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Hybrid dual-injection locked 1610 nm quantum-dash laser for MMW and THz applications

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ABSTRACT

Dual-mode hybrid injection-locking scheme is reported over an L-band InAs/InP quantum-dash laser to generate tunable millimeter (MMW) and Terahertz (THz) beat frequencies. In addition to the inherent enhancements that are provided by injection locking, the system provides comparable high dual-mode peak power, side mode suppression ratio (SMSR) up to 30 dB, and large beat frequency tunability of ∼1.7 THz. As such, four different beat frequencies are demonstrated, namely 62.6- and 263-GHz MMW and 1.21- and 1.75-THz signals. The stability of the generated waves is then investigated showing a minimal fluctuation of 0.35 dB and 0.1 dB in the SMSR and peak power, respectively.

1. Introduction

The ever-increasing demand for high-speed data connectivity, due to the proliferation of smart devices, calls for advancements in existing wireless communication technologies, particularly capacity, bandwidth, security, and mobility. In this view, millimeter waves (MMW) have been identified as a potential last mile access platform for short-distance communications to reduce spectrum congestion. In particular, 60 GHz and higher bandwidths offer effective frequency reuse prospects and license-free feature that attracted research focus to these frequency bands [1–4]. Besides, integration of MMW technology with optical fiber infrastructure (radio-over-fiber, RoF) enables seamless penetration into already-existing passive optical networks (PON) and hybrid fiber-coaxial (HFC) infrastructures, thus reducing capital and operational expenditures (CapEx and OpEx) of the networks [3–6]. In fact, the recent demonstrations of multiplexed hybrid fiber-MMW with free space optical communication further strengthens the prospects of this technology [4].

Working towards this end, many affirmative research findings have been reported on the photonic generation of MMW and THz waves providing myriad advantages over the traditional electronic means, such as compactness, cost-effectiveness, less power consumption, superior mobility and flexibility, and more importantly, a high degree of frequency tunability. Furthermore, photonic generation of MMW and THz waves have shaped themselves as a strong contender in RoF wireless, 5G, and satellite communication systems [3–6].

One of the most traditional techniques of MMW and THz wave photonic generation is the separation of the radio frequency (RF) spectrum of a light source into sidebands via electronic means. However, these techniques require costly and bulky electronic systems that are already operating at their limits. In this regard, optical heterodyne mixing, wherein the MMW and THz beat signal is generated as the frequency difference between two free-running lasers has garnered much attention [3,5]. Unfortunately, this technique suffers from relatively high phase noise, broad linewidths resulting ultimately in reducing the spectral purity of the beat frequency generated MMW photonic signals, which is a paramount in wireless communications [7].

Consequently, optical injection in the form of optical feedback and injection locking have been introduced in tandem with heterodyne mixing to overcome these drawbacks. For instance, [6] employed self-optical feedback for selecting the second mode in a dual-wavelength operation for MMW applications. On the other front, injection locking, wherein one or two master lasers are combined with a multimode slave Fabry–Perot (FP) laser diode to selectively injection lock two modes, has garnered much attention owing to the inherently improved dynamic performance associated with injection-locking [7]. As such, 25 GHz [8] and 60 GHz [9,10] MMW beat frequencies from a distributed feedback (DFB) and FP laser diodes have been reported with

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this technique showing superior performances at 1550 nm. Very recently, a two-colored DFB laser diode was used to externally injection lock a colorless FP laser diode in order to generate a 28 GHz MMW beat frequency [7]. Moreover, non-linear phenomena were also exploited with external injection locking to generate dual-wavelength modes with a single master laser exhibiting MMW beat frequencies in the range of 28 to 60 GHz [11–13] at 1550 nm.

Recently, quantum-confined InAs/GaAs quantum-dot (Qdot) and InAs/InP quantum-dash (Qdash) nanostructures, besides the conventional quantum-well counterparts, have also been receiving recognition as a potential diode laser active medium for MMW and THz applications. For instance, a MMW beat frequency tunability between 1–40 GHz is reported from a 1310 nm Qdot DFB laser diode by exploiting the device period-1 dynamics in external injection locking configuration [14]. Moreover, 1550 nm Qdash mode-locked lasers have been employed to generate a fixed beat tone of 55 GHz from a single 780-μm cavity length and 24 GHz from 1700 μm cavity length, which essentially represents the laser's free spectral range (FSR) or mode spacing, thus lacking the tunability feature [15–17]. By utilizing a multiplexer and a combiner configuration, a beat frequency of 100 GHz has also been reported over a 1550 nm Qdash laser by essentially filtering out a single mode corresponding to double the FSR of the laser diode [18]. Nevertheless, a more stable and flexible system with a large MMW beat frequency tunability would be more attractive for practical applications.

This work proposes and demonstrates a novel hybrid dual-injection-locking (DIL) technique on an L-band InAs/InP Qdash multi-wavelength laser to realize a dual-wavelength operation with tunable mode spacing, for MMW and THz applications. The scheme is simple and flexible exhibiting a ~1.7 THz discrete beat frequency tunability from ~62 GHz to ~1.75 THz, in addition to exhibiting the inherent advantages associated with injection locking. The modes exhibited SMSR as high as ~30 dB with extremely stable dual locked modes in terms of wavelengths and power, indicative of a potentially low noise system. This qualifies this technique as a more robust solution with the existing optical communication network infrastructure, as well as for the extended L-band network, which is under consideration for the next generation PONs. Moreover, it provides a great deal of beat frequency tunability, controllability and enhancement to the RF characteristics of the signal all while maintaining simplicity and low cost.

2. Experimental setup

Fig. 1(a) depicts the experimental setup of photonic MMW and THz waves generation underlining the key technique that is hybrid dual-injection locking. At the core of the system lies a broadband InAs/InP L-band Qdash laser diode (Qdash LD) whose free-running emission is passed into port 1 of an optical circulator (OC) after fine-tuning its polarization via a polarization controller (PC) that plays a crucial role in efficient injection locking, as has been demonstrated in literature [19]. The output optical signal from port 2 of the OC is then amplified via an Erbium-Doped Fiber Amplifier (EDFA, Amonics AEDFA-L-18BR) before splitting into two halves through a 50:50 optical coupler (CP1). One half is then passed through a tunable bandpass filter (BPF, Santec Optical Tunable Filter-350 with a tunable bandwidth of 0.1–15 nm) that is adjusted to pass a single selected FP mode among those associated with the broad emission of the employed Qdash LD. Finally, the selected tuned mode is feedback into port 3 of the OC via another 50:50 optical coupler (CP2), to be re-injected back again into the Qdash active region past the front facet of the laser diode. Given proper tuning of different parameters, mainly the PC, central wavelength and bandwidth of the BPF, this self-seeded injection forces subsequent emissions to match the injected photons in terms of frequency (wavelength) and phase, thereby locking the selected FP mode of the Qdash emission. The other arm of the CP1 is then connected to an optical spectrum analyzer (OSA) via CP3 8% output for performance analysis.

On the other side of the setup, an external tunable laser (Agilent, 81600B) is utilized to externally injection-lock yet another FP mode from the Qdash broadband lasing emission spectrum through a similar mechanism to that of the aforementioned self-injection locking, albeit with the seeding injected photons being generated externally rather than being back-fed in self-seeded manner. As such, a tunable master laser is set at the desired wavelength given that it precisely matches one of the FP modes of the slave Qdash LD with high enough optical power or in other terms, injection ratio (defined as the ratio between the slave and master laser power calculated at the slave laser front facet of the Qdash LD). At that point, the external seeding emission is also injected into the Qdash active region through port 3 of the OC, after passing through an optical isolator (OI) and CP2. It is noteworthy to mention here that CP2 essentially combines the optical signals from both injection locking setups, i.e., the self-seeding and the external-seeding as illustrated in Fig. 1(a).

3. Results and discussion

The Qdash LD is pumped with a continuous wave (CW) electrical current of 90 mA ($1.1 I_{th}$) under a constant heatsink temperature of 18 °C. Each of the two injection locking methods that are implemented in this work is responsible for producing a respective single high-power locked FP mode. When combined, a simultaneous two injection-locked modes would be produced from the Qdash LD that could be used as a photonic generated MMW and THz waves with the beat frequency dictating the generated frequency and could simply be tuned to any desired frequency as discussed in the following.

3.1. Hybrid dual-injection locking procedure

Fig. 1(b) shows the free-running emission spectrum of the Qdash LD alongside a single FP mode that is back-fed into the laser cavity through the self-injection locking loop, discussed earlier. It is evident from Fig. 1(b) that the presence of both spectra indicates no injection locking occurrence at this instance. However, when the passband and central wavelength of the BPF were tuned to match the 1607.2 nm FP mode of the Qdash LD, in addition to the fine-tuning of the PC, all the side modes adjacent to the aforesaid mode were greatly suppressed as depicted in Fig. 1(c), a clear signature of successful self-injection locking. The self-injection locked mode exhibited an SMSR of ~36 dB, which represents the dB differences between the peak power of the locked mode and the highest peak power of any side mode of the Qdash spectrum. Note that the master laser is switched off during the above analysis of self-injection locking.

Next, external injection looking is separately carried out to lock a different FP mode from the Qdash LD emission with the aid of the tunable master seeding laser whose wavelength was tuned to match a different FP mode of the Qdash LD. Fig. 1(d) shows a single FP mode spectrum of tunable seeding laser in tandem with the free-running spectrum of the Qdash LD prior to external-injection locking taking place. Nonetheless, when the master laser is tuned to 1592.2 nm at an injection ratio of 5 dB, external-injection locking was exhibited as evident in Fig. 1(e), with an SMSR of ~32 dB. Note that the uniformly suppressed side modes that are witnessed in the case of external injection locking, despite selecting the locked mode near the short wavelength edge of the Qdash free-running spectrum, as illustrated in Fig. 1(e), is not observed in the case of self-injection locking of Fig. 1(c). We attribute this to an efficient locking efficiency in the former case due to associated higher injection ratio and less-sensitive polarization control of the system compared to the latter one of self-injection locking method. Ultimately, both external- and self-injection locking mechanisms were combined in action to injection-lock two different FP modes simultaneously, each locked through respective locking mechanism and Fig. 1(f) displays the hybrid dual-injection locking in effect where 1596.7 nm and 1607.2 nm were locked simultaneously.

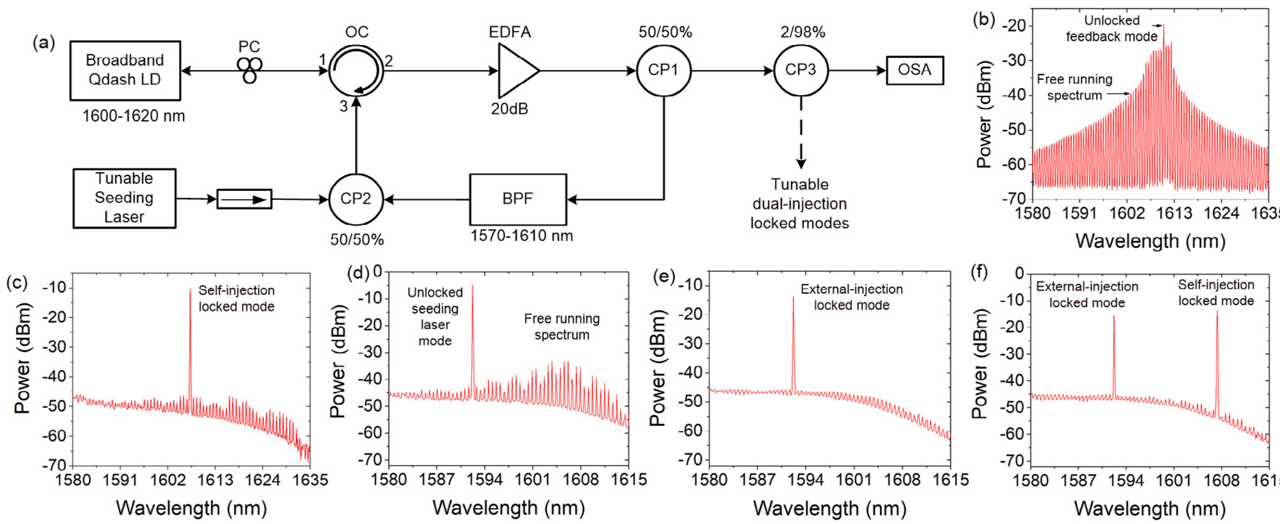

Fig. 1. (a) Hybrid dual-injection locking setup for generation of tunable MMW and THz waves. (b) Free-running spectrum of Qdash LD with one particular mode being optically fed back (self-feedback) with no form of injection locking taking place. (c) Single self-injection locked mode at 1607.2 nm with an SMSR of 36 dB. (d) Master laser mode alongside the free-running Qdash LD emission spectrum before external injection locking taking place. (e) Single External injection locked mode at 1592 nm after proper tuning the tunable seeding laser. (f) Hybrid dual-injection locking demonstration wherein both modes are injection locked simultaneously. In all cases, the optical power is measured from the 2% output of the CP3.

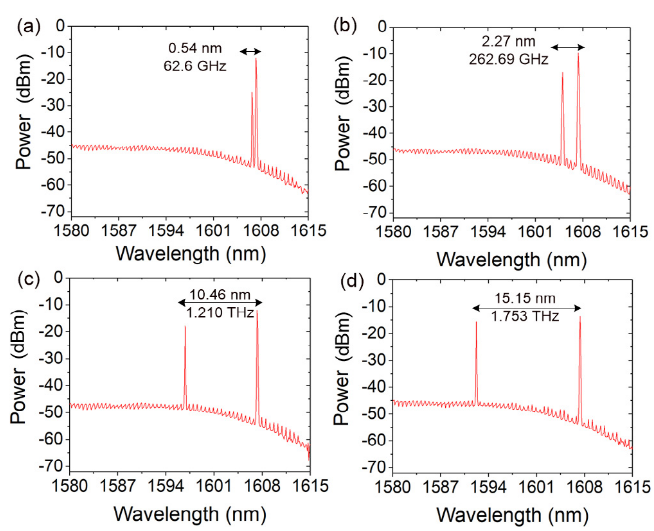

Fig. 2. Different beat frequency generation via hybrid dual-injection locking technique with beat frequencies of (a) 62.6 GHz, (b) 262.69 GHz, (c) 1.210 THz, and (d) 1.753 THz.

3.2. Beat frequency tunability and stability

One of the attractive features of our proposed hybrid dual-injection locking method is the ease in beat frequency tunability. This can be accomplished by fixing one mode while varying the other locked mode of the system, thus providing a total freedom in the selection of the beat frequency, which was not possible in a single injection locking mechanism system that was limited to a single beat frequency corresponding to the spacing between two adjacent modes [20]. In the present case, we demonstrate the system tunability in Fig. 2(a)–(d) by firstly fixing the self-injection locked mode at 1607.2 nm and then varying the external-injection locked mode by simply selecting any other available FP mode. This dictates a discrete tunability of the system in multiples of the FP mode spacing or the FSR of the Qdash LD, which is measured to be ∼0.54 nm (∼62 GHz) [21]. It is to be noted that employing a large cavity length Qdash LD in the system could easily increase the tuning resolution of the MMW and THz waves.

Nevertheless, two-mode locked optical spectrum with various mode spacing (beat frequencies) of 0.54- (0.062), 2.27- (0.263), 10.46- (1.21) and 15.15-nm (1.753-THz) affirm the capability of the system, with minimum spacing exhibited by two adjacent locked modes. Hence, the two locking operations would not affect each other (i.e., no crosstalk is expected). Moreover, it is worth mentioning here that the generated MMW and THz beat frequencies from a single Qdash LD in our hybrid dual-injection locking scheme provides significant advantages over a merely optical feedback and unlocked dual-mode spectrum [6]. Our system implicitly inherits the features of injection locking, such as, high coherency, reduced linewidth, low-frequency chirp, and in particular low system noise [22]. Typically, the relative intensity noise (RIN) is expected to be reduced by ∼10 dB/Hz, as has been demonstrated in [18] for the case of SIL. Whereas the RIN of EIL mode is expected to reduce and exhibit the RIN profile of the tunable seeding laser, which is ∼ −140 to −150 dB/Hz.

A closer inspection of the hybrid dual-locked spectrums in Fig. 2 shows a disparity between the peak optical power and SMSR of both modes, which is more specifically represented in Fig. 3, as a function of achieved dual-mode spacing or MMW and THz beat frequency tunability. While the self-injection locked mode showed a nearly uniform peak power and SMSR of −10 ± 2 dBm and 34 ± 3 dB, respectively, across beat frequency range from 1.752 THz to 62.6 GHz, the corresponding values for the external-injection locked shorter wavelength mode is −20 ± 5 dBm and 25 ± 5 dB, which displays rather inferior features. Moreover, a progressive decrease in peak power and SMSR, which resulted in larger fluctuations, is observed with a red-shift of the external injection locked mode wavelength, or in other words, decrease in the beat frequency of MMW or THz waves. We attribute these observations, in part, to the higher amplification of the external locked mode by the EDFA at the short wavelength region which is close to the EDFA gain peak (∼1570 nm) compared to the longer wavelength regime (>1602 nm) that exists at the tail of the EDFA gain spectrum. Moreover, though the injection ratio is unaltered in Fig. 2, we postulate a decrease in the localized injection ratio of an individual external-injection locked mode owing to the increase of its peak power in free-running case as its red-shifts and approaches the central lasing wavelength (∼1607 nm) of the Qdash LD.

However, it is to be noted that the performance of the system could be greatly enhanced with comparable SMSR and peak power from both the locked modes by employing an appropriate L-band EDFA

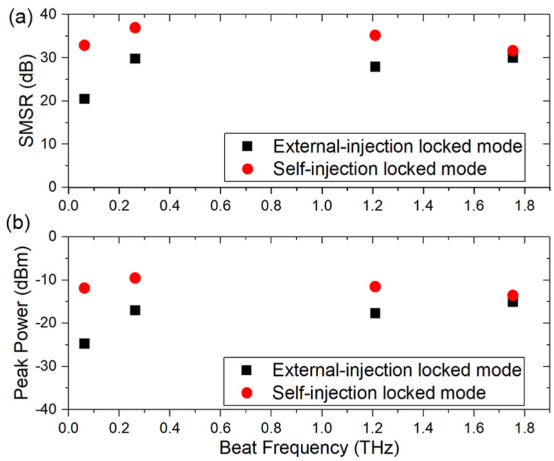

Fig. 3. (a) The SMSR and (b) peak power, exhibited at different beat frequencies by the external- and self-injection locked modes.

whose gain profile coincides with Qdash LD lasing spectrum. This also essentially improves the signal-to-noise ratio (SNR) (dB difference between the peak power of the locked mode to the ASE hump observed at ∼1570 nm) of the system, which is presently ∼20 to 25 dB. Moreover, the BPF in the system could potentially be replaced by a suitable customized L-band tunable fiber Bragg grating (FBG), thereby significantly reduce the size and cost of the system for practical applications.

Finally, we investigated the stability of the hybrid dual-injection locked system by plotting the peak wavelength, the peak power, and SMSR of both injection-locked modes, as shown in Fig. 4(a)–(c) corresponding to 62.6 GHz MMW photonic signal of Fig. 2(a). In this case, the locked modes are monitored for 30-min at 3 min step. In general, a stable operation is exhibited by both the locked-modes, and hence the system, particularly an extremely stable wavelength operation, as depicted in Fig. 4(a), suggesting a significantly low noise system, which is crucial for high-speed MMW and THz wireless communications. Furthermore, referring to Fig. 4(b) and (c), the external-injection locked mode showed ±0.5 dB and ±0.25 dBm fluctuations in the SMSR and peak power, respectively, while the self-injection locked mode showed a much more stable locking with corresponding ±0.17 dB and ±0.05 dB minor variations. This behavior complies with our previous findings and is ascribed to the fact that any variation in the feedback optical spectrum follows the very same fluctuation exhibited by the free-running lasing spectrum of Qdash LD, thereby maintaining a relatively constant injection ratio as opposed to external injection locking wherein the master laser require to be stable for a better performance. Nevertheless, the fluctuation exhibited in the peak power of both the locked modes are strikingly lower than ∼2 dB value that is reported in [23], further validating the robustness of our hybrid dual-injection locking scheme.

As for the feasibility and practicality of the proposed scheme is concerned, Table 1 summarizes the power budget of the system if the proposed scheme is deployed as a MMW/THz transmitter. As seen, most of the losses are minimal except for the tunable BPF that exhibited injection loss of 5–6 dB, however, if substituted by an appropriate FBG filter, would substantially reduce the system loss and cost.

4. Conclusion

A hybrid dual injection-locking scheme was demonstrated on a broadband InAs/InP 1610 nm Qdash LD as a potential source for MMW and THz beat frequency generation. A flexible configuration in terms of discrete beat frequency tunability of ∼1.7 THz and comparable high dual-mode power features were exhibited by the system besides inheriting the locking benefits with potential superior dynamic performance.

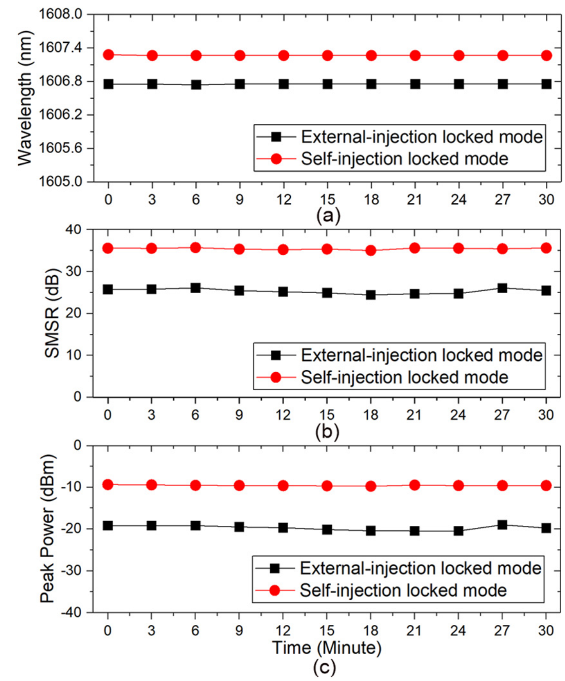

Fig. 4. The stability of the two dual-injection locked modes in terms of (a) peak wavelength, (b) SMSR and (c) mode peak power for 30-min time period.

Table 1
Approximate power budget analysis for the transmitter with the proposed hybrid dual-mode injection locked scheme.

Parameter	With	
	BPF	FBG
Qdash LD fiber coupled free running power (dBm)	−4	−4
EDFA gain (dB)	20	20
CP insertion losses (dB)	3	3
OC insertion loss (dB)	1	1
BPF/FBG insertion loss (dB)	5	1
Other losses (connector, PC, etc.) (dB)	2	2
Available usable dual-mode power (dBm)	**5**	**9**

This was qualitatively substantiated by extremely stable dual-mode power and wavelength with time. Four different beat frequencies of 62.6- and 263-GHz, and 1.21- and 1.753-THz were shown from the tuning window, which was mainly limited by the system components rather than Qdash LD. This scheme is evidently a promising flexible, robust, and tunable beat frequency source for MMW and THz applications, in the present as well as next-generation optical networks that are looking into extended C-band (i.e., mid and far L-band) operation.

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References

[1] S.E. Alavi, et al., Towards 5G: A photonic based millimeter wave signal generation for applying in 5G access fronthaul, Sci. Rep. 6 (2016) 19891.

[2] G.C. Mandal, et al., Bidirectional and simultaneous transmission of baseband and wireless signals over RSOA based WDM radio-over-fiber passive optical network using incoherent light injection technique, AEU-Int. J. Electron. Commun. 80 (2017) 193–198.
[3] H. Song, et al., Terahertz wireless communication link at 300 GHz, in: IEEE International Topical Meeting on Microwave Photonics, Montreal, QC, 2010, pp. 42–45.
[4] M. Khaleda, et al., Hybrid MMW-over fiber/OFDM-FSO transmission system based on doublet lens scheme and POLMUX technique, Opt. Fiber Technol., Mater. Devices Syst. 52 (2019).
[5] T. Nagatsuma, et al., Millimeter- and THz-wave photonics towards 100-Gbit/s wireless transmission, in: 23rd Annual Meeting of the IEEE Photonics Society, Denver, CO, 2010, pp. 385–386.
[6] J. Wu, B. Nakarmi, Y. Hyub Won, Optically tunable microwave, millimeter-wave and submillimeter-wave utilizing single-mode Fabry-Pérot laser diode subject to optical feedback, Opt. Express 24 (2016) 2655–2663.
[7] C.-Y. Lin, et al., Two-color laser diode for 54-Gb/s fiber-wired and 16-Gb/s MMW wireless OFDM transmissions, Photon. Res. 5 (2017) 271–279.
[8] C. Kim, et al., Optical microwave/millimeter-wave links using direct modulation of two-section gain-coupled DFB lasers, IEEE Photonics Technol. Lett. 17 (8) (2005) 1734–1736.
[9] C. Zhang, et al., 60 GHz millimeter-wave generation by two-mode injection-locked Fabry–Perot laser using second-order sideband injection in radio-over-fiber system, in: Conference on Lasers and Electro-Optics and Conference on Quantum Electronics and Laser Science (CLEO), San Jose, CA, 2008, pp. 1–2.
[10] T. Kuri, K. Kitayama, Y. Ogawa, Fiber-optic millimeter-wave uplink system incorporating remotely fed 60-GHz-band optical pilot tone, IEEE Trans. Microw. Theory Tech. 47 (7) (1999) 1332–1337.
[11] T.B. Simpson, J.M. Liu, K.F. Huang, K. Tai, Nonlinear dynamics induced by external optical injection in semiconductor lasers, Quantum Semiclass. Opt.: J. Eur. Opt. Soc. B 9 (5) (1997) 765.
[12] C.-Yu. Lin, et al., Millimeter-wave carrier embedded dual-color laser diode for 5G MMW of link, J. Lightwave Technol. 35 (2017) 2409–2420.
[13] R.-P. Braun, G. Grosskopf, D. Rohde, F. Schmidt, Low-phase-noise millimeter-wave generation at 64 GHz and data transmission using optical sideband injection locking, IEEE Photonics Technol. Lett. 10 (5) (1998) 728–730.
[14] A. Hurtado, et al., Simultaneous microwave- and millimeter-wave signal generation with a 1310-nm quantum-dot-distributed feedback laser, IEEE J. Sel. Top. Quantum Electron. 21 (6) (2015) 568–574.
[15] R. Rosales, et al., InAs/InP Quantum dash based mode locked lasers for 60 GHz radio over fiber applications, in: International Conference on Indium Phosphide and Related Materials, Santa Barbara, CA, 2012, pp. 185–187.
[16] F. van Dijk, et al., Quantum dash mode-locked lasers for millimeter wave signal generation and transmission, in: 23rd Annual Meeting of the IEEE Photonics Society, Denver, CO, 2010, pp. 187–188.
[17] S. Joshi, et al., Quantum dash based single section mode locked lasers for photonic integrated circuits, Opt. Express 22 (2014) 11254–11266.
[18] G.C. Mandal, R. Mukherjee, B. Das, A.S. Patra, A full-duplex WDM hybrid fiber - wired / fiber - wireless / fiber - VLC /fiber - IVLC transmission system based on a self-injection locked quantum dash laser and a RSOA, Opt. Commun. 427 (2018) 202–208.
[19] M.A. Shemis, et al., Broadly tunable self-injection locked inas/inp quantum-dash laser based fiber/FSO/hybrid fiber-FSO communication at 1610 nm, IEEE Photonics J. 10 (2018) 1–10.
[20] M.A. Shemis, et al., L-band quantum-dash self-injection locked multiwavelength laser source for future WDM access networks, IEEE Photonics J. 9 (2017) 1–7.
[21] E. Alkhazraji, et al., Terahertz photonic signal generation employing InAs/InP quantum dash laser, in: IEEE Asia Communications and Photonics Conference (ACP), 2018, pp. 1–2.
[22] C.J. Buczek, R.J. Freiberg, M.L. Skolnick, Laser injection locking, Proc. IEEE 61 (10) (1973) 1411–1431.
[23] X. He, et al., A tunable and switchable single-longitudinal-mode dual wavelength fiber laser with a simple linear cavity, Opt. Express 17 (24) (2009) 21773–21781.