A 66-GHz Lumped-EML Submodule Using Resistance-Optimized LC Resonance with Low Temperature Dependence of 3-dB Bandwidth

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Abstract: We report on a lumped-EML submodule with 3-dB bandwidths of 68.2 GHz at 25℃ and ~66 GHz at 70℃ using a resistance-optimized LC resonance effect, showing low temperature dependence and making it suitable for 112-Gbaud operation. © 2023 The Author(s)

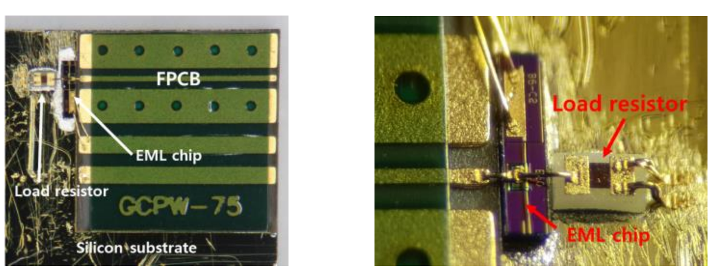
1. Introduction

Due to the explosive growth of bandwidth-intensive services such as ever-increasing OTT streaming and cloud-native mobile, etc, transmission capacity required for data-center communication is exponentially increasing. To address these bandwidth demands, 12.8-Tbps switches utilizing 400-Gbps Ethernet optical modules are being widely deployed in intra-datacenter networks. To further increase the transmission capacity, there is an emerging demand for the development of 800-Gbps and 1.6-Tbps optical modules applicable to 25.6-Tbps and 51.2-Tbps switches. Recently, the 800G-FR4 multiple source agreement (MSA) group published a specification of 800G optical modules, adopting 4-lambda × 200Gbps/lane optical interface based on 112.5-Gbaud PAM4 signaling [1]. Furthermore, a standard for the 1.6-Tbps Ethernet at distances between 500 m and 2 km is being actively discussed by IEEE802.3df, suggesting 106.25-Gbaud PAM4 signaling [2].

As a result, the research on high-speed light sources capable of supporting 100-Gbaud or higher operations is intensively investigated. Electro-absorption modulator-integrated lasers (EMLs) are regarded as a competitive solution for over 100-Gbaud operation due to their superior high-speed characteristics, low chirp, and low driving voltage [3-6]. Although EMLs with traveling-wave electrode can realize extremely high modulation bandwidth [3], lumped-EMLs are considered as a more promising candidate for 800G and 1.6T optical modules due to their easy fabrication and small chip size [4-6]. In our previous work [6], we experimentally demonstrated that 3-dB electro/optic (E/O) bandwidths of the EML submodule can be extended to 55 GHz by using the LC resonance effect with optimized load resistance although the length of an EAM is 150 um. However, bandwidths over 50 GHz were only achieved in room temperature in [6], not fully satisfying the requirement of 800G-FR4 MSA [1], demanding uncooled operation in CWDM wavelength grids. To accommodate 112-Gbaud PAM4 operations in uncooled condition, light sources exhibiting high modulation bandwidth over a wide temperature range are required.

In this paper, we report on a lumped-EML submodule with very low temperature dependence of 3-dB bandwidth suitable for uncooled 112-Gbaud operation. While utilizing the resistance-optimized LC resonance effect reported in [6], we employed an EML chip having an EAM length of 100 um and low temperature dependence. By optimizing LC resonance effect for a given EML chip, our lumped-EML submodule achieved 3-dB bandwidths of over 65 GHz over wide temperature range from 25℃ to 70℃ with very low variation of only 3.2% (i.e. 68.2 GHz at 25℃, and ~66 GHz at 70℃).

2. Fabrication of Lumped-EML Submodule and its Static Characteristics



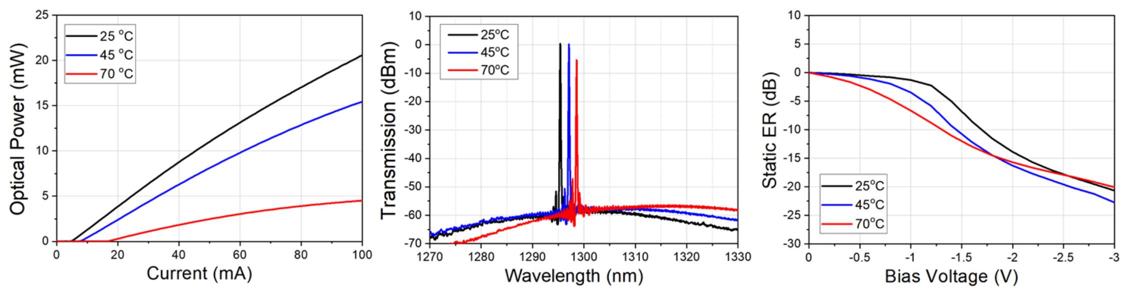
(a) (b)

Fig. 1. (a) Photographs of our fabricated lumped-EML submodule and (b) magnified view near the EML chip.

Figure 1(a) shows a photograph of our fabricated lumped-EML submodule which consists of a lumped-EML chip, a FPCB with a length of ~3 mm, and a surface-mountable device (SMD)-type load resistor. Instead of an EML chip with an EAM length of 150 um deployed in [6], we used an EML chip with a shorter EAM length of 100 um to obtain higher 3-dB bandwidths by reducing an EAM capacitance. To secure high extinction ratios and high bandwidths for the shorter EAM length of 100 um, we carefully controlled the detuning between an absorption peak of the EAM and a lasing wavelength of the DFB-LD, while optimizing a MQW design of the EAM to avoid a deterioration of the modulation bandwidth caused by a hole-pileup effect.

The FPCB and EAM were connected via wire-bonding. Then, SMD-type load resistor was connected in parallel with the EAM by wire bonding. In such an impedance matching configuration, the parasitic inductance of bondwire connecting the EAM and the load resistor is effective to increase the modulation bandwidth by the LC resonance effect, whereas the bondwire length connecting the FPCB and EAM should be minimized to prevent bandwidth degradation [7]. Since the FPCB has a thickness of ~100 um, similar to that of the EML, a height difference can be overcome so that the bondwire length between the FPCB and EAM can be sufficiently reduced to ~110 um.

Because the E/O frequency responses of the EML are highly dependent on load resistances, the value of load resistance should be carefully chosen according to the capacitance of an EAM to make the most of the LC resonance. Instead of using 35-Ω load resistance, which was used for extending a modulation bandwidth of the EML with an EAM length of 150 um in [6], we chose 45-Ω load resistance to improve S11 at low frequencies and modulation efficiency simultaneously.

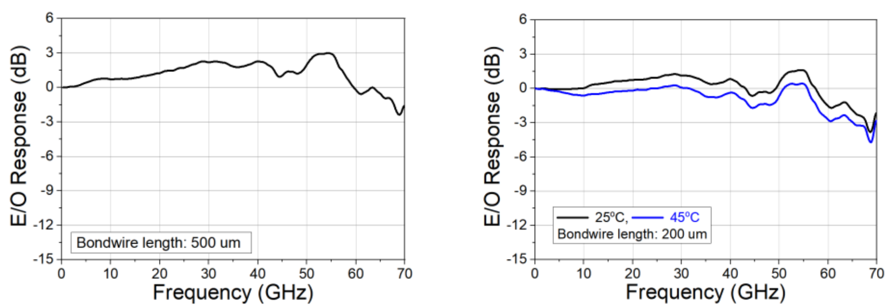


(a) (b) (c)

Fig. 2. Measurement results of (a) optical output powers, (b) wavelength spectrum curves, and (c) static extinction ratio curves of the fabricated lumped-EML submodule at 20ºC, 45ºC, and 70ºC.

Figure 2(a) shows optical output powers of the fabricated submodule as a function of DFB-LD bias currents under different temperature conditions with an EAM bias voltage of 0 V. The output power values reach 20 mW, 16 mW, and 4.5 mW at 25ºC, 45ºC, and 70ºC, respectively at a DFB-LD bias current of 100 mA. Fig. 2(b) shows the lasing wavelength spectrum curves for the fabricated submodule at a DFB-LD bias current of 100 mA. The side mode suppression ratio (SMSR) values of more than 40 dB are obtained, exhibiting stable single-mode operations over a wide temperature range. Static extinction ratio (ER) curves of the fabricated submodule are plotted in Fig. 2(c), which is measured as a function of the EAM bias voltage at 25ºC, 45ºC, and 70ºC and a DFB-LD bias current of 100 mA. The above results indicate that high static ERs of over ~14 dB @ -2 V are obtained from 25ºC to 75ºC, thanks to the optimized MQW design of the EAM section.

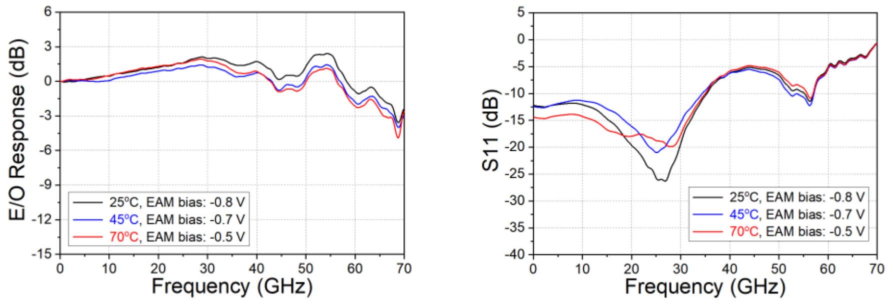
3. Experimental results



(a) (b)

Fig. 3. Measured E/O response curves of the EML submodule for bondwire lengths of (a) 500 um and (b) 200 um.

To examine high-speed characteristics of our fabricated submodule, we measured E/O responses (S21) and electrical S11 using a 70-GHz vector network analyzer (VNA) and a 70-GHz photo-detector (PD). The small RF signal from the VNA was applied to the FPCB of the submodule using a GSG probe, and an O/E response of the 70-GHz PD was de-embedded. Figs. 3(a) and (b) show measured E/O responses of the lumped-EML submodule for a load resistor of 45 Ω and two different bondwire lengths connecting the EAM and load resistor. As shown in Fig. 3(a), a 3-dB bandwidth of more than 70 GHz is obtained for a bondwire length of 500 um, measured at a temperature of 25℃. However, a rather high magnitude of overshoot of ~3 dB is observed, which could cause an eye pattern distortion under PAM4 operations. When the length of bondwire is shortened to ~200 um, a 3-dB bandwidth is measured to be ~68 GHz, with a magnitude of overshoot mitigated to ~1.5 dB at 25℃ as shown in Fig. 3(b). Although the overshoot is reduced at 25℃, a 3-dB bandwidth decreases to ~60 GHz at 45℃ owing to the insufficient inductive peaking by the LC resonance.



(a) (b)

Fig. 4. Measured (a) E/O response (S21) and (b) electrical S11 of the EML submodule at temperatures of 25℃ to 70℃.

To obtain wide temperature range operations of our submodule while maintaining large 3-dB bandwidth characteristics, the value of load resistance was decreased from 45 Ω to 40 Ω, and the length of bondwire was increased to 300 um to moderately induce overshoot caused by inductive peaking. E/O responses and S11 curves measured at various temperatures are shown in Fig. 4. The bias voltages of EAM are varied from -0.8 V to -0.5 V for temperatures from 25℃ to 70℃, while a bias current of the DFB-LD was fixed to 100 mA. As a result of the moderately enhanced overshoot, 3-dB bandwidths over 66 GHz are maintained up to 70℃ as shown in Fig. 4(a). Moreover, within a temperature change of 45℃ (i.e. 25℃ to 70℃), the 3-dB bandwidth was changed by an amount of only 2.2 GHz (68.2 ~ 66 GHz), showing the variation of ~3.2% relative to the maximum value. Such a small amount of change in 3-dB bandwidths are attributed to the optimized MQW design of the EAM as well as the resistance-optimized LC resonance. In addition, S11 values at low frequencies are kept below -10 dB in spite of a reduced load resistance of 40 Ω as shown in Fig. 4(b). The above results indicate that by carefully inducing the LC resonance with an EML chip having low temperature dependence, it is possible to achieve 3-dB bandwidths of over 66 GHz with moderate overshoots of less than 2 dB for wide temperature ranges between 25℃ and 70℃.

4. Conclusion

We demonstrated a 66-GHz lumped-EML submodule showing a small variation of 3-dB bandwidths (~3.2%) over wide temperature ranges from 25℃ to 70℃. By carefully inducing the LC resonance effect with an EML chip having low temperature dependence, we experimentally confirmed that our fabricated submodule can achieve 3-dB bandwidths of over 66 GHz as well as moderate overshoots of less than 2 dB for 25℃ to 70℃. From these results, we expect that our lumped-EML submodule can support uncooled 112-Gbaud PAM4 operations, which will prevail in the near future.

5. Acknowledgments

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