Free-space combiner unit with PCF output for SLEDs covering an ultra-broadband spectral range

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Free-space spectral combiner unit for multiple superluminescent light emitting diodes (SLEDs) with single-mode polarization maintaining photonic crystal fiber (PCF) output covering a wide spectral range from 400 to 1600 nm. This spectral combiner unit has been designed, built and tested for coupling efficiency, alignment tolerances and stability.

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Introduction

Broadband light sources are widely used in many applications ranging from spectroscopy to OCT imaging and biosensors. Superluminescent diodes offer broadband optical spectra at predefined center wavelengths, high output power levels and low relative intensity noise (RIN) in a very compact form factor. Here, the first ultra-broadband, SLED-based light source shall be realized where light from more than ten SLED sources, covering a wavelength range from 400nm to 1600nm, is coupled into a single polarization-maintaining (PM) output fiber.

Objective

The goal of the project is to design, realize and test an optical combiner box, where the optical spectra of several SLED sources are combined into a single photonic crystal fiber (PCF). The SLED chips are packaged in individual, temperature-stabilized 14-pin Butterfly modules, each with a PM fiber output. The free-space beam collimation of each fiber output into free space as well as the coupling from free space into the PCF output fiber shall be realized with achromatic parabolic metal mirrors. The spatial and spectral combination of all beams shall be done using broadband dichroic edge filters. Finally, the ultra-broadband combiner unit shall be realized as a compact box with a machined metal base that acts as an optical bench with multiple fibers being connected to the collimators.

Methods

Multiple SLED sources in the visible spectral range (400-700nm) are connected to the optical combiner unit with PM fibers that are suitable for single-mode propagation in this wavelength range. Similarly, multiple SLED sources in the near-infrared wavelength range (750-1600nm) are coupled into various types of PM fibers that are specific for the emission wavelength of the SLEDs. Depending on the type of fiber, the center wavelength of the SLED, the numerical aperture (NA) and thus the mode-field diameter (MFD) will be different. This, in turn, results in different parameters of the free-space beams and, as a consequence, different coupling into the output PCF. Therefore, the beam collimation, propagation and coupling efficiency need to be evaluated for each wavelength. An angular and positional tolerance analysis should be performed to evaluate coupling losses. Furthermore, the thermal and mechanical stability shall be analyzed. ZEMAX simulations were done to evaluate the theoretical coupling efficiency (CE) for each wavelength.

Results

As a result of this thesis, the first prototype of an ultra-broadband, free-space combiner unit was realized and tested. Several SLED sources with PM fibers were connected, collimated and coupled into a common PCF output port carrying an ultra-broadband combined spectrum that ranges from 400nm to 1600nm. Preliminary results indicate that the lateral misalignment is less critical, i.e., a large misalignment of 300 microns results in a CE reduction of 36%. On the other hand, the angular alignment is crucial as a small misalignment of 0.35 mrad leads to a 34% loss in CE.

Outlook

The following stage of this work will be further miniaturization of the combiner box down to the size similar to a 14 pin butterfly module (approx 30x15x10mm). To achieve high coupling efficiencies and robust mechanical stability the incoming fiber tips as well as output PCF tip should be fixed on the optical bench at a predefined height and output emission should be collimated in horizontal plane using parabolic collimators. Positioning and alining of the parabolic mirror plays the crucial role and thus must be performed by a high-precision assembly robot.