Dual wavelength Y-junction glass integrated waveguides for mm-wave carrier generation

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ABSTRACT

This paper presents the use of co-integrated lasers on glass for the generation of radio-frequency carriers by optical heterodyning. By using the ion exchange glass platform, two DFB lasers and a power combiner have been fabricated on a single substrate. Thanks to the excellent thermal stability of these lasers, a drift of the beating signal frequency as low as 5 MHz has been measured without any thermal regulation. These performances represent an improvement by several orders of magnitude when compared to heterodyned semiconductor lasers technology and have the potential to generate mm-wave carrier frequencies up to a few THz.

Keywords: glass integrated optics, DFB laser, waveguide, frequency generation, heterodyning, frequency drift.

1 INTRODUCTION

The generation of radio-frequency carriers, in the millimeter and sub-terahertz range is required for different applications such as radar, spectroscopy or communication systems. Optical systems offer interesting solutions to reach this frequency range that is difficult to access by electrical means. Different devices and architectures have been developed over the last decades. Among them, heterodyning using semiconductor lasers offers very high beating frequencies but with intrinsic large linewidths due to the low coherence of the lasers employed. Consequently, they require additionnal features like injection locking in order to reach the tenth of kiloHertz [1]. Additionally, in order to access large tunabilities or accordabilities over large ranges which restrict the use of electrical and optical feedback system, optical solutions are usually impaired by a large frequency drift [2], thus limiting the performance of the global system.

We propose here the use of two DFB lasers co-integrated on a glass substrate with the ion-exchange technology. Indeed, the Erbium-doped glass material presents a slower dynamic and allows a larger photon lifetime compared with semiconductor technology, which have a positive impact on laser linewidths and noise. Our integrated device contains two DFB lasers and a Y-junction coupler. Since properties of the heterodyned signal such as power, noise, linewidth and drift are similar whatever the carrier frequency [3], we have targeted a generated frequency of 5 GHz, compatible with our electrical characterization equipment. However, a similar device with minor design modifications would allow reaching carrier frequencies from 3 GHz to 3 THz. This article is organized as follows. The lasers description and fabrication are first presented. The heterodyne electrical signal obtained from the structure is then described and discussed. Finally, results of transmission experiments with standard communication protocoles are exposed to prove the performances of such sources as a carrier generator.

2 DESIGN AND FABRICATION

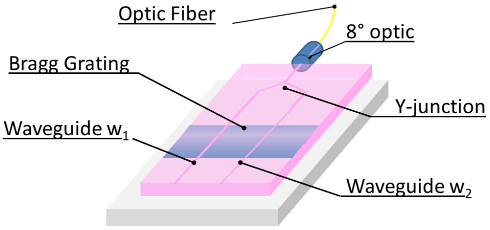

Figure 1. Design of the proposed dual-frequency laser.

The whole device has been fabricated on a co-doped Erbium-Ytterbium Phosphate glass (IOG-1 Schott^{TM}) using the process described in [4]. A schematic of the structure is presented on figure 1. The waveguides needed for the different elements have been manufactured using a silver/sodium ion-exchange. Two laser cavities are then formed by two waveguides covered by a single 2 cm long Bragg grating etched at the surface of the glass wafer. The grating of period Λ=510 nm is defined by a standard holographic process in a photoresist followed by a Reactive Ion Etching step. It has been chosen to adjust the effective refractive index n_{eff} in each laser cavity by adapting each waveguides' width through their diffusion aperture size. Indeed, each laser produces a wavelength λ_i corresponding to $\lambda_i = 2.n_{eff}(w_i).\Lambda$.

This allows having different lasing wavelengths while using the same Bragg grating with an identical period Λ for both waveguides. The beating frequency f_b obtained by heterodyning the two lasers is given by: $f_b = c.\frac{\lambda_2-\lambda_1}{\lambda_1.\lambda_2}$. A modification of the lasing wavelengths through the adjustement of the waveguide width allows generating a beating frequency as high as 300 GHz, while keeping all other technological parameters constant. An individual laser has been fabricated using the same process. Its threshold is close to 150 mW pump power and its efficiency is 10%. Its optical linewidth has been measured using an auto-heterodyne setup having a 25 km path difference. A value of $\leq$2 kHz, has been extracted from a Voigt fit of this measurement[5].

3 HETERODYNE SIGNAL CHARACTERIZATION

The device used for high-frequency carrier generation has been designed with two waveguide aperture widths of 9.3 and 9.4 μm in order to generate a frequency close to 5 GHz. The signal emitted by the two lasers are combined by the Y-jonction coupler and are then collected using a 8° angled facet optical fiber, to avoid any back-reflection from the interface. The detection by a photodiode then produces the desired electrical carrier. To pump the device, a 1550/980 pigtailed multiplexer is employed so both lasers are fed using the same pump diode and the counter-propagating laser signals are collected through the 1550nm branch of the multiplexer. Finally, the generated RF-signal is produced by a rapid PIN photodiode.

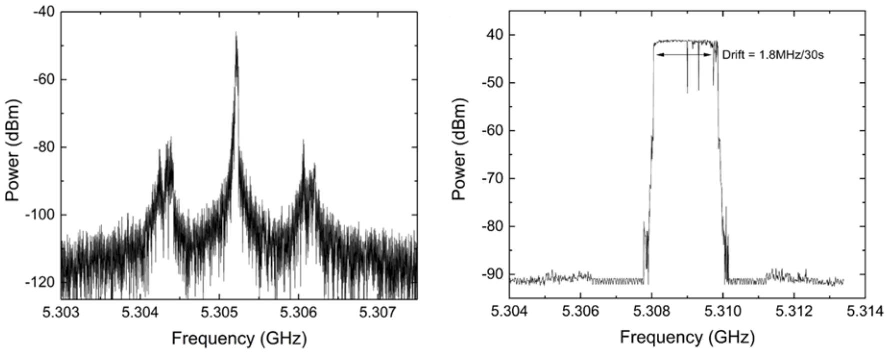

Figure 2. Electrical spectrum of the heterodyne signal at 5.3GHz : 50 ms measurement (left) and 30s Max Hold (right).

Figure 2-left shows the spectrum measured using an acquisition time of 50 ms. The extracted linewidth is 1.8 kHz, assuming a Lorentzian profile of the central feature. Note that the sidebands centered 800 kHz away from the carrier correspond to an increased noise of the lasers close to their relaxation frequencies (this feature also appears when measuring single lasers). Figure 2-right represents the result from a max-hold measurement of the beating spectrum over an acquisition time of 30 s. The total drift observed is 1.8 MHz, the lowest observed in the literature for free running heterodyne lasers in this frequency range and more than ten times lower than the values reported for free running semiconductor lasers [6]

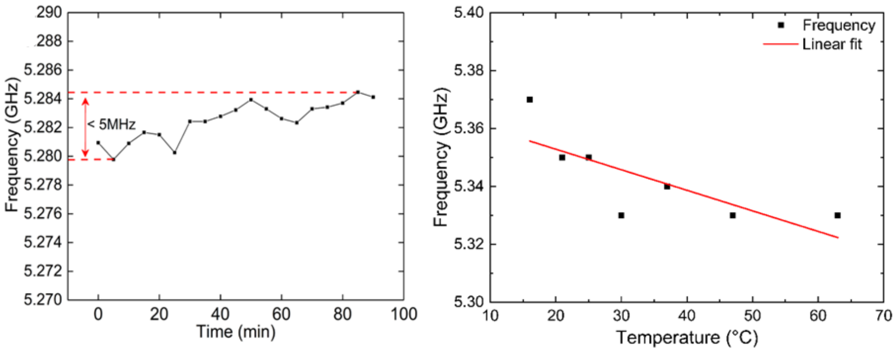

Figure 3. Impact of temperature variation on the frequency generated.

In order to qualify the long term stability of our system, we have measured the beating frequency over a period of 90 min, while the system was not being actively thermally stabilized. The result of this experiment is shown on the figure 3-left. A total variation smaller than 5 MHz has been measured. One explanation for the slow frequency drift observed in this experiment may be a change of the ambient temperature. In order to test this hypothesis, we have determined the thermal sensitivity of the beating frequency by actively changing the temperature of the device. Figure3-Right shows the evolution of the emitted frequency with the temperature of the device. A linear fit of this variation leads to an average of 0.6 MHz/°C.

4 DATA TRANSMISSION EXPERIMENTS

To demonstrate the capability of our solution to provide electrical carriers suitable for telecommunication applications, we used our device as a frequency carrier generator for a radio-over-fiber communication system. The optical signal from our device is modulated with data, so that a dual band modulation is performed. This signal is then detected by a rapid photodiode and analyzed with a Vector Signal Analyzer.

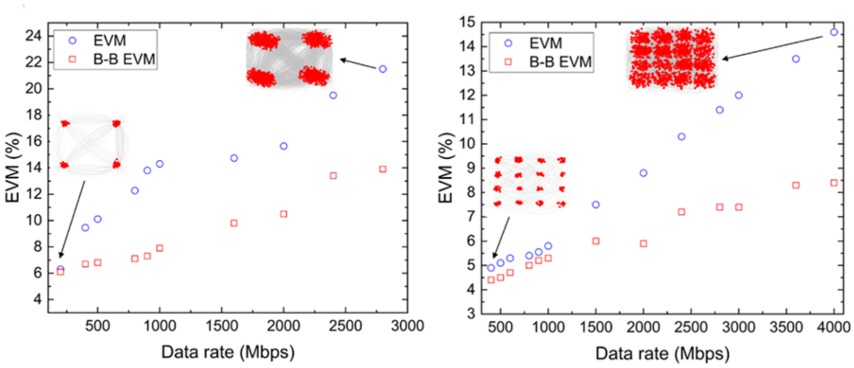

Figure 4. EVM measurements for different bitrates using QPSK (Left) and 16QAM (right) modulation formats. Back-to-back measurements are shown in red.

Figure 4 shows the demodulated signal transmitted by our system for Binary Phase Shift Keying (left) from 0.2 to 2.8 Gbps data rates, and for 16-Quadrature Amplitude Modulation from 0.4 to 4 GHz modulating an electrical subcarrier, applied on the optical modulator. The back-to-back reference measurement given consist in direct demodulations of the electrical signal applied to the optical modulator,thus including no electro-optical conversion. Once again, no electrical amplifier has been inserted in the transmission link. Based on the IEEE communication standards at 60 GHz, such results would allow the use of an equivalent frequency generator operating at 60 GHz for all bit rates tested using the BPSK modulation and for bit rates up to 2 GBps for both modualtion formats, despite the high back-to back values. The values are partially limited by the bandwidth available in our experiment has the generated carrier is only 5 GHz. An electrical amplifier may be inserted after detection to compensate for additional conversion losses in a standard 60 GHz communication system.

5 CONCLUSION

In conclusion, we have presented an integrated device based on a photonics on glass platform producing two wavelengths with controlled and stable spacing. The optical signal from this device has been detected using a rapid photodiode and analyzed, showing a very small linewidth of 1.8 kHz and a frequency drift of 1.8MHz, ten times smaller than values reported for similar devices using semiconductor lasers. The device has then successfully been used in transmission experiments using advanced modulation formats such as 16 QAM, where it validated IEEE communication standards at 60 GHz up to 2,5 GBps bit rates.

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