seven core fibers with nominal specifications of 400 micron 0.6 NA pump core, and 30-35 micron signal cores. Crystal Fibre shall fabricate 1 pre-form worth but not less than 50 meters of passive and active versions of each fiber designed under this task. Crystal Fibre shall provide characteristics of the fiber fabricated to include core and cladding diameters, core and cladding numerical apertures, Yb doping concentration, and pump absorption at 976nm. Passive multicore fiber versions without airclad will be available approximately 1½ month after fiber design agreement. Active multicore airclad fiber versions will be available approximately 3 months after fiber design agreement. Within this project we will deliver a passive and active version of multicore fiber iteration 1 and a passive version of multicore fiber iteration 2.

15. SUBJECT TERMS

EOARD, Laser physics, Fibre Lasers, Photonic Crystal, Multicore, Fiber Laser

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18, NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			DONALD J SMITH
UNCLAS	UNCLAS	UNCLAS	UL	10	19b. TELEPHONE NUMBER *(Include area code)* +44 (0)20 7514 4953

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39-18

AQ F07-06-06638

CRYSTAL FIBRE

FINAL REPORT ITEM 0006

DOCUMENT INFO

Government Purpose Rights

Agreement No.:	FA8655-05-1-3046
Recipient's Name:	Crystal Fibre A/S
Recipient's Address:	Blokken 84, DK-3460 Birkerød Denmark
Date:	December 2005
Customer organization:	Air Force Research Laboratory, AFRL/Kirtland
Customer contact:	Capt. Benjamin G. Ward
Project Manager:	Jes Broeng (jb@crystal-fibre.com)
Report By:	Kim P. Hansen (kph@crystal-fibre.com)

Approved for public release; distribution is unlimited.

INDEX

DOCUMENT INFO 1
INDEX 1
INTRODUCTION 2
PASSIVE 6-CORE FIBER 2
PHYSICAL PROPERTIES 2
FIBER STRUCTURE 3
PASSIVE 7-CORE FIBER 4
PHYSICAL PROPERTIES 4
FIBER STRUCTURE 5
ACTIVE 6-CORE FIBER 5
PHYSICAL PROPERTIES 5
FIBER STRUCTURE 6
ACTIVE 7-CORE FIBER 7
PHYSICAL PROPERTIES 7
FIBER STRUCTURE 8
PASSIVE POLARIZING FIBER 8
FIBER DESIGN TARGETS 8
ACTIVE POLARIZING FIBER 9
FIBER DESIGN TARGETS 9

INTRODUCTION

This report describes the photonic crystal fibers developed under agreement No FA8655-05-1-3046. All information in this report is approved for public release with unlimited distribution.

The following six fiber types are included in this report:

- Passive 6-core fiber
- Passive 7-core fiber
- Active Yb-doped 6-core airclad fiber
- Active Yb-doped 7-core airclad fiber
- Passive polarizing fiber
- Active Yb-doped polarizing air-clad fiber

Each fiber type is described separately in the following paragraphs and fiber specifications are listed for finalized fibers.

PASSIVE 6-CORE FIBER

The fiber designed for this part of the project is a passive pure silica 6-core fiber. The fiber structure is shown schematically in Figure 1 below.

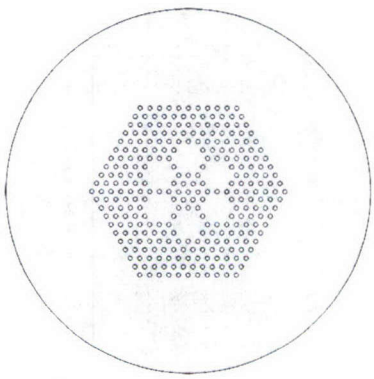

Figure 1 Schematic of the fiber design. Gray denotes pure silica areas, white denotes air. Please note that the fiber cross-section is not drawn to scale.

Targets for the structural dimensions and optical properties can be found in the subsequent section.

PHYSICAL PROPERTIES

The physical properties and structural dimensions of the fibers are listed below. Values listed in the "Fiber" column are measured values on the fabricated fiber. Values listed in the "Target" column are the design targets.

	Fiber	*Target*
Material		
Core material:	Pure silica	
Cladding material:	Pure silica	
Coating material:	Acrylate (single layer)	
Dimensions, Fiber 1		
Pitch:	10 µm	10 µm
Relative hole size:	0.176	0.18
Cladding diameter:	590 µm	~600 µm
Coating diameter:	715 µm	-

Dimensions, Fiber 2

Pitch:	10 µm	10 µm
Relative hole size:	0.20	0.20
Cladding diameter:	590 µm	~600 µm
Coating diameter:	715 µm	-

Dimensions, Fiber 3

Pitch:	10 µm	10 µm
Relative hole size:	0.225	0.22
Cladding diameter:	590 µm	~600 µm
Coating diameter:	715 µm	-

[1]: Measured as diameter of the largest inscribed circle within the inner cladding layer.

FIBER STRUCTURE

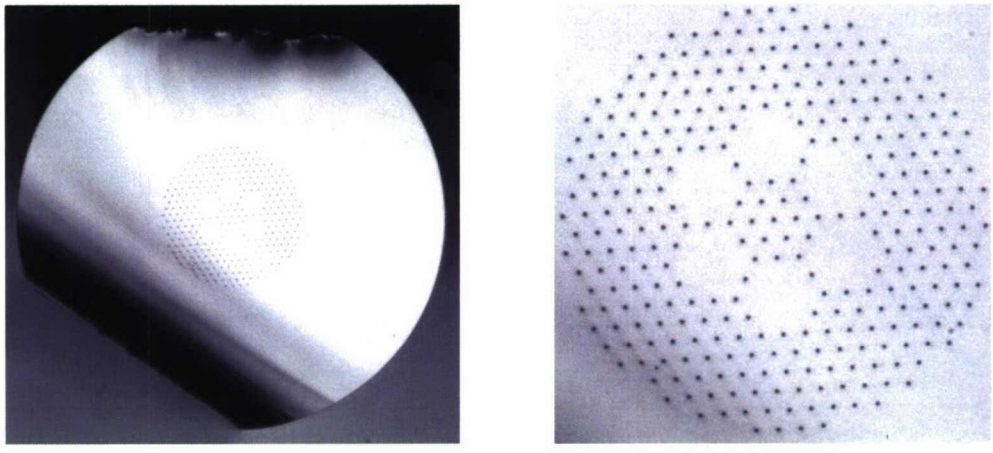

Figure 2 Top illuminated microscope pictures of the entire fiber cross section and the microstructured region.

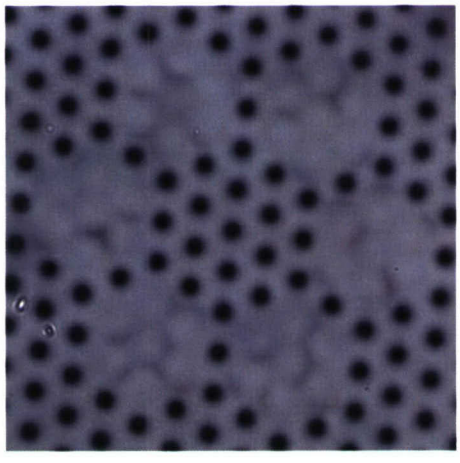

Figure 3 Bottom illuminated microsope picture of the microstructured part of the fiber. The dark regions in the core are low-index areas formed by the outer part of the rods used to create the core. This kind of low index regions has not been observed in a fiber before and originate from the raw glass. The glass manufacturer has been notified and the origin of the low index is being investigated. It was mutually agreed that no redrawing of the fibers was needed.

PASSIVE 7-CORE FIBER

The fiber designed for this part of the project is a passive pure silica 7-core fiber. The fiber structure is shown schematically in Figure 4 below.

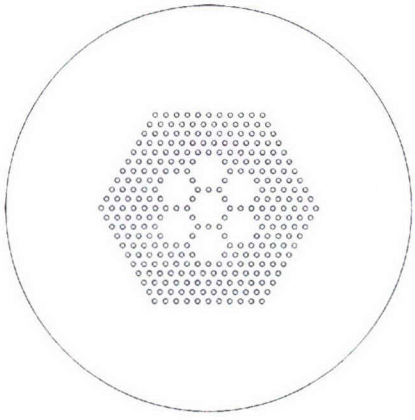

Figure 4 Schematic of the fiber design. Gray denotes pure silica areas, white denotes air. Please note that the fiber cross-section is not drawn to scale.

Targets for the structural dimensions and optical properties can be found in the subsequent section.

PHYSICAL PROPERTIES

The physical properties and structural dimensions of the fibers are listed below. Values listed in the "Fiber" column are measured values on the fabricated fiber. Values listed in the "Target" column are the design targets.

	Fiber	*Target*
Material		
Core material:	Pure silica	
Cladding material:	Pure silica	
Coating material:	Acrylate (single layer)	
Dimensions, Fiber 1		
Pitch:	10.05 µm	10 µm
Relative hole size:	0.177	0.18
Cladding diameter:	593 µm	~600 µm
Coating diameter:	714 µm	-
Dimensions, Fiber 2		
Pitch:	10.1 µm	10 µm
Relative hole size:	0.197	0.20
Cladding diameter:	592 µm	~600 µm
Coating diameter:	714 µm	-
Dimensions, Fiber 3		
Pitch:	10.1 µm	10 µm
Relative hole size:	0.212	0.22
Cladding diameter:	587 µm	~600 µm
Coating diameter:	714 µm	-

[1]: Measured as diameter of the largest inscribed circle within the inner cladding layer.

FIBER STRUCTURE

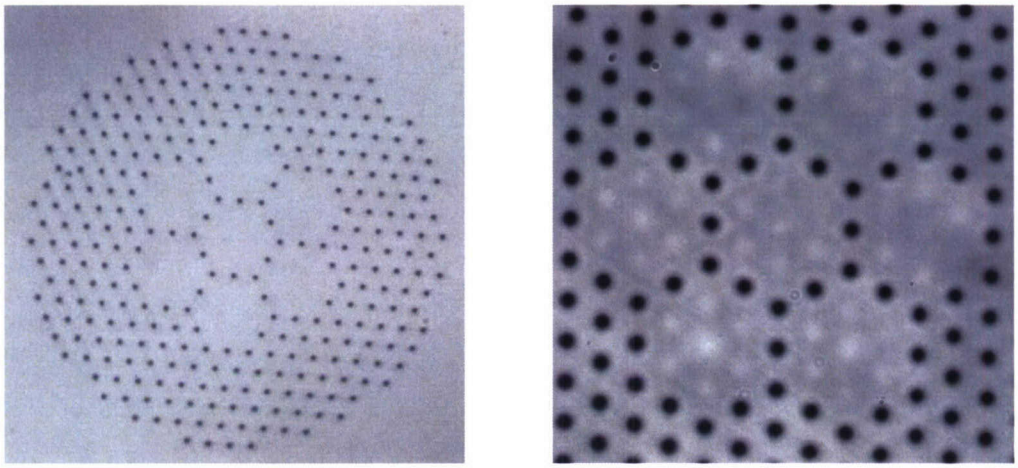

Figure 5 Top illuminated (left) and bottom illuminated (right) microscope pictures of the microstructured region.

ACTIVE 6-CORE FIBER

The fiber designed for this part of the project is an active Ytterbium-doped, 6-core fiber equipped with a high NA air-clad multimode pump-guide. The fiber structure is shown schematically in Figure 6 below.

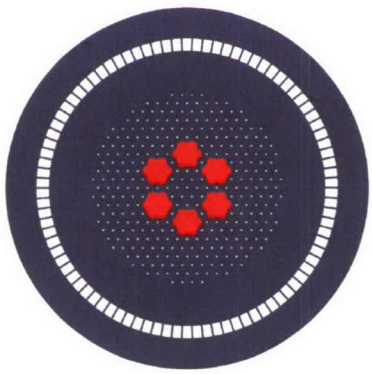

Figure 6 Schematic of the fiber design. Dark gray denotes pure silica areas, white denotes air and the six ytterbium doped cores are shown in red. Please note that the fiber cross-section is not drawn to scale.

Targets for the structural dimensions and optical properties can be found in the subsequent section.

PHYSICAL PROPERTIES

The physical properties and structural dimensions of the fibers are listed below. Values listed in the "Fiber" column are measured values on the fabricated fiber. Values listed in the "Target" column are the design targets.

	Fiber	*Target*
Material		
Core material:	Yb-doped silica	
Cladding material:	Pure silica	
Coating material:	High temperature acrylate (single layer)	
Dimensions		
Pitch:	10.0 µm	10 µm
Relative hole size:	0.195	0.2
Core diameter:	38 µm	38 µm
Cladding diameter:	635 µm	~600 µm
Coating diameter:	800 µm	~700 µm
Air-cladding dimensions		
Length of silica bridges:	15-16 µm	~15 µm
Inner diameter [1]	399	380 µm
Optical Properties		
Pump absorption at 976 nm:	-	10-15 dB/m
Air-cladding NA	0.56	~0.6

[1] : Measured as diameter of the largest inscribed circle within the inner cladding layer.

FIBER STRUCTURE

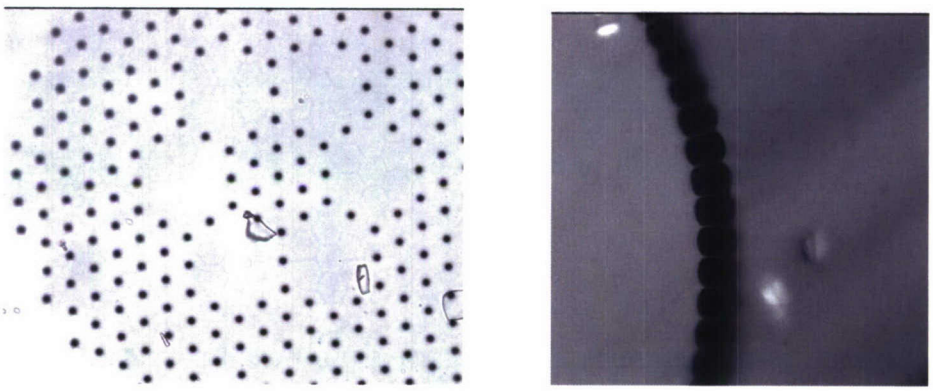

Figure 7 Microscope pictures of (left) the six Yb-doped inner cores, and (right) the air-clad.

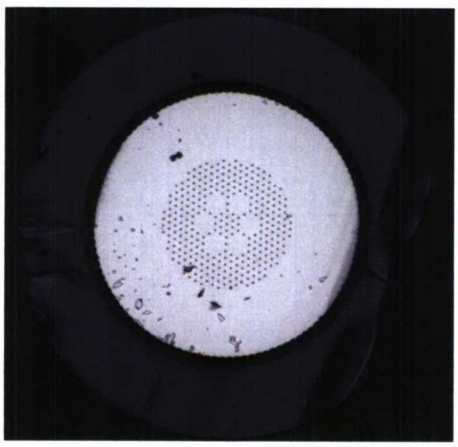

Figure 8 Microscope pictures of the entire fiber cross section. The fiber is illuminated from below.

ACTIVE 7-CORE FIBER

The fiber designed for this part of the project is an active Ytterbium-doped, 7-core fiber equipped with a high NA air-clad multimode pump-guide. The fiber structure is shown schematically in Figure 9 below.

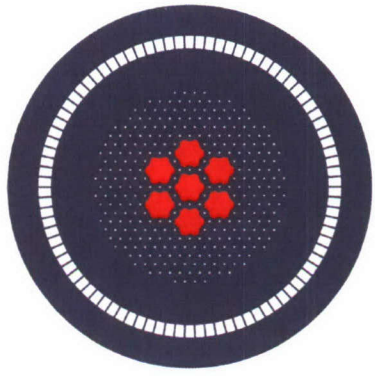

Figure 9 Schematic of the fiber design. Dark gray denotes pure silica areas, white denotes air and the seven ytterbium doped cores are shown in red. Please note that the fiber cross-section is not drawn to scale.

Targets for the structural dimensions and optical properties can be found in the subsequent section.

PHYSICAL PROPERTIES

The physical properties and structural dimensions of the fibers are listed below. Values listed in the "Fiber" column are measured values on the fabricated fiber. Values listed in the "Target" column are the design targets.

	Fiber	*Target*
Material		
Core material:	Yb-doped silica	
Cladding material:	Pure silica	
Coating material:	High temperature acrylate (single layer)	
Dimensions		
Pitch:	10 µm	10 µm
Relative hole size:	0.2-0.22	0.2
Core diameter:	38 µm	38 µm
Cladding diameter:	650 µm	~600 µm
Coating diameter:	820 µm	~700 µm
Air-cladding dimensions		
Inner diameter [1]	404 µm	380 µm
Optical Properties		
Pump absorption at 976 nm:	-	10-15 dB/m
Air-cladding NA	0.55	~0.6

[1] : Measured as diameter of the largest inscribed circle within the inner cladding layer.

FIBER STRUCTURE

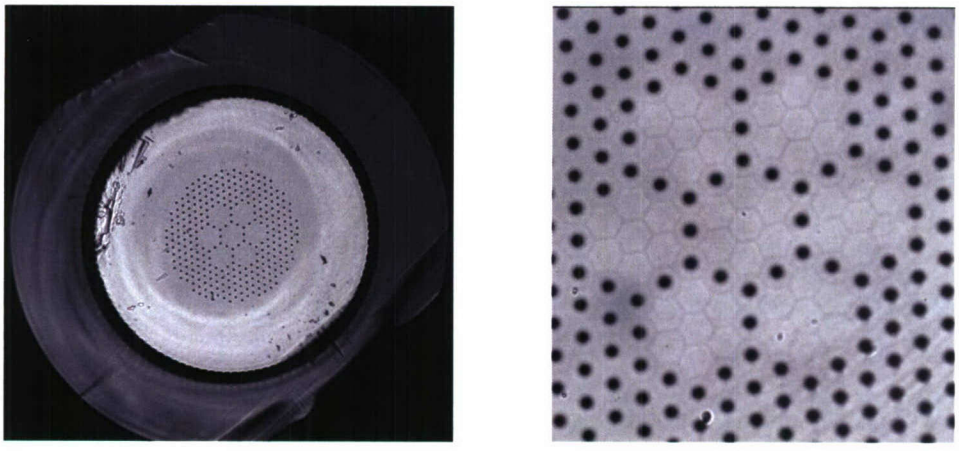

Figure 10 Microscope pictures of the entire fiber cross section (left). And the 7 active Yb-doped cores (right). The fiber is illuminated from below.

PASSIVE POLARIZING FIBER

The fiber designed for this part of the project is a pure silica, polarizing large-mode area fiber. The fiber structure is shown schematically in Figure 11 below.

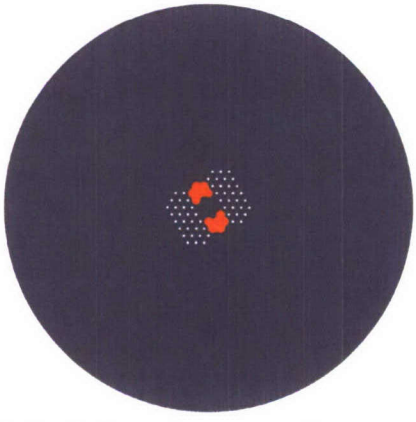

Figure 11 Schematic of the fiber design. Dark gray denotes pure silica areas, white denotes air. The polarizing properties are obtained using stress inducing elements (shown in orange). Please note that the fiber cross-section is not drawn to scale.

Targets for the structural dimensions and optical properties can be found in the subsequent section.
This fiber is scheduled for delivery primo 2006.

FIBER DESIGN TARGETS

Material

Core material:	Pure silica
Cladding material:	Pure silica
Coating material:	High temperature acrylate (single layer)

Dimensions

Pitch:	10 µm
Relative hole size:	0.2
Core diameter:	38 µm
Cladding diameter:	~600 µm
Coating diameter:	~700 µm

Air-cladding dimensions

Number of silica bridges:	120
Thickness of silica bridges:	~0.4 µm
Length of silica bridges:	~15 µm
Inner diameter [1]	380 µm

Optical Properties

Birefringence:	$> 1 \cdot 10^{-4}$
Polarizing bandwidth:	> 100 nm
PZ center wavelength	1 µm

[1] : Measured as diameter of the largest inscribed circle within the inner cladding layer.

ACTIVE POLARIZING FIBER

The fiber designed for this part of the project is an active Ytterbium-doped, polarizing large-mode area fiber equipped with a high NA air-clad multimode pump-guide. The fiber structure is shown schematically in Figure 12 below.

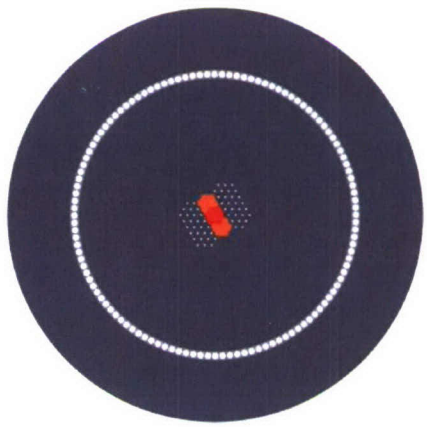

Figure 12 Schematic of the fiber design. Dark gray denotes pure silica areas, white denotes air and the ytterbium-doped core is shown in red. The polarizing properties are obtained using stress inducing elements (shown in orange). Please note that the fiber cross-section is not drawn to scale.

Targets for the structural dimensions and optical properties can be found in the subsequent section.
This fiber is scheduled for delivery primo 2006.

FIBER DESIGN TARGETS

Material

Core material:	Yb-doped silica
Cladding material:	Pure silica
Coating material:	High temperature acrylate (single layer)

CRYSTAL FIBRE

Dimensions

Pitch:	10 µm
Relative hole size:	0.2
Core diameter:	38 µm
Cladding diameter:	~600 µm
Coating diameter:	~700 µm

Air-cladding dimensions

Number of silica bridges:	120
Thickness of silica bridges:	~0.4 µm
Length of silica bridges:	~15 µm
Inner diameter [1]	380 µm

Optical Properties

Pump absorption at 976 nm:	~2.5 dB/m
Air-cladding NA:	~0.6
Birefringence:	$> 1 \cdot 10^{-4}$
Polarizing bandwidth:	> 100 nm
PZ center wavelength	1 µm

[1] : Measured as diameter of the largest inscribed circle within the inner cladding layer.

We certify that there were no subject inventions to declare during the performance of this grant.

Kim P. Hansen

Jes Broeng