

High bandwidth constant current modulation circuit for carrier lifetime measurements in semiconductor lasers

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ABSTRACT

In this paper we present a novel implementation of high bandwidth constant modulation current circuit to the traditional small signal optical response technique used to determine the differential carrier lifetime of a semiconductor laser. This circuit is designed for the voltage to current conversion and to deliver a constant modulation current to the laser diode. The circuit rectifies parasitic effects of high value surface mount resistor at high frequencies used in the impedance independent optical technique and also has lower crosstalk. The application of this circuit can be generalized where the requirement arises for a high bandwidth constant modulation current circuit.

Keywords: Semiconductor laser, carrier lifetime, small signal response, impedance technique, high bandwidth

1. INTRODUCTION

Carrier lifetime measurements are a powerful tool to understand the fundamental properties of semiconductor lasers. The carrier lifetime versus bias current characteristic of a semiconductor laser allows extracting the recombination coefficients related to the various recombination mechanisms and to study their relative strength in the active region of semiconductor lasers.

There are three main techniques used to measure the carrier life time such as turn on delay, impedance and small signal optical response and each of them has their own unique features. The delay in the turn on of the lasing with respect to the injection current is used to extract the carrier lifetime in the turn on delay technique, which requires very fast rise times and very large current pulses for the turn on delay measurements and is very difficult to achieve, limiting the effectiveness of extracted carrier life time [1-3]. In the impedance technique the lifetime is extracted by fitting the small-signal impedance model of diode to the measured electrical impedance which contains four fitting parameters. [4-6]. To properly fit this model and effectively extract the lifetime it is important to take measurements at much higher frequencies > 2 GHz. However, at these high frequencies there could be the observation of additional poles and zeros due to carrier capture and escape times in case of multi-level laser systems and can limit the extraction of differential carrier lifetime [7].

The other technique found in the literature is small signal optical response in which the carrier lifetime is extracted from a fit of the measured small signal modulation response of a laser. Since the laser diode is current driven device, this technique requires a high bandwidth voltage to current converter which can modulate the semiconductor laser at a constant current. At low bias currents not only does the dynamic impedance of laser diode changes significantly with bias but it also become frequency dependant thus causing the modulation current to change with bias and frequency and determined by varying laser diode impedance. Therefore, the differential carrier lifetime extracted using this technique from the small signal modulation response is in error and has shown to decrease at low bias current [4, 5].

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Shtengel *et. al* proposed a way to correct this situation [4]. They derived an equation for the electrical impedance of the laser diode which is not always complete [8] and requires an additional step of measurements, making this technique time consuming. Another disadvantage of this technique is the large impedance mismatch that occurs at the laser diode. This mismatch causes electrical power to be radiated out and mistakenly picked up by the receiver thus affecting the measured response.

To remove the effect of varying laser impedance and avoid additional measurements, we proposed an impedance independent technique based on the passive components to measure the carrier lifetime in semiconductor lasers [8, 9]. In this technique a 10 K Ω series resistor and the 50 Ω shunt resistor referred as the impedance stabilization circuit is added to the traditional small signal optical response technique and is used to provide the necessary constant modulation current to the semiconductor laser as described in Ref 8. In this technique, the modulation current delivered to the laser diode is determined by the series resistor instead of varying laser impedance. The disadvantage of this technique is the parasitic associated with the high value chip resistor [10]. The impedance behavior of a typical surface mount resistor can be observed in Fig. 1.

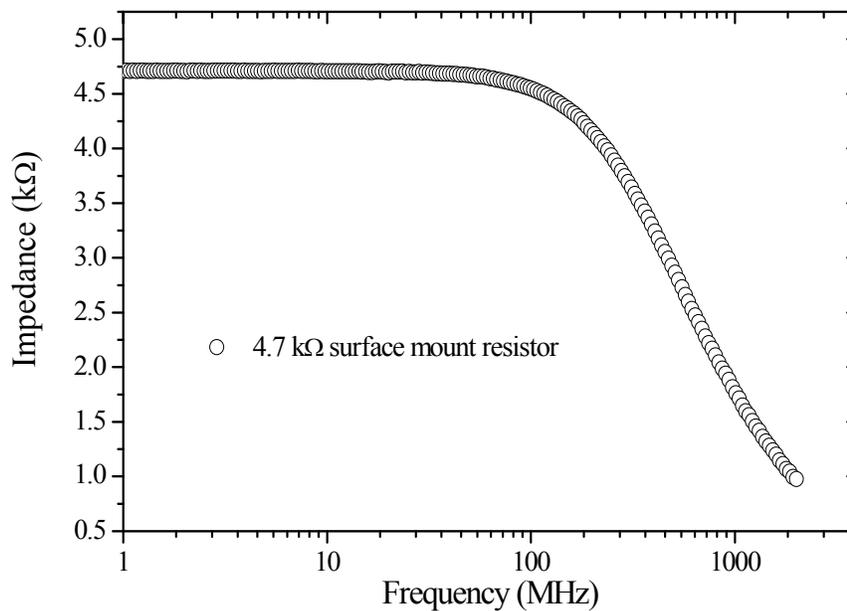


Fig. 1 Actual impedance data taken on a 4.7 k Ω surface mount resistor.

From Fig. 1 we can see that the surface mount resistor exhibits an ideal resistive behavior at low frequencies and parasitic capacitive effects can be observed as early as 100 MHz for resistive values of a few k Ω 's. At this point, the parasitic capacitor begins passing the AC signal rather than forcing the AC signal through the resistor. Therefore the frequency response may be limited due to the parasitic capacitance and may introduce an error in the carrier lifetime extraction from the measured small signal modulation response of laser diode.

Another disadvantage of this technique is the high power level used which increases the crosstalk between the instruments. Since we are interested in the sub-threshold behavior of laser where the light output is very low (\sim -115 dBm) we want to get the signal at least 8-10 dBm higher than the crosstalk. Therefore, it is important to have minimal or complete absence of cross talk. In this article we present a high bandwidth constant modulation current derive circuit based on the active components which we used in the traditional small signal optical response technique for the direct determination of carrier lifetime of semiconductor laser.

2. ACTIVE CIRCUIT

In our new technique we eliminate the electrical impedance technique's disadvantages of fitting four model parameters and requiring data to be taken at high frequencies. We also eliminate the traditional optical technique's disadvantage of needing additional measurements to account for laser impedance changes. Further we removed the parasitic effects of 10 K Ω series resistor at high frequencies used in impedance independent technique and achieved almost no crosstalk. In this approach we implemented a high bandwidth voltage to current convertor circuit using active components to the traditional small signal optical response technique to deliver the constant modulation current to the laser diode from 500 KHz to 3 GHz. The experimental setup using this high bandwidth voltage to current convertor is shown in Fig. 2.

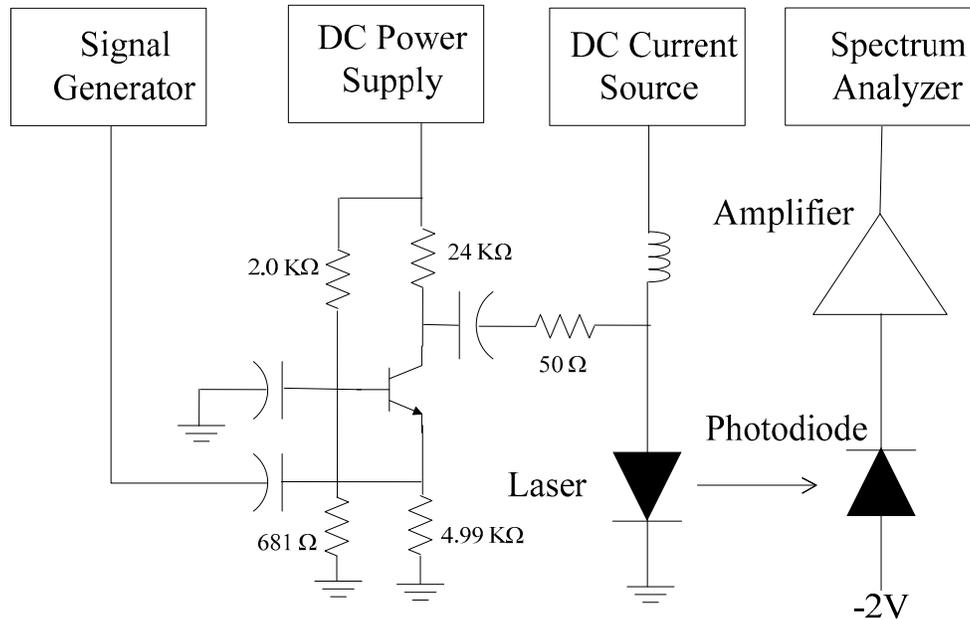


Fig. 2. Experimental setup for small-signal response technique with high bandwidth voltage to current convertor circuit.

The high bandwidth voltage to current convertor circuit contains a dc biased NESG 2030M04 NPN SiGe transistor and is chosen because of very high output resistance and high-frequency operation. The transistor is used in the common base configuration such that the output resistance is determined by $r_o \parallel R_C$ where R_C is the collector resistance set equal to 24 K Ω . The higher value $r_o \parallel R_C$ derive a changing load with the constant modulation current such as complicated load of laser diode. This configuration has several advantages as compared to the CE configuration such as unity current gain and excellent high-frequency response. Since this transistor is originally manufactured for CE configurations but as we wanted to have unity gain to avoid the extra step to keep up with the β value to determine the output current we choose to use common base configuration which also has the better high-frequency response than CE configuration. Our simulation showed that the CE configuration is also possible for the frequency range of interest.

The transistor is voltage divider biased such that the emitter current is nearly 0.5 mA and helps to set the emitter resistance around 50 Ω to provide the matching load to the source to reduce the radiated power. Initially we had issues driving the laser as transistor became unstable at high bias currents therefore; a 50 Ω series resistor is added to the output for the stability of the amplifier. This resistor may not be necessary in CE configuration as it tend to be more stable compared to CB configuration.

Fig. 3 shows the comparison between above threshold optical response of the laser diode taken using with and without high bandwidth voltage to current convertor circuit. The curve taken with high bandwidth voltage to current convertor

circuit is more flat as compared to without high bandwidth voltage to current convertor circuit, which implies a constant modulation current driven laser diode.

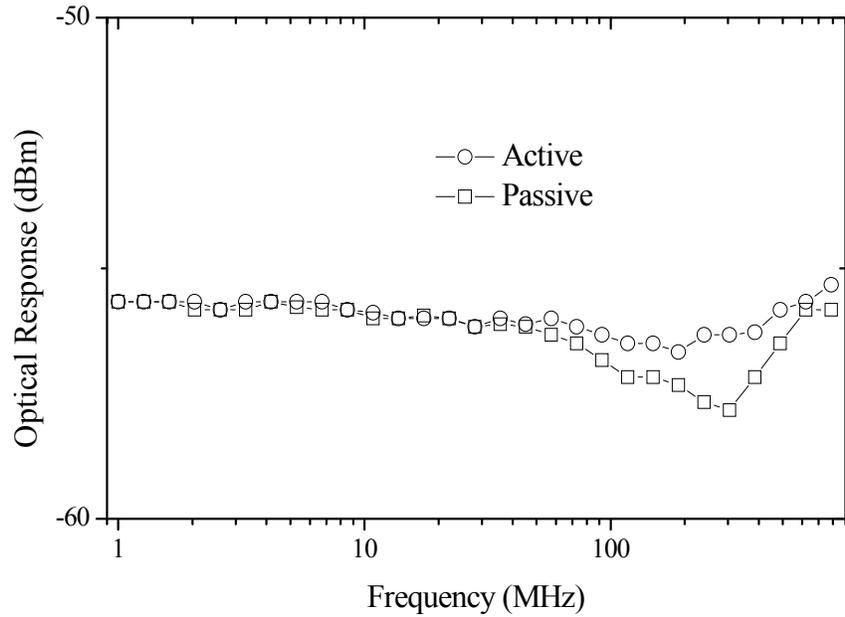


Fig. 3 Calibration curves for the small signal optical response technique with and without high bandwidth voltage to current convertor circuit.

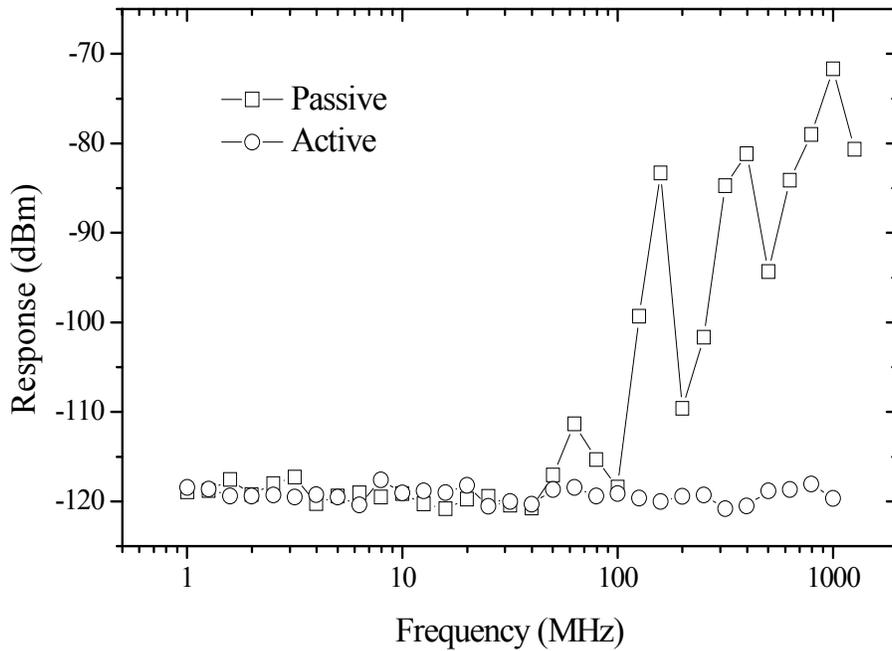


Fig. 4 Comparison between the measured crosstalk's using small signal optical response technique with and without high bandwidth voltage to current convertor circuit.

The high bandwidth voltage to current convertor circuit uses very low powers (< -40 dBm) to drive the laser diode, thus it significantly reduces the RF crosstalk between the instruments. Fig. 4 shows the comparison between the cross talk data

taken by the small signal optical response technique with and without high bandwidth voltage to current convertor circuit.

In the above Fig. 4, open square plot represent the data taken without the high bandwidth voltage to current convertor circuit using the small signal technique. Clearly seen, the crosstalk will start to interfere with the measured frequency response above 100 MHz and introduce an error in the extraction of lifetime decreasing the accuracy of extracted parameters.

On the other hand, the open circles represent the data with the high bandwidth voltage to current convertor circuit. As noticed the crosstalk is completely absent and we have only noise floor set by the high speed photodetector. Therefore, there won't be any interference between the measured frequency responses because the noise floor is at least 8-10 dBm lower than the measured data point at the lowest current and the frequency of interest increasing the accuracy of extracted lifetime.

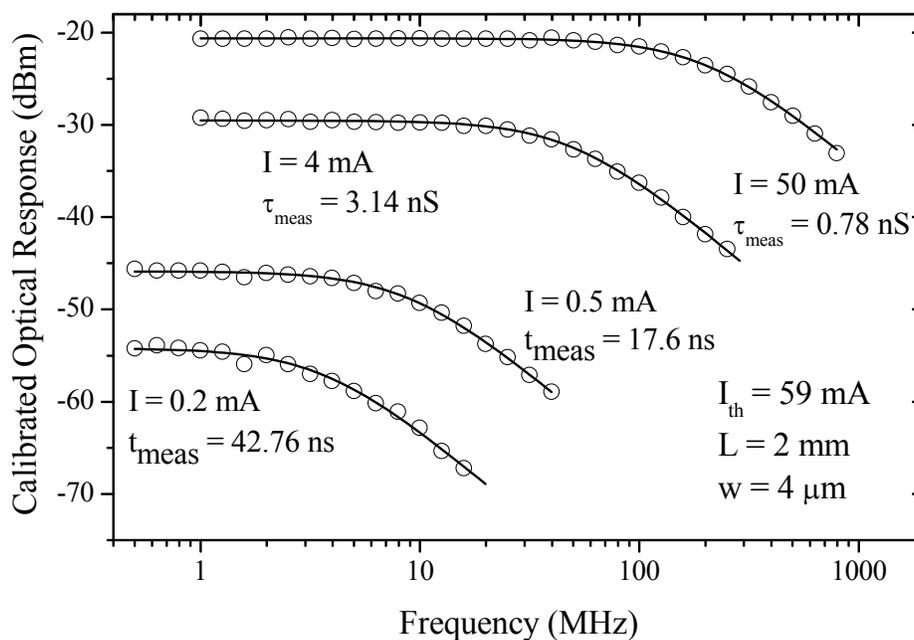


Fig. 5. Typical subthreshold modulation response of InAs/GaAs quantum dot laser.

For both, low and high bias currents we measured the single pole modulation response of 1.1 μm InAs/GaAs quantum dot laser grown using metal organic chemical vapor deposition [11] across the frequency range of interest using the high bandwidth voltage to current convertor circuit as shown in the Fig. 5.

In order to remove the effect of nonlinearities associated with instruments, cables, photodiode, and amplifier: the optical response curves were calibrated by subtracting off the above threshold frequency response of the laser diode. Excellent fits to the single pole response equation were obtained which allowed the extraction of single dominant time constant (τ_{meas}) indicating the absence of any high frequency zeros and poles in the frequency range of interest ($< 1\text{GHz}$).

To verify the measured lifetime data of small signal technique, the lifetime measurements were done using the impedance technique up to 2 GHz in contrast to 1 GHz. Although the high frequency zeros and poles were absent those have found to create problem to the multi-level semiconductor laser systems [7].

Fig. 6 shows the carrier lifetime measured using small signal optical response technique with high bandwidth voltage to current convertor circuit and impedance technique. The excellent agreement with both the techniques was obtained. The

both techniques clearly measure the same carrier lifetime, which does not saturate or decrease at low bias.

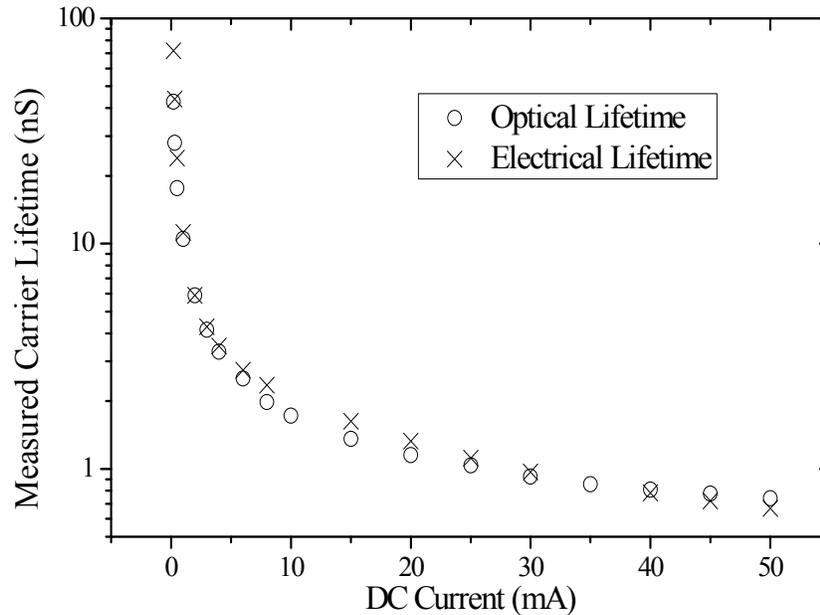


Fig. 6 Measured lifetimes using optical response (circle) and impedance (cross) techniques of InAs/GaAs quantum dot lasers.

3. CONCLUSION

In summary, we demonstrated the use of high bandwidth constant modulation circuit in the traditional small signal optical response technique to directly determine the lifetime from the measured small signal optical response of a semiconductor laser. The circuit rectifies the parasitic effects associated with the high value surface mount resistor which can introduce the error in extraction of lifetimes at high frequencies. Excellent agreement has been obtained in measured differential lifetime using small signal optical response and electrical impedance techniques. Further the application of the circuit presented can be extended where it requires delivering constant modulation current to the load.

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