Development of an active mode-locked fibre ring laser for time division multiplexing applications

Patrick V. Nimwa, R. Martinez Manuel, JJM Kaboko
Photonics Research Group, Department of Electrical and Electronic Engineering Sciences
University of Johannesburg, P. O. Box 524, Auckland Park 2006
Tel: +27 11 559 2462, Fax: +27 11 559 2343
Email: pnimwa@gmail.com

Abstract- The work in progress on the development of a tunable actively mode-locked Erbium-doped fibre ring laser is presented. The exponential growth of data traffic in optical telecommunication has increased the need of ultra short pulse sources. Actively mode-locked fibre ring lasers can produce ultra-short pulses which play a key role in optical time and wavelength-division multiplexing communication. The main goal of the project is to design, to simulate and to implement an active mode-locked fibre laser operating in the telecommunication C-band. The focus of this experimental investigation is to optimize the mode-locked fibre laser in terms of output peak power, stability and tunability of both wavelength and output peak power.

Index Terms— active mode-locking, fibre laser, erbium doped fibre.

I. INTRODUCTION

The concept of laser was first published by A. L. Schawlow and C. H. Townes in 1958. Successful operation of the first laser (ruby laser) was obtained in 1960 by T. H. Maiman [1]. The combination of optical fibres and lasers has led to the development of fibre lasers. Fibre lasers are more robust, compact, and cheaper compare to the bulk lasers. In addition, they have excellent quantum efficiency and quality beam. Fibre lasers can be produced in continuous and in pulsed schemes. Q-switching and mode-locking are the two main techniques enabling pulsed lasers. Q-switched fibre lasers generate pulses in the range of nanoseconds with a repetition rate in the kilohertz. Mode-locking fibre lasers have produced so far the highest repetition rate (gigahertz) and the shortest pulses duration (pico to femto seconds). Mode-locking fibre lasers are well suited as sources of ultra-short and stable optical pulses operating in gigahertz. These sources are required for bitrates communication systems using time and wavelength division multiplexing, for all optical switching, and for signal processing in optical telecommunication [2]. Mode-locking fibre lasers can also be used in clocking signals, medicine, sensing technology and material processing.

The work in progress presented in this paper explores different approaches to produce short pulses with maximum power, less noise and less vulnerability to external influences using active mode-locking technique for time division multiplexing.

II. PROTOTYPE DESIGN

Fibre lasers can be mode-locked to generate one or more pulses per round-trip by modulating the optical resonator (cavity) losses or the round-trip phase change [3]. As the electromagnetic wave travels through the cavity, it generates standing wave patterns called longitudinal modes. The pulse generation is achieved by simultaneous lasing multiple longitudinal modes having fixed mode spacing and fixed phase relationship with each other. If sufficiently many longitudinal modes are locked together with only small phase differences between the individual modes, it results in short pulse train as depicted in figure 1.

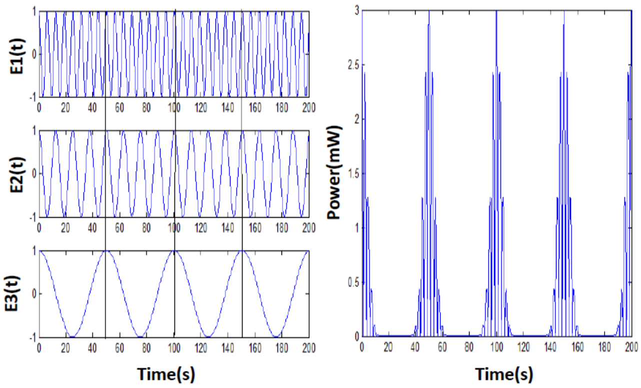

Figure1. Pulse train formed where 3 modes of the same amplitude are phase locked and the total power of the periodic short pulse train

Figure 2 shows the set up of the prototype design.

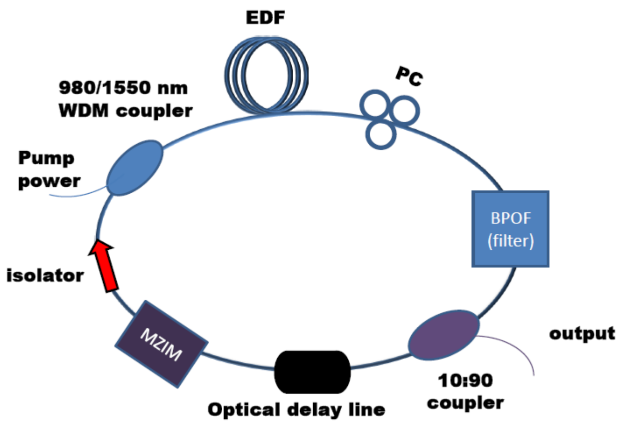

Figure2.experimental set up

The pump power is introduced in the fibre ring laser through a 980/1550nm wavelength division multiplexing (WDM) coupler. The Erbium doped fibre is used to provide the gain for the travelling light inside the ring. The polarization controller (PC) is used to optimize the polarization state of the cavity modes. The wavelength selectivity or tunability is assured by the bandpass optical filter (BPOF). Ten percent of the cavity energy of the mode-locked laser system is coupled to the output through the

90:10 coupler. An optical delay line (ODL) is inserted for cavity length adjustment and to reduce the instability of the output pulse. The Mach-Zender intensity modulator (MZIM) periodically modulates the travelling light through the fibre ring. The unidirectionality operation of the pulse in the cavity is assured by the isolator.

III. PROJECT OBJECTIVES

The main objective of this research project is to design, to implement and to characterise an active mode-locking fibre laser. The project sub-objectives are as followed:

- Theoretical investigation of pulsed fibre laser systems with a focus on mode-locking techniques.
- Design and simulation of an active mode-locked Erbium-doped fibre laser system.
- Build, optimize and characterize the designed system.

IV. PARAMETERS TO OPTIMIZE

The design of a mode-locked laser is generally a non-trivial task. There is a complicated interplay of many effects, including dispersion and several nonlinear effects. Changing one design parameter often influences several others. A careful design of the cavity parameters is necessary to achieve a balance of dispersion and nonlinearity effects for optimal operation. The focus here is on improving the output power and on stabilizing the pulse.

• The output power

The output power can be improved by the following actions:

- Increasing the modulation frequency shortens the output pulse width and increases the output peak power [4].
- Broadening the filter bandwidth shortens the output pulse and increase the peak power [4], [5].

•Pulse stabilization

Some of the following actions may be undertaken to have stable output laser pulses:

- Reduction of the cavity length in order to limit the super modes noise leading to instability [4].
- Use of polarization maintaining fibres to build the ring cavity which eliminate polarization instabilities and vibration sensitivity [5].
- Include detuning devices such as fibre Fabry-Perot filter, piezo-electric drives to eliminate the formation of super mode [6].
- Use of the regenerative mode-locking technique to allow the centre frequency to drift free and to be fixed to the modulation frequency.

However, tradeoffs between stability, noise generation and production of shorter pulses with high peak power are not only inevitable but necessary.

V. METHODOLOGY

A thorough literature review is currently undertaken to understand the fundamental principles underlying the mode- locking lasers and ways to improve them in light of the project objectives. The following activities are to be conducted:

- Numerical simulations to determine the optimal characteristics of the parameters to improve in the actively mode-locked fibre ring laser (AMLFRL) systems
- Experimental tests and characterization of the parameters of the AMLFRL.
- Implementation of the prototype design of the AMLFRL and further characterization and improvement of the parameters
- Experimental optimization of the AMLFRL set-up.
- Applications to TDM communications systems and basic resolution in the sensing technology.

VI. CONCLUSION

Short pulsed lasers have constituted an extensive field of research as their applications range from the multiplexing in telecommunications, the military, the material processing, and the sensing technology. In this paper, a prototype design for an active mode-locking fibre laser to use in the time division multiplexing has been presented. Some plans of action have been proposed in order to improve the output power and to stabilize the pulse output. Production of ultra short pulses with mode-locking technique remains a great challenge. Nonetheless, with the suitable tradeoffs between the parameters to optimize, stable and high peak power pulses can be obtained.

VII. REFERENCES

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VIII. ACKNOWLEDGEMENTS

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Patrick Venadiambu Nimwa received his bachelor degree in electrical and electronic engineering science at the university of Johannesburg in 2012.He is now part of the photonics research group of the same university pursuing his master in photonics. His work is focused on pulsing lasers (mode-locking) for telecommunication applications and for sensing technology.