

Characterization of 60 GHz Multi Quantum well passively mode-locked laser under optical self-injection locking

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The quality and pulse compression of the 60 GHz millimeter wave signals generated by 750 m long InAlGaAs Multi Quantum Well (MQW) passively mode locked laser under free running and optical self-injection locked conditions are experimentally characterized in terms of longitudinal modes under certain bias currents that range from 24 mA to 90 mA. Initially, the MQW laser is characterized in free running condition with no external injection. The measurements reflect that the free spectral range of laser under test is around 61 GHz and exhibit more than 22 lasing modes. The laser is then integrated into low phase noise self-injection locking oscillator by feeding a part of output RF signal back into the laser cavity to enhance passive mode locking. By doing so the microwave line width of our laser is reduced from 900 kHz to 24 kHz with significant increase in output of resultant beat tones which exhibits strong passive mode locking. This is the first time that the free running microwave line width of MQW laser is reduced up to this level. It is evident from our experimental investigation that as we increase the power and phase correlation between different longitudinal modes inside laser cavity through optical self-injection, the strength of the passively mode locked mechanism is significantly increased and the phase noise of radio frequency signal is drastically reduced.

1. Introduction

As compared to fiber lasers, semiconductor mode locked lasers bearing the capability of generating ultra short pulses have unique features of compactness and high repetition rate in Terahertz range [1,5-7]. They are of great interest as they can be easily implemented for several applications ranging from high speed optical communication to all optical signal processing including optical sampling and clock recovery [2,6-8,10]. These lasers can be used to generate millimeter or terahertz waves through mode beating process on high bandwidth photo detector which does not require any complex setup. They are also used for comb generation that can be exploited in wavelength division multiplexing (WDM) [11]. More-over these lasers are widely used as self-injection locked oscillators for generation of stable and low noise signals [9].

There have been extensive research on semiconductor based passively mode locked lasers for high frequency signal generation and self-injected locked oscillators as they exhibit a periodic time variation of their output emission under dc-bias condition without using any saturable absorber in the cavity. The synchronization of the phase of the lasing modes is achieved by four wave mixing as proved in [4]. The linewidth of the beating signal features a value small than the sum of the optical mode linewidth. This demonstrates that the phases of the optical modes are synchronized. These devices offer cost effective solution for generation of microwave signals at 60 GHz or beyond by direct detection with high speed photo detector. In fact, these devices have already been used for RF signal generation up to 100 GHz [6]. Pulse generation at 370 GHz and 1.1 THz has been demonstrated using MQW InAlGaAs FP lasers with a one-dimensional photonic band-gap embedded in its structure [3,6,8].

The linewidth of the microwave signal in free running condition of these lasers is few hundreds of MHz. By taking advantage of self-injection, we have successfully reduced the line width and phase noise of these lasers down to few tens of kHz. We conclude that strength of passively mode locked mechanism can be enhanced by increasing the number of longitudinal modes oscillating into laser cavity, the power of main lasing modes inside the laser cavity which allows the reduction in the free running line width, as the cavity is extended by the feedback loop, or reducing the effect of the material dispersion on lasing mode phase as previously demonstrated [12]. Exploiting above mentioned idea the focus of this work is to reduce the linewidth of the microwave signal by coupling an external cavity through optical self-injection locking in order to enhance power and phase correlation between different lasing modes inside laser cavity.

2. Experiment

The schematic diagram of the experimental setup to characterize MQW laser under free running conditions is shown in Fig. 1. The schematic diagram of the experimental setup to character-The device under test is stabilized at 24 °C and dc-bias. The optical output power is coupled to 60 dB isolator in order to avoid back reflections and a 20 m long spool of single mode fiber (SMF). A 50/50 coupler is used to separate the optical power into two parts, one for optical spectrum measurements using 20 MHz resolution optical spectrum analyzer (ANTITSU MS9717A) and other one for RF detection with a high speed 60 GHz photo detector that converts the output optical power into current which will be analyzed by an electrical spectrum analyzer (ESA) set at 120 MHz span and 30 kHz resolution. The optical spectrum provides the central lasing wavelength, the number of longitudinal modes and mode spacing while electrical spectrum provides the output power of the signal in terms of RF frequency under a bias range spanning from 24 mA to 90 mA.

2.2. Characterization of 60 GHz MQW laser under optical self-injection locking

The experimental setup for optical self-injection is depicted in Fig. 2. All the parameters including temperature and current are kept the same for free running setup. This setup delays the coherent signal produced by MQW laser into external cavity and sends it back again into laser cavity in order to couple the laser cavity with a longer external cavity. The coherent light generated by mode locked laser passes through an optical circulator and is split into two halves using 50/50 optical coupler. The half of the optical power is launched into the polarizer in order to match the polarization states of the injected optical light to the polarization state emitted by the laser. An attenuator is used to modify the injected optical power into the laser. A tunable optical delay line tunes the overlap between the delayed pulses and the generated pulse inside the cavity. The part of the light that leaving the fiber loop is sent to an optical spectrum analyzer set at 20 MHz resolution and to an electrical spectrum analyzer associated to a high speed photo detector set at 120 MHz span and 30 kHz resolution. For this experiment we have measured the line width of generated RF signal centered at 61.9 GHz as a function of bias current applied and output power is measured in terms of frequency, as it will be presented in Section 3. The total optical power maintained inside the loop is -30 dBm.

3. Results and discussions

The first part of the experiment corresponds to the schematic shown in Fig. 1. The typical voltage and optical power collected in a single mode fiber versus bias current for the analyzed 60 GHz MQW laser are shown in Figs. 3 and 4 respectively. The device is temperature controlled at 24°C and dc-biased. The output power is collected on a slow response optical meter as function of increasing and decreasing bias current which range from 24 mA to 90 mA for bout experiments. The device has threshold current of ~ 18 mA and maximum average collected power of about 1.6 mW. Its FSR is measured at 61.9 GHz and exhibits more than 30 lasing modes. First the free running characterization of laser is conducted in order to get minimum free running line width and the quality of generated output beat tones at various bias currents. The minimum FWHM line width observed is 900 kHz at 62 mA with average power collected of -40 dBm. The generated RF signals at various bias currents under free running conditions are shown in Fig. 5.

The second part of the experiment corresponds to the schematic shown in Fig. 2. The device under test is integrated into optical self-injection oscillator that delays the signal in external cavity and sends back part of laser output into laser cavity to enhance the power of main lasing modes and phase correlation between different modes inside cavity. The resultant microwave signals at various bias currents with different FWHM line width values are shown in Fig. 6a. These results show a significant compression of the linewidth of RF signal from 900 kHz to 24 kHz measured in the same bias condition of 62 mA. This demonstrates enhancement of passive mode locking due to the external loop.

More details on the reduction of the RF linewidth are shown in Fig. 7. There are some undesired side bands in RF signals generated in case of self-injection due to coupled loop oscillations and they further increase if the power in external cavity is not maintained properly which is kept around -30 dBm for the experiment. It is observed that laser becomes unstable and produces huge unwanted sidebands in case of strong optical feedback. Therefore we have to maintain balance between pulse compression and optical self-injected power into external cavity in order to avoid these spurious side bands. The detailed insight of RF line width as function of bias current that ranges from 24 mA to 90 mA is shown in Fig. 8(a) and

(b). As it is evident from figures that when laser does not undergo injection, the line width can be as high as 40 MHz and as short as 90 kHz, but when same device is under optical self-injection, then largest line width is at 280 kHz while smallest line width observed is at 24 kHz as shown in Fig. 8(b).

4. Conclusion

In this work we have experimentally analyzed the FWHM of RF signal generated by 60 GHz passively mode-locked Multi Quantum well (MQW) FP laser dc-biased under free running and self-injection locked conditions. The analysis has been done in terms of various bias currents range from 24 mA to 90 mA and number of longitudinal modes that are controlled through optical self-injection locking mechanism. The FWHM line width of MQW laser is measured under these conditions. It is observed that as the laser is integrated into optical self-injection pulse are compressed due an increase in power of main lasing modes resulting in stronger phase correlation. The free running spectral line width of MQW mode locked laser is significantly reduced from 900 kHz to 24 kHz which shows strong passive mode locking inside laser cavity.

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Figures

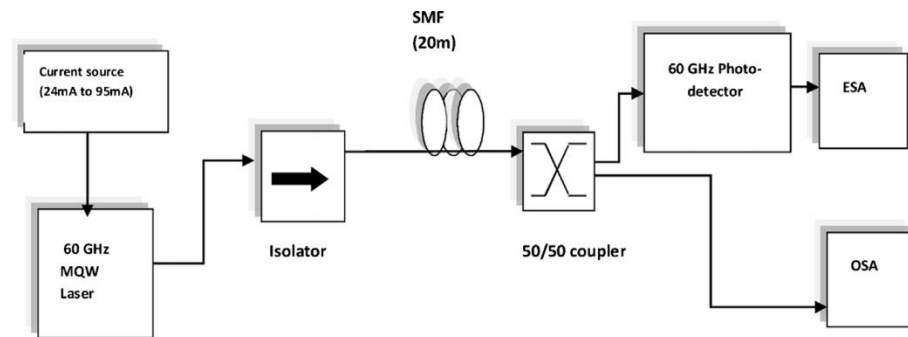


Fig. 1. Schematic of the experimental setup for characterization of 60 GHz MQW laser under free running condition.

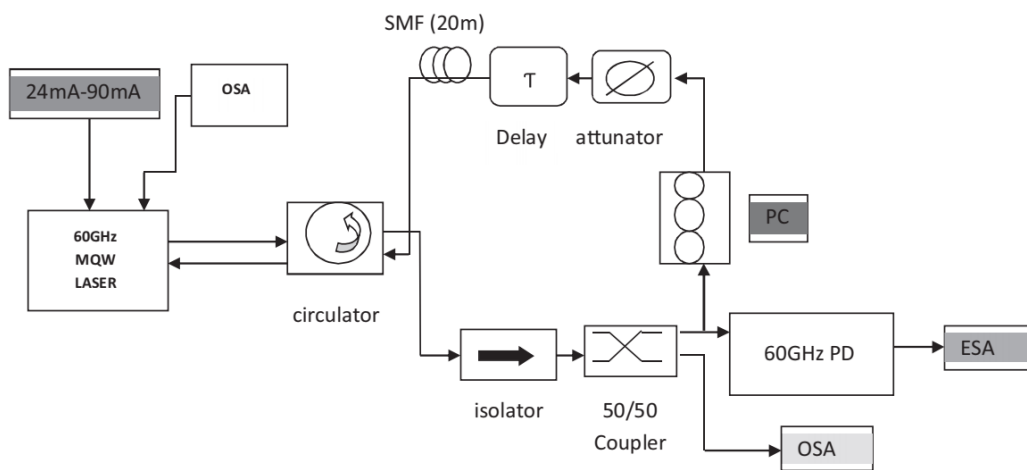


Fig. 2. Schematic of the experimental setup for optical self-injection.

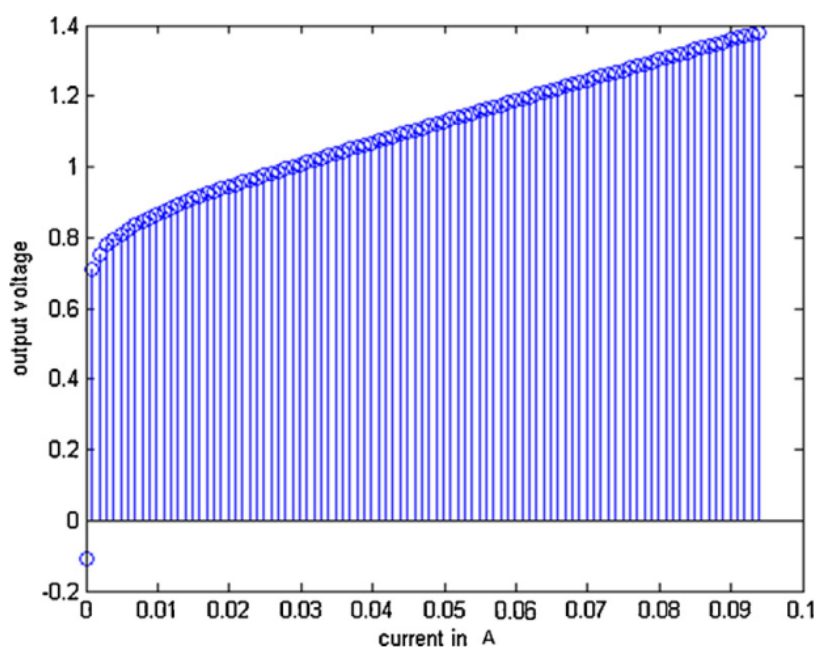


Fig. 3. Output voltage vs. drive current.

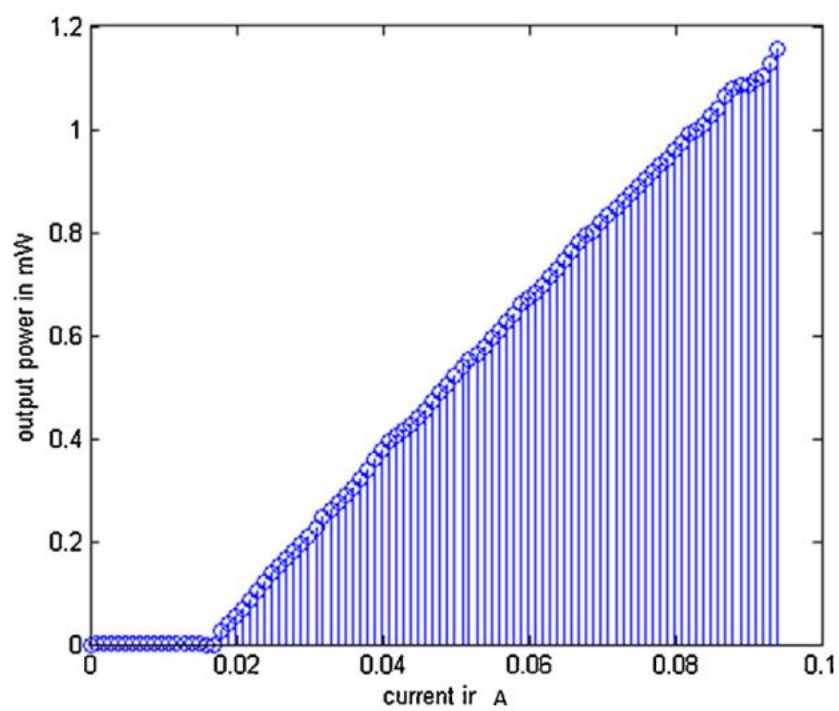


Fig. 4. Output power vs. drive current.

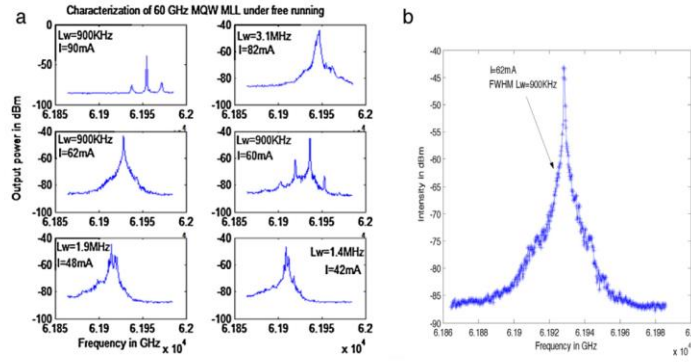


Fig. 5. (a) RF signal generated by 60 GHz MQW laser in free running condition at various bias currents along with shortest pulse obtained at 62 mA centered at 61.9 GHz shown in (b).

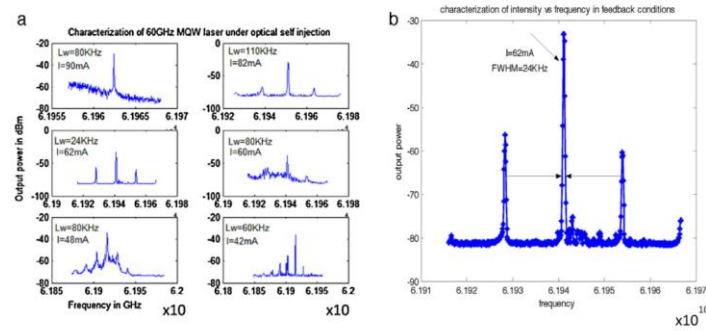


Fig. 6. (a) Compressed RF signal generated by 60 GHz MQW laser in under optical self-injection locking at various bias currents and (b) compressed pulse obtained at 62 mA is shown.

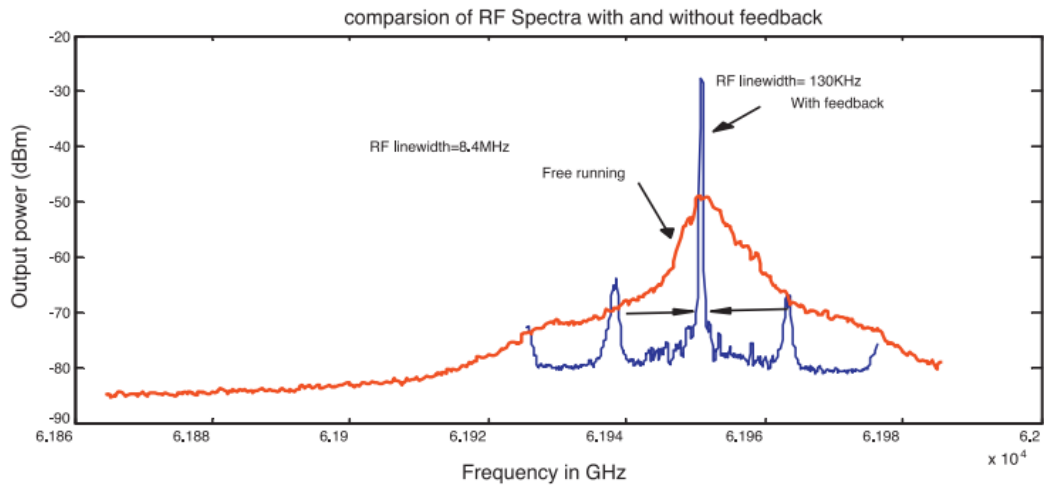


Fig. 7. Comparison of electrical spectrum under free running and self-injection locked conditions for a bias of 88 mA.

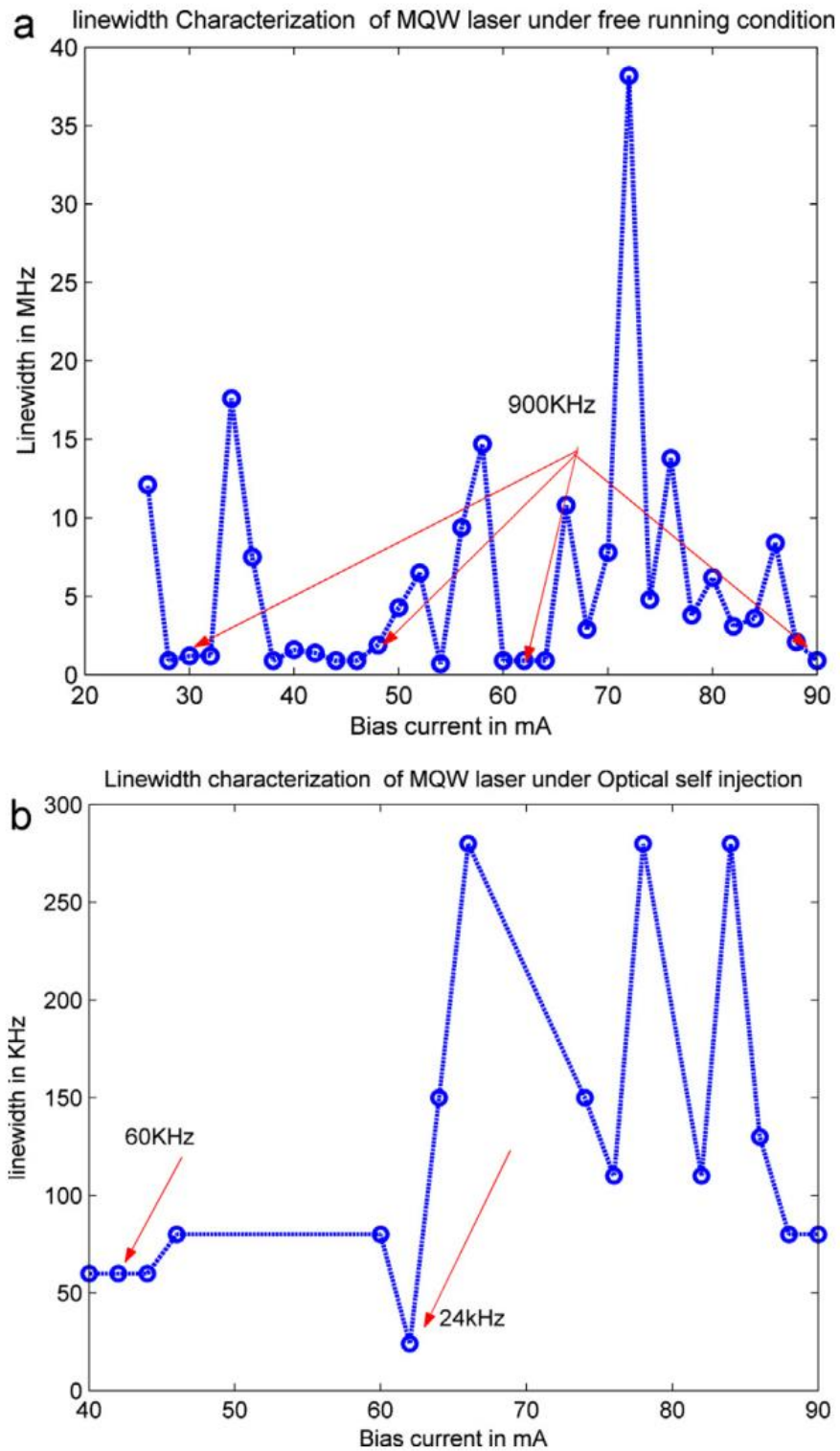


Fig. 8. (a) and (b) Free running and self-injected linewidth analysis as function of bias current

