Direct Modulation of Membrane DR Laser Involving Photon-Photon Resonance by 5G Mobile Signal in Millimeter-Wave Band

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***Abstract*— Membrane lasers that can be directly modulated at millimeter-band frequency by assistance of photon-photon resonance is fabricated. Direct modulation by 5G mobile signals around 31 GHz and 1-km optical fiber transmission are successfully demonstrated.**

Keywords—Photon-photon resonance, membrane laser diode, analog Radio-over-Fiber transmission

I. INTRODUCTION

In 5th Generation (5G) mobile communication system, millimeter-wave band is exploited for allocating a wide signal bandwidth of 400 MHz for a single channel or of 800 MHz by bonding two channels. A short reach analog Radio-over-Fiber (A-RoF) transmission system would be useful for installing millimeter-wave band remote antennas covering small areas [1], for reducing their footprint and power consumption. For realizing such an A-RoF transmission system, semiconductor lasers enabling direct modulation at millimeter-wave frequency is required, but normal lasers cannot be adopted at such a high frequency due to their modulation bandwidth limited by photon-carrier resonance (i.e., relaxation oscillation). Recently, photon-photon resonance (PPR) lasers are attracting much attention due to their potential for enhancing modulation bandwidth [2]. In the case of A-RoF system conveying single channel, an ultra-wide modulation bandwidth covering from mega-hertz order up to several ten giga-hertz are not essentially required. As described above, the bandwidth of 5G mobile signal is less than 1 GHz, high response within a limited bandwidth at the target frequency is required. On the other hand, as for reducing power consumption of short reach optical transmission system, a membrane laser is an promising device thanks to its high optical confinement factor resulting in low threshold current [3].

Considering such situations, we have fabricated the membrane lasers with PPR effect and have tested direct modulation at millimeter-wave band frequency, and short reach optical fiber transmission as well. The laser was successfully modulated by 5G mobile signals around 31 GHz, which is within frequency range of FR2-1 defined by 3GPP [4], and the signal qualities including that after the fiber transmission were assessed. We have successfully confirmed that the signal qualities satisfy the requirement defined in the 3GPP specification [5].

II. LASER STRUCTURE

The membrane laser consists of 270-nm-thick III-V layers including 1.55-μm-band GaInAsP quantum wells and optical confinement layers sandwiched by SiO_2 and air on a Si substrate to enhance optical confinement factor as shown in Fig. 1. Gratings for a distributed feedback (DFB) and a distributed Bragg reflector (DBR 1) are formed on surface by etching. For introducing PPR effect in a distributed reflector (DR) laser, which consists of DFB and DBR 1 sections, a passive GaInAsP waveguide section consisting of another DBR section (DBR 2) are newly introduced. The DBR 2 was designed to have a high reflectivity for achieving optical feedback while minimizing the emission toward backside. The strength of optical feedback can be controlled by the reflectivity of DBR 1, while the resonant frequency can be controlled by the distance between DBR 1 and DBR 2. Thus, the device structure provides a large design flexibility for PPR effect. In this experiment, the section length of waveguide and DBR 1 were designed to be 250 μm and 10 μm, respectively, targeting a PPR peak at millimeter-wave frequency.

III. DIRECT MODULATION AND FIBER TRASMISSION

The threshold current of the PPR LD was 0.33 mA. The frequency response was measured by inputting RF tone under the bias conditions of 1.81 V and 4.58 mA (Fig.2). As can be seen from the figure, it has a relatively broad peak reaching -8.7 dB, with reference to the peak value at low frequency range, at 32.8 GHz, which is attributed to the PPR effect.

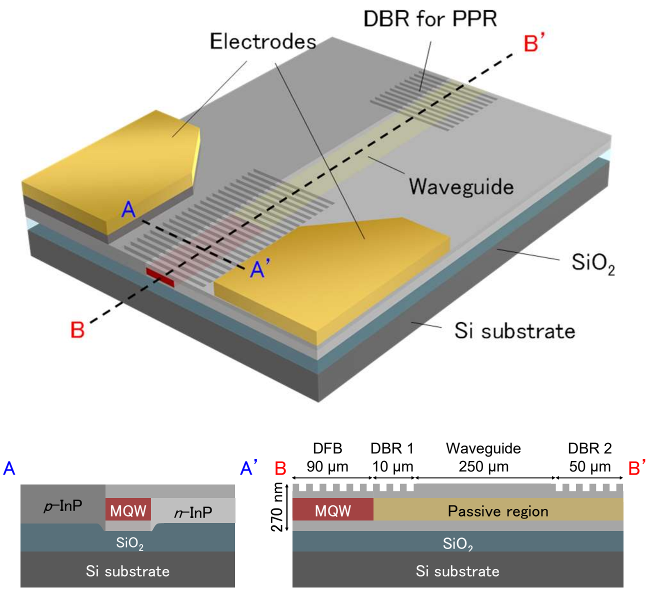


Fig. 1. Decixe structure of PPR LD

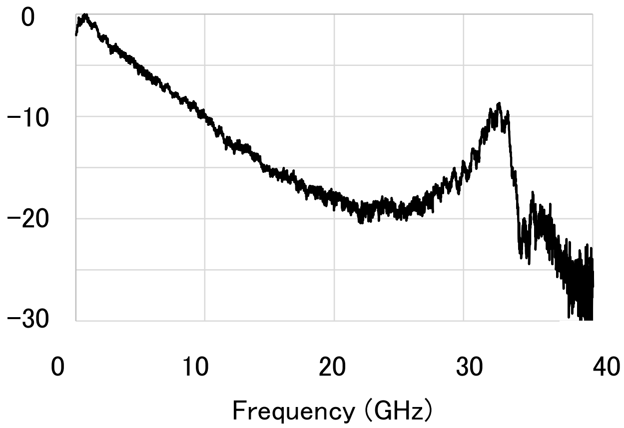


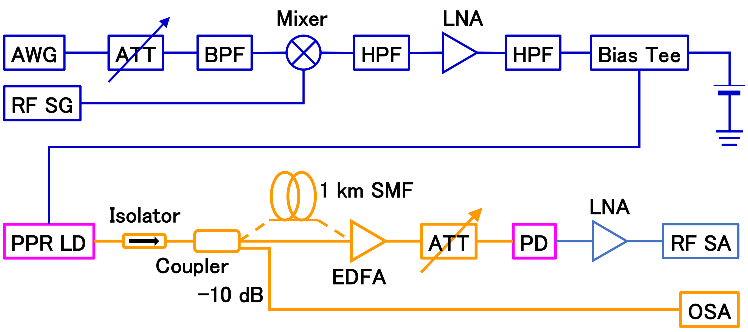
Fig. 2. Frequency response of PPR LD

Under the aforementioned bias conditions, we have tried to modulate the PPR LD by OFDM signal with 64 QAM format using the experimental setup shown in Fig. 3. The input signal with 400 MHz bandwidth centering at 31.0 GHz or with 800 MHz bandwidth by bonding two channels centering at 31.2 and at 31.6 GHz are generated by upconverting 5G-compliant signals with the center frequency of 9.6 GHz. For the single channel case, 1-km single mode fiber (SMF) transmission test was also conducted. It should be noted that the above-mentioned bias conditions and signal frequencies were carefully selected so as to achieve the best EVM value, which is described below. The optimum frequency did not coincide with the peak frequency of PPR at this time. The reason is not clarified yet, and further optimization would be necessary for realizing a higher conversion efficiency from end to end.

Fig. 4 shows constellations of signals for (a) single channel modulation, (b) single channel modulation and 1-km SMF transmission, and (c) lower-band and (d) upper-band channels for dual channel modulation, respectively. The average EVM was 1.8 % and 4.1 %, respectively, for single channel case before and after optical modulation. The values were 2.2% and 5.1% for lower band channel, and 2.3% and 5.4 % for upper band channel, respectively, for dual channel case. For the case with single channel modulation and 1-km SMF transmission, the value was deteriorated down to 6.7%, although it is still lower than 8.0% that is defined for 64QAM signal by 3GPP specification. The signal quality degradation after 1-km SMF transmission would be partly due to the power fading taking frequency chirp induced by modulation into account [6].

IV. Concclusion

The experimental results verified that membrane DR laser with PPR structure is a promising device for a short reach A-RoF system conveying RF signal in the millimeter-wave band. Since the laser structure has design flexibility for determining PPR resonant frequency, it may be possible to be adjusted to a higher frequency such as 60 GHz band allocated for 5G or even higher frequency bands that would be employed in next generation mobile systems. Since it was the first trial for such an attempt, it is expected that we can achieve better performances by optimization of various parameters in device structures as well as in experimental conditions.



AWG: Arbitrary Waveform Generator, ATT: Attenuator, BPF/HPF: Band/High-Pass Filter, LNA: Low Noise Amplifier, EDFA: Erbium Doped Fiber Amplifier, PD: Photodiode, SA: Signal Analyzer, OSA: Optical Spectrum Analyzer

Fig. 3. Schematic experimental setup.

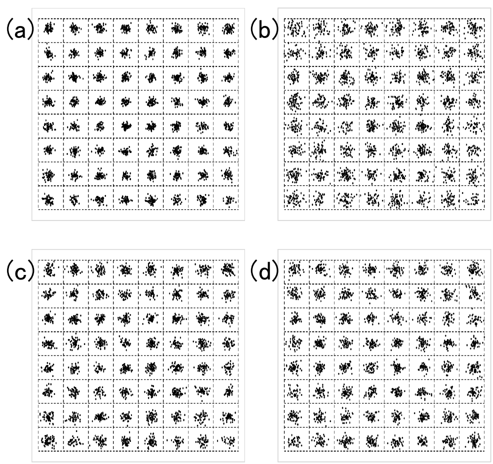


Fig. 4. Constellations of signals: (a) single channel modulation, (b) single channel modulation and 1-km SMF transmission, and (c) lower-band and (d) upper-band channels with dual channel modulation.

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