A Simple Half-Duplex Optical Link Using Two Identical Fabry–Pérot Lasers at 1.55 µm Wavelength

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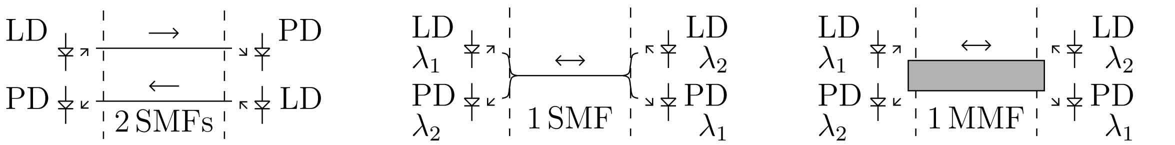
We report on a simple bidirectional optical link using two InP-based Fabry–Pérot (FP) lasers operating at 1.55 µm wavelength as optical transmitter and receiver. Since the emitted light of one FP laser is absorbed by the other when it is reverse biased, no additional photodiode is required. The optoelectronic devices are butt-coupled to single-mode fibers (SMFs). With this configuration, up to 100 Mbit/s operation over a 50 km-long standard SMF is demonstrated. The optical link length is limited by fiber attenuation and coupling losses. In addition, we suggest a simple electrical driver circuit which acts as an interface between a RS 232 computer port and the FP laser. It enables half-duplex operation. A combined transimpedance receiver circuit improves the sensitivity of the optical system and allows successful bidirectional communication of two personal computers (PCs) over 100 km of SMF.

1. Introduction



(a) Two unidirectional SMFs (b) One bidirectional SMF with fiber couplers (c) One MMF with narrow spaced LD and PD

Fig. 1: Schematics of some basic approaches of bidirectional optical links.

Bidirectional optical links have been established in different configurations. The most straightforward configuration consists of two independent SMFs which operate in unidirectional mode (see Fig. 1(a)). With optical circulators or wavelength-division muliplexing, the use of only one SMF becomes possible, however, expensive components are required, e.g. wavelength filters and a laser and a photodiode on both sides (Fig. 1(b)). The optical system configuration is much relaxed if multimode fibers (MMFs) are used, because laser and photodiode can be placed close to each other and be directly butt-coupled to the MMF (Fig. 1(c)) [1]. However, the bandwidth–length product of this approach is limited by modal dispersion.

In this article we use only one optoelectronic component at each side of the optical link, as indicated in Fig. 2. We operate at $\lambda = 1.55$ µm wavelength in order to benefit from

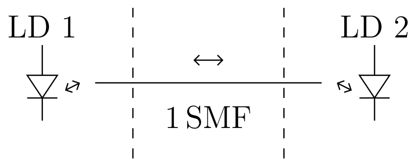


Fig. 2: Schematic of our bidirectional approach incorporating two identical FP lasers.

the attenuation minimum of the SMF. FP lasers are the first choice because they do not have wavelength-selective mirrors, what enables the use as a detector as well. FP lasers emit on several longitudinal modes and have a rather broad spectrum, which limits the modulation speed to several Mbit/s over a 50 km-long SMF.

2. Design and Fabrication

We use an InP-based ridge-waveguide structure to ensure lateral single-mode behavior. The active layer consists of six 6 nm-thick compressively strained InGaAlAs quantum wells. The simulated modal gain is shown in Fig. 3, where the simulation model of [2] has been used. The given laser waveguide provides a transverse optical confinement factor of about 7 %. Due to the strong excitonic absorption at around $\lambda = 1550$ nm, we observe high absorption for reverse-biased waveguides. Figure 4 shows the simulated modal absorption for the same waveguide as in Fig. 3 for several applied reverse voltages.

The 2 µm-wide ridge-waveguide is realized by wet-etching while using the metal p-contact as etch mask. Benzocyclobutene (BCB) has been employed for passivation. P-type bond-pads are created with a lift-off process. After the samples are thinned to a thickness of

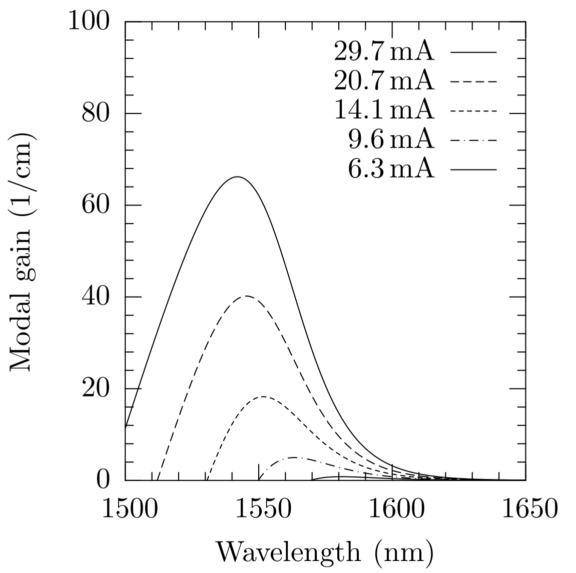


Fig. 3: Simulated modal gain of the ridge-waveguide structure for several pumping currents.

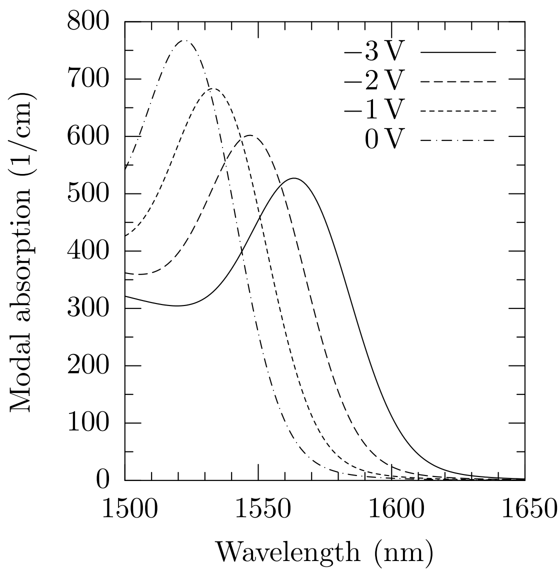


Fig. 4: Simulated modal absorption of the ridge-waveguide from Fig. 3 for several reverse bias voltages.

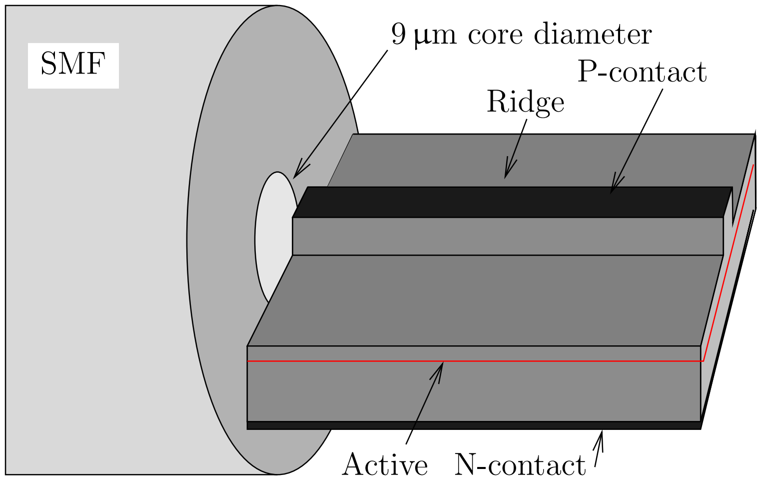


Fig. 5: Schematic of a FP ridge-waveguide laser diode coupled to a SMF.

about 100 µm, the n-contact is evaporated. The devices are cleaved to lengths of 500 µm and resulting short laser bars are glued to SMA-type connectors and wire-bonded.

The devices are directly placed in front of the core of a SMF, as indicated in Fig. 5. Figure 6 shows photographs of mounted lasers prepaired for bidirectional operation. Although relatively high coupling losses are to be expected with this configuration, no additional optics are used in order to keep the setup as simple as possible.

Figure 7 displays the simulated mode field within the ridge-waveguide structure of the laser diode, which is found by a numerical solution of the scalar wave equation. Figure 8 illustrates the simulated field of the fundamental mode of a SMF which is calculated in the same way. Please note the difference in the scaling of the axes. The mode mismatch is chiefly responsible for the low coupling efficiency.

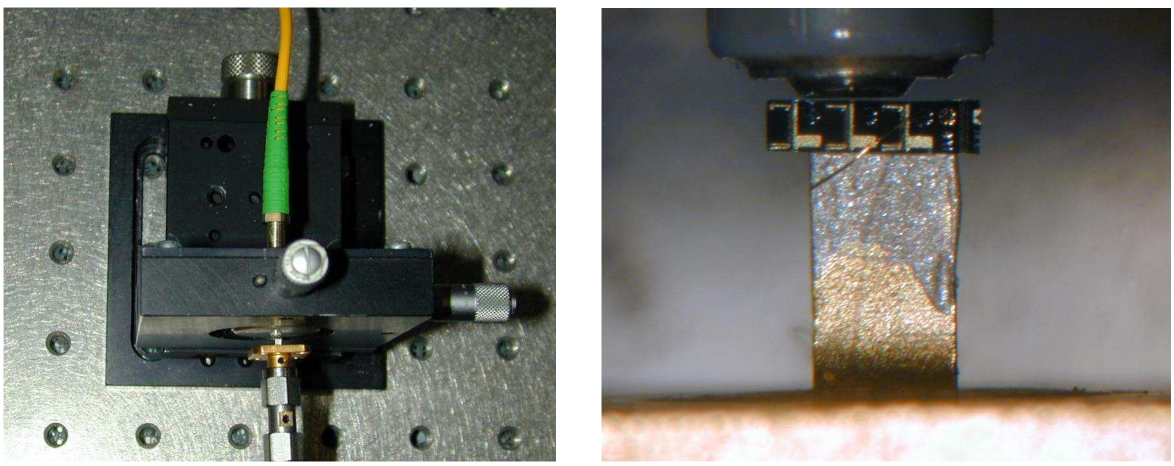


Fig. 6: Photographs of a laser-to-fiber coupling unit. A FP laser bar is glued with its epitaxial side to the inner electrode of a SMA connector. The p-contact is wire-bonded. Laser aligned in front of a SMF (left) and close-up (right).

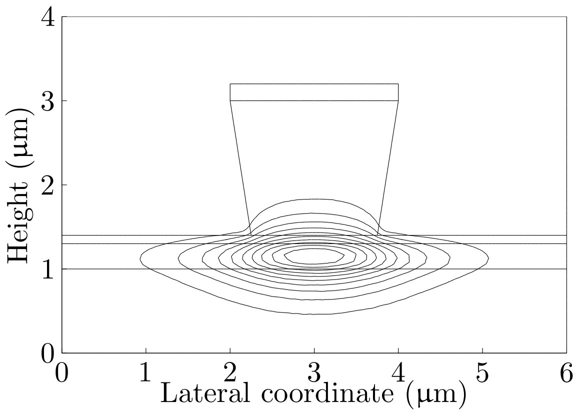


Fig. 7: Simulated transverse mode pattern in the ridge-waveguide laser structure.

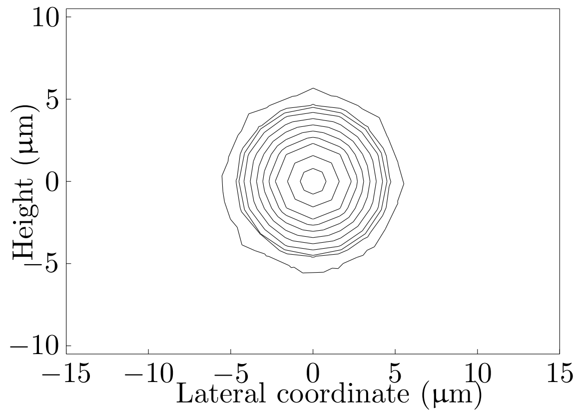


Fig. 8: Simulated fundamental mode of a SMF with 9 µm core diameter.

2.1 Laser characteristics

Figure 9 shows the static light–current–voltage characteristics of the fabricated lasers. The threshold current is 25 mA. An optical output power of more than 8 mW at a laser current of 70 mA is measured at the front facet. The fiber-coupled power is much smaller, corresponding to a coupling coefficient of 10 %. The measured optical spectrum at a laser current of 60 mA features a large number of longitudinal modes, centered at about 1526 nm wavelength.

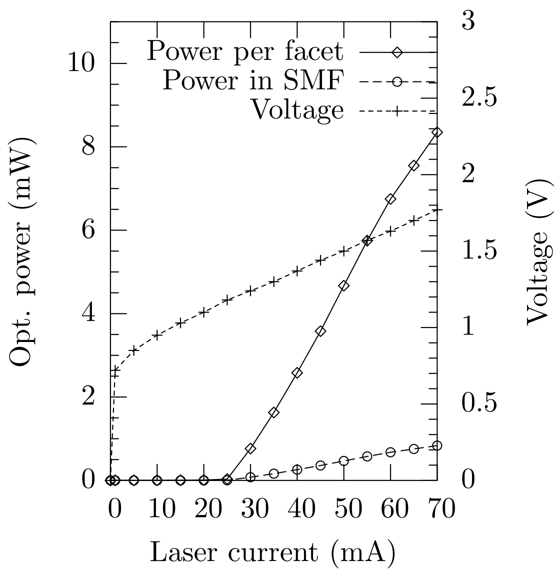


Fig. 9: Operation characteristics of the FP laser, including the light versus current curve for single-mode fiber coupling.

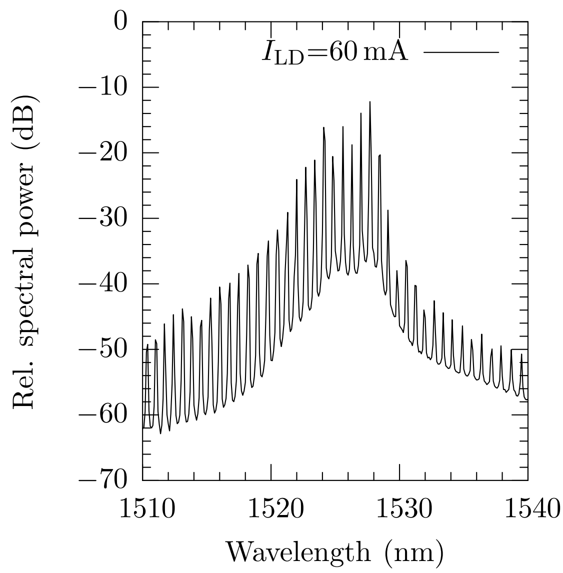


Fig. 10: Measured optical spectrum of the laser in Fig. 9 at 60 mA current.

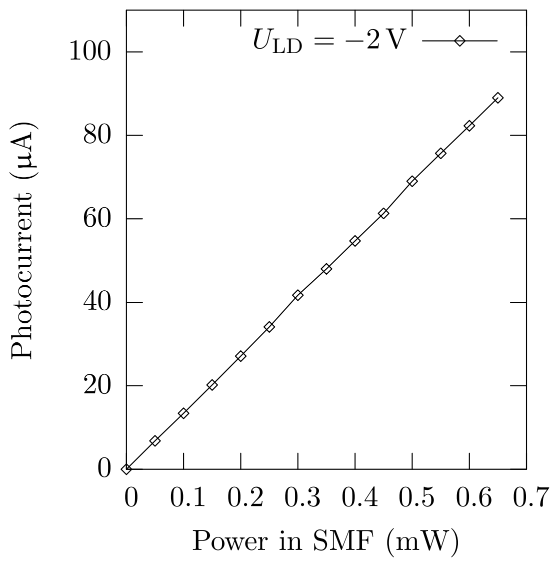


Fig. 11: Measured photocurrent as a function of the power in the single-mode fiber for a reverse voltage of 2 V.

3. Half-Duplex Operation

Figure 11 shows the static characteristic of a fabricated FP laser acting as a photodiode, where the photocurrent has been measured as a function of the incident optical power at an applied reverse voltage of 2 V. A coupling efficiency of 18 % is calculated for the detection process, which is much higher than in the case of forward operation. This might be explained by an increased detection (as compared to emission) area, since photons incident with moderate lateral offset might also contribute to the photocurrent.

Figures 12 and 13 demonstrate the proper modulation capability of the established optical link. One FP laser is directly modulated with a digital pseudorandom bit sequence of

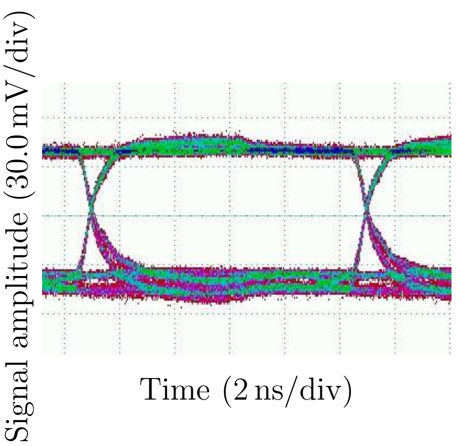


Fig. 12: Measured eye diagram at a data rate of 100 Mbit/s, back-to-back.

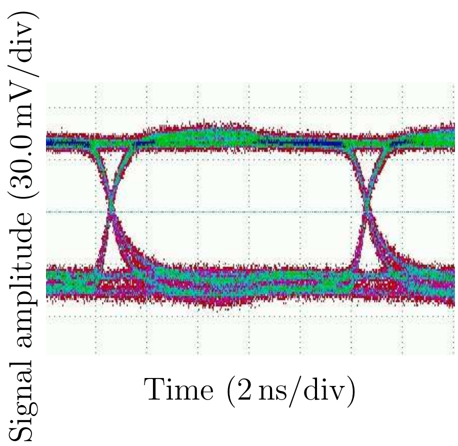


Fig. 13: 100 Mbit/s, eye diagram after transmission over a SMF with 4 km length.

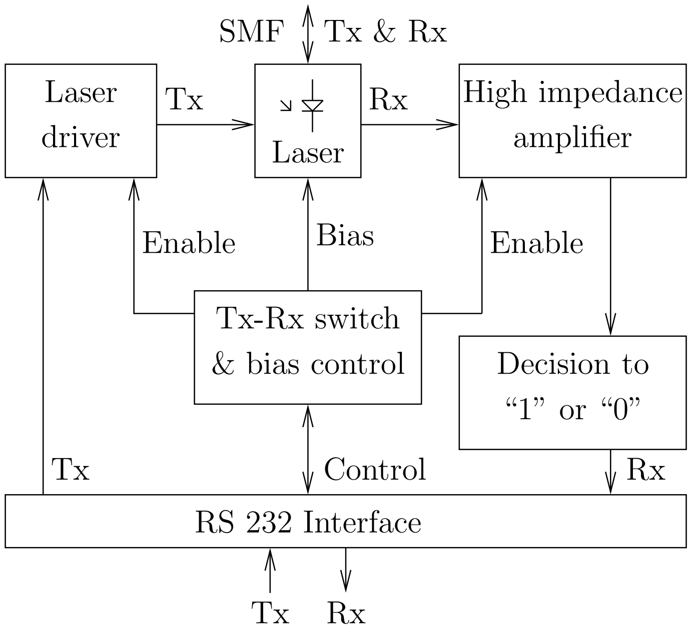


Fig. 14: Block diagram of the bidirectional RS 232 interface.

$2^7 - 1$ word length, where the bias current is 60 mA and the modulation voltage is $2\,V_{pp}$. A second FP laser is reverse biased with 2 V and connected to an amplifier with 50 Ω input impedance and 1.3 GHz bandwidth. The signal is displayed by a sampling oscilloscope. Both eye diagrams are recorded for the same photocurrent of 50 µA. The dispersion of the 4 km-long SMF does not alter the shape of the eye. The rise and fall times are limited by the detection process to a few nanoseconds. The eye diagrams are very similar if the link operates in the opposite direction.

For longer SMFs, the fiber attenuation increases and optical detection with higher sensitivity is required. Since we are operating at 1.55 µm wavelength, the modulation speed would be then limited by group velocity dispersion[2]. For increasing the detection sensitivity, the measurement bandwidth can be decreased and high-impedance amplification can be used.

4. RS 232 Interface with Transimpedance Receiver

A block diagram and a full circuit diagram of the computer interface are shown in Figs. 14 and 15, respectively. The signal-to-noise ratio and therefore the receiver sensitivity can be optimized by choosing a low-noise amplifier with high-impedance input [3]. On the other hand, the electrical time constant given by the product of the impedance R and the input capacitance C sets an upper limit for R. Since the suggested link is supposed to work at very low data rates of several kbit/s, we decided to use a BC 547 npn-type bipolar transistor in emitter configuration with high-impedance input for this purpose. When the laser is reverse biased, the photo-generated current will directly flow through its base.

[2]Dispersion compensation would not be implemented in such a low-cost optical link.

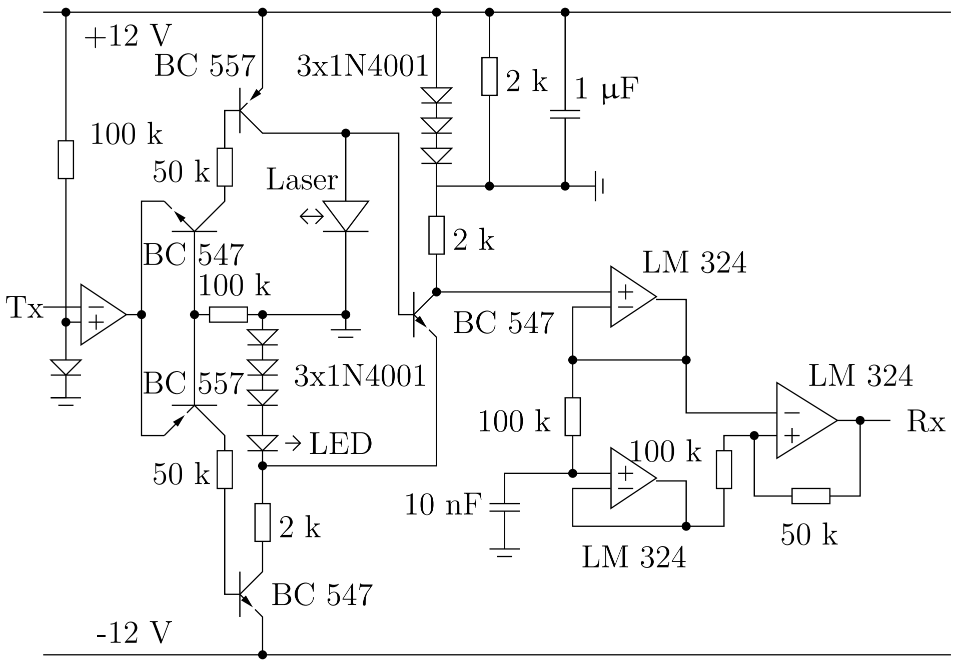


Fig. 15: Electrical circuit diagram of FP laser with driver electronics for bidirectional operation.

The collector current is much higher according to the current amplification factor and will induce a voltage drop at the 2 kΩ-large resistor. Proper digital signals are recovered using three operational amplifiers. They make a digital decision as well, using the low-pass filtered analog signal as reference. In addition, the circuit contains some electronics on the left-hand side. It drives the laser diode for bias-free transmit (Tx) operation and switches back to the reverse-biased receive (Rx) state. With two of the given circuits, a fully operational link has been established between two PCs over a 100 km-long SMF, where the data rate is 2400 bit/s.

5. Conclusion and Outlook

A simple half-duplex bidirectional optical link with FP lasers which act as both transmitter and photodetector is successfully demonstrated. The bandwidth of this link is limited to a maximum data rate of 500 Mbit/s, which might be explained by carriers which are generated lateral to the ridge-waveguide and are expected to have quite high transport time constants. This bandwidth might be improved by using lensed fibers which focus the light more directly into the waveguide. At the same time, the laser coupling efficiency would thus be increased. Unfortunately, the mechanical stability of this configuration is rather critical and not suited for long-term experiments at the moment. It is expected that the bandwidth can be increased to several GHz. A simple electronic interface is suggested which enables bidirectional communication of two PCs. It features transimpedance amplification and automatic decision levelling. Its operation speed is limited to a few kbit/s but is expected to be drastically higher with an improved electronics design.

References

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