Laser Diode for LiDAR

Laser Diode Drive Circuit Design Method and Spice Model

ROHM offers laser diodes (LDs) for Light Detection and Ranging (LiDAR). This application note will introduce ROHM's LD line-up and show how to design the drive circuits of ROHM LDs. In addition, ROHM provides an evaluation board and a Spice model for evaluating LDs and will show how to use them and some important points.

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1. The Lineup and Features of ROHM's Pulse LD

Pulse laser diodes are LDs that produce high optical output power with short current application time (pulse width). In recent years, many applications, such as distance measurement, have emerged.

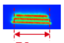
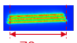
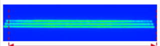
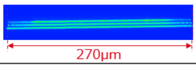
Many LDs are designed with continuous wave (CW) drives that produce optical output from a few mW to several W. When such LDs try to output higher optical output power than a specific optical output power, even if the pulse width is short, the optical cavity is damaged, and the optical output cannot be generated.

However, pulse LDs are designed to produce high optical output power with short pulse widths. The drive of the pulse LD must be determined by the pulse width and duty cycle. In order to achieve high optical output power, the duty cycle must be very small. For example, a duty cycle of 0.05% (100 μs per cycle, 50 ns pulse width) means that very short pulse currents are repeatedly applied in the kHz range. The applied current to the LDs is from several A to several tens of A to produce high optical output power pulses.

The wavelength of pulse LDs is material-dependent, and ROHM can offer 905 nm. 905 nm wavelength range is made up of AlGaAs, a material with high reliability, high beam quality and stable temperature characteristics. Pulse laser diodes use a stack structure consisting of multiple light-emitting layers to achieve high optical output power. ROHM's three-layered stacks are used to achieve Up to 120 W optical output can be provided.

ROHM's pulse LDs are characterized by a narrow luminescence width and good wavelength temperature dependence. Table.1 shows the emission images for the optical output lineup. The narrower the luminescence width, the higher the optical density, and the longer the distance can be measured with the same optical output power. In addition, the narrower the luminescence width, the smaller the beam area can be when irradiating an object, which enables a higher resolution LiDAR module to be used.

Table 1. Luminescent Images for Optical Output Lineup

output※	25W		75W	120W
model	RLD90QZW6	RLD90QZW5	RLD90QZW3	RLD90QZW8
Emitting width (Physical size)	**50μm**×10μm	**70μm**×10μm	**225μm**×10μm	**270μm**×10μm
Emitting width (FWHM)	**44μm**×10μm	**64μm**×10μm	**170μm**×10μm	**210μm**×10μm
Emitting figure	 50μm	 70μm	 225μm	 270μm

※ Optical output with a pulse width of 50 ns

Improving Signal to Noise (S/N) ratio in LiDAR's optical system, put in a band-pass filter to cut other than required wavelength range. The wavelength temperature dependence of ROHM's pulse LDs have an outstanding wavelength temperature dependence of 0.15 nm/℃. This makes it possible to design a narrower wavelength range for the band-pass filter to cut, thus improving the S/N ratio of LiDAR modules.

2. LiDAR and ToF method

LiDAR is an abbreviation for "Light Detection and Ranging" and has been attracting attention in various fields such as automobiles, robots, drones, surveillance cameras, etc. Time of Flight (ToF) method is the most used distance measurement method in LiDAR. In the ToF method, as shown in Fig. 2-1, the distance is calculated by measuring the time it takes for the light emitted from the light source to be reflected by the object and returned to the detector (flight time).

The distance between the light source and the object is defined by the following equation, where *d* is the distance between the light source and the object and t_f is the time of flight.

$$d = \frac{c \cdot t_f}{2} \quad \cdots (2\text{-}1)$$

c is the speed of light in above equation.

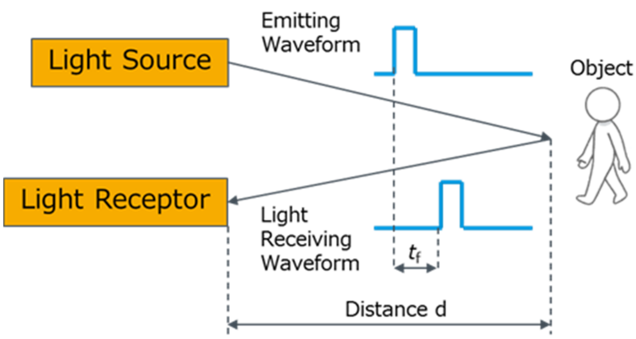


Fig. 2-1. Conceptual diagram of the Time of Flight(ToF) method.

Higher optical output power is required to improve the measuring distance. The farther away the distance is, the lower the rate of return of the optical output power. That is caused by light attenuation in the air. *1 For this reason, higher optical output power is required to view objects over long distances.

In order to improve the distance resolution, the pulse width must be made shorter. When the pulse width is longer, the light pulses received by the detector tend to overlap, making it difficult to distinguish between two or more objects that are close to each other. For this reason, shorter pulses are required to improve distance accuracy. Shorter pulses can also increase the maximum optical output power from an eye safe standpoint.

The required distance resolution and distance range are different for each application, as shown in Fig. 2-2. Therefore, the required optical output power and pulse widths are different for each application, and it is important to select the right device and design the circuit for each application.

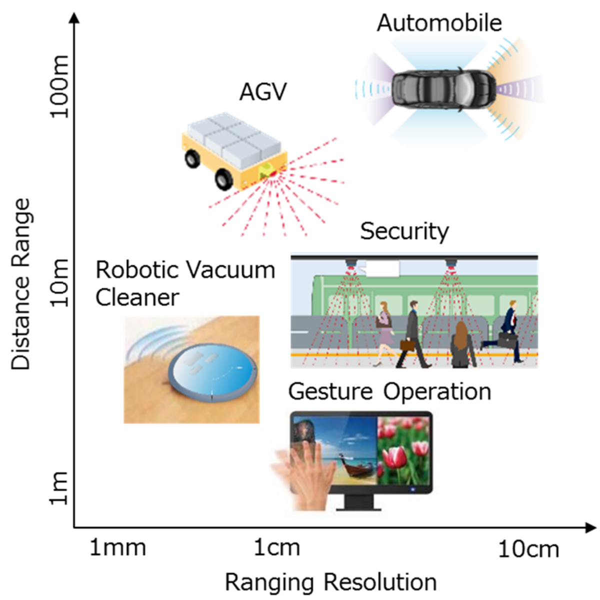


Fig. 2-2. Assumed uses of the ToF method.

3. LD Drive Circuit Design Method

To output high power with short pulses, not only the selection of the LD, but also the design of the LD drive circuit is important. There are various types of LD drive circuits, and here we will discuss the current resonant circuits. Current-resonant circuits are characterized by high optical output power and short pulses.

The drive circuit is shown in Fig. 3-1. The main current paths are the LD, the resonant capacitor C_r and the switching element Q1. When Q1 is switched off, C_r is charged in the I_1 path. The moment Q1 is turned on, current flows in the path from C_r to I_2, allowing light to be output from the LD. If you don't add a resistor R_l to limit the current of I_1, the current of I_2 will be small.

Due to the current in I_2, reverse electric charge gradually builds up in the C_r in the opposite direction. This electric charge in the C_r causes the current to start flowing in the I_3 path. At this time, if a diode D_p is not connected to the LDs, the voltage is applied to the LDs, which may damage the device. (In the resonant wave circuit shown in Fig. 3-1, the LDs cannot be driven normally without the D_p because it also serves as a charging path.) If vibration is not suppressed while current is flowing through the I_3 path, current will flow through the I_2 path again, which will generate unnecessary optical output power. Normally, Q1 is turned off at the time when the LDs move from I_2 to I_3, so the second and subsequent currents are less likely to flow. However, even when Q1 is turned off, current flows through the drain-source capacitance of Q1, so the higher the optical output, the more likely it is that unwanted optical output is generated. The second and subsequent optical output can cause false positives, so it is important to suppress vibrations while the current flows back. For this reason, R_D is connected in series with the D_p to suppress the vibration, and when the C_r charge is removed, it is recharged again through I_1.

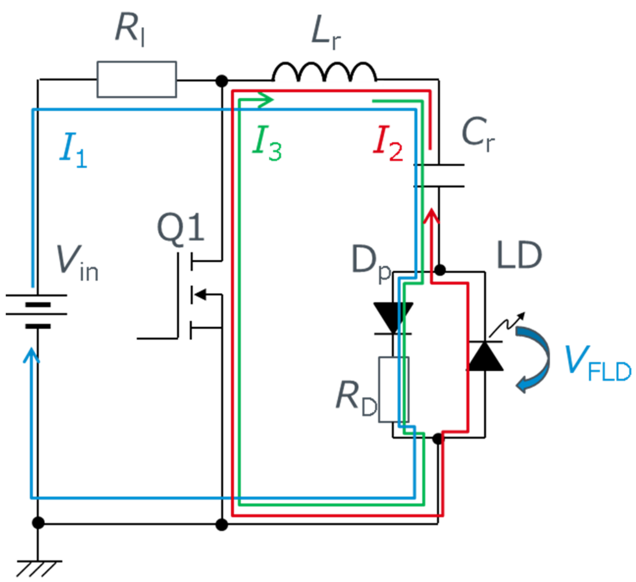


Fig. 3-1. Current resonance circuit diagram.

Because the current path of the I_2 shown in Fig. 3-1 is a free oscillation circuit of LCR, the current can be defined by the following equation.

$$I_2 = \frac{V_{in}}{\gamma L_r} e^{-\alpha t} \sin(\gamma t) \quad \cdots (3\text{-}1)$$

Here.

$$\alpha = \frac{R}{2L_r} \quad \cdots (3\text{-}2)$$

$$\gamma = \frac{\sqrt{\left(\frac{4L_r}{C_r}\right) - R^2}}{2L_r} \quad \cdots (3\text{-}3)$$

and R is the sum of the on-resistance of Q1, the resistance component (V_{FLD}/I_2) due to the forward drop voltage V_{FLD} of LD, the ESR of C_r, and the wiring resistance of the main current path. V_{in} is the input voltage and L_r is the parasitic inductance of the current path of I_2.

Here, Q1 is assumed to be an ideal switch.

From equation (3-1), the resonant period T_{res} is expressed by the following equation.

$$T_{res} = \frac{2\pi}{\gamma} \quad \cdots (3\text{-}4)$$

Since the maximum current I_{2max} is the current at 1/4 cycle from the beginning of the current flow, I_{2max} can be expressed by the equation (3-5). The larger this I_{2max}, the greater the optical output power can be.

$$I_{2max} = \frac{V_{in}}{\gamma L_r} e^{-\frac{\alpha T_{res}}{4}} \sin\left(\frac{\gamma T_{res}}{4}\right) \cdots (3\text{-}5)$$

The pulse width T_p can be expressed by the equation (3-6).

$$T_p = \frac{T_{res}}{3} = \frac{2\pi}{3\gamma} \quad \cdots (3\text{-}6)$$

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Using these equations, Fig. 3-2 shows the relationship between the T_p and I_{2max} for C_r and L_r. (Fig. 3-2 shows the results for V_{in}=80 V, R=0.3 Ω.) Fig. 3-2 shows that the T_p can be shortened by reducing the L_r, while improving the I_{2max}. Although the T_p can be shortened by reducing the C_r, the I_{2max} decreases at the same time, so that the selection of a suitable C_r value for the application is important.

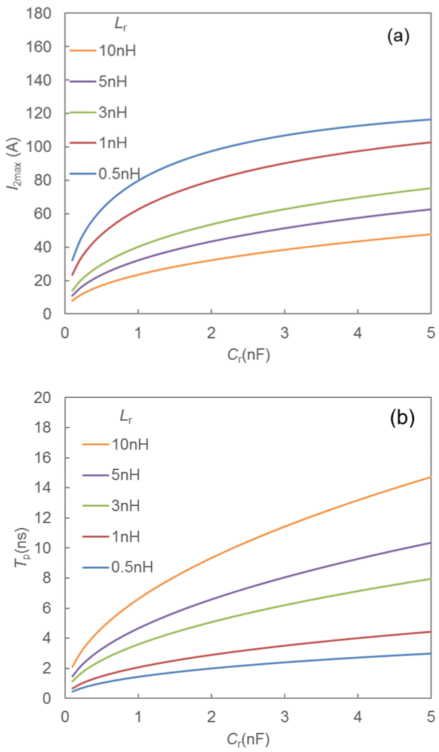

Fig. 3-2. Relationship between (a) maximum current I_{2max} and (b) pulse width T_p for resonant capacitor C_r and parasitic inductance L_r.

Impact of layout design

L_r value varies greatly depending on the circuit layout design, so care must be taken when designing. In general, the smaller the area of the closed loop in the current path, the smaller the inductance. Therefore, by reducing the area of the current loop of the I_2 shown Fig 3-1, the value of L_r can be reduced. To reduce the area of the current path loops, L_r can be reduced by forming loops in the thickness direction of the substrate rather than forming the loops in a planar shape. *2 In addition to the main current loop, it is also important to reduce the inductance L_g between the gate and source. If the L_g is large, the gate surge voltage becomes large and exceeds the breakdown voltage of the device, so it is important to design the gate-source loop as small as possible so that the L_g is as small as possible.

Effect of LD

As shown in Equation (3-1), it is important to select an element with a small V_{FLD} to increase the output power. Also, the higher the quantum efficiency of the device, the higher the output power can be when the same current is applied.

ROHM's datasheet shows the output power with a pulse width of 50 ns, but the optical output power varies depending on the pulse width. In general, the shorter the pulse width, the less affected by heat, and the more electrons that can contribute to optical coupling, the higher the optical output power tends to be. Therefore, the optical output power may be higher than the data sheet value when using a pulse width shorter than 50ns.

Selection of Resonant Capacitor C_r

Select a capacitor with as small ESR as possible to increase the optical output power from Equation (3-1).
If the capacitance of the capacitor varies according to the input voltage, the results become different from the circuit design conditions. For this reason, it is recommended to use a C0G ceramic capacitor with a small ESR and small capacitance variation.

About Drive Frequency, R_l and R_D

Note that the larger the drive frequency f_{sw}, the shorter the time required to charge the C_r.
If the time to charge the C_r voltage to 99% is defined as T_{charge}, T_{charge} is expressed as

$$T_{charge} = (R_l + R_D)C_r \ln\left(\frac{V_{in}}{V_{in} - 0.99V_{in}}\right) \cdots \text{(3-7)}$$

Where the time discharge until the capacitor is discharged is expressed as

$$T_{discharge} = \frac{T_{res}}{2} = \frac{\pi}{\gamma} \cdots \text{(3-8)}$$

Then R_l and R_D should be selected to meet equation below.

$$\frac{1}{f_{SW}} - T_{discharge} > T_{charge} \cdots \text{(3-9)}$$

Effect of SW element Q1

The package shape also affects the optical output characteristics. In the case of a transistor with a current loop on the front and back sides, the inductance of the main loop tends to be large because it needs to be wired. Therefore, inductance can be reduced by using transistor which pad located on one side only, and it is easier to achieve high optical output power and short pulse. *3 Turning off Q1 in the middle of resonance can make the T_p shorter, in that case, the lower capacity transistor can make turn off faster. Also, to make it difficult to emit unnecessary optical output, a lower-capacity transistor is required.

4. Evaluation Board (Resonant Wave Circuit)

ROHM offers a resonant current type evaluation board(Resonant wave B-01).A picture of the evaluation board is shown in Fig. 4-1.

The Resonant wave B-01 can be used to evaluate a 5.6Φ CAN package LD and can be installed without soldering. The pulse width and the maximum optical output power P_{peak} can be changed by changing the value of the capacitor C_r for resonance. The total inductance of this evaluation circuit is approximately 4 nH, including the CAN package. (However, the inductance may vary slightly depending on how well the CAN package is inserted, so be sure to insert the CAN package into the circuit firmly.) Please change the capacitance value of the C_r according to the optical output power and pulse width you want. This evaluation board can apply an input voltage of up to 120 V.

Fig. 4-1. Evaluation board Resonant wave B-01.

Actual measurement results

The model number of the measuring instrument used
Oscilloscope: DPO5204B (Tektronix)
Power Meter: S121C (THORLABS)
PD: DET025AL/M (THORLABS)
Function generator: 33250A (Agilent)

How to calculate peak output power

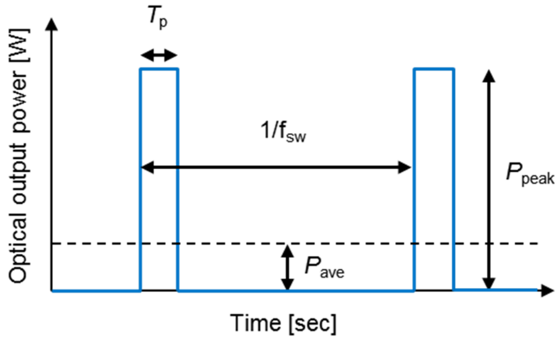

Fig. 4-2. Relationship between peak optical output power P_{peak} and average optical output power P_{ave}.

If we set the average optical output power obtained by the power meter be P_{ave}, as shown in Fig. 4-2, and the peak optical output power be P_{peak}, the equation of P_{peak} is below.

$$P_{peak} = \frac{P_{ave}}{f_{sw} \times T_p} \cdots (4\text{-}1)$$

Fig. 4-3 shows the waveforms of a 100 V V_{in}. The measurement sample is a 120 W ROHM product. This result shows that the T_p is 4.5 ns and the P_{peak} is 120 W. The P_{peak} relative to the V_{in} is shown in Fig. 4-4.

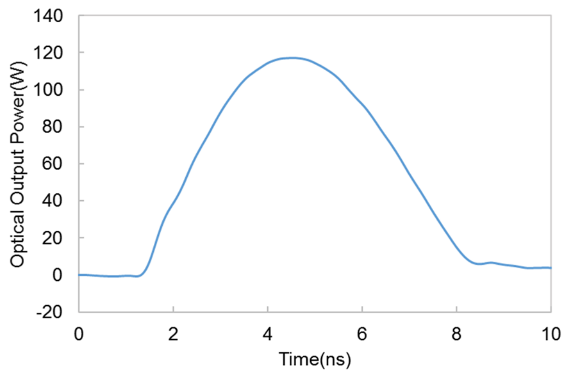

Fig. 4-3. Optical output waveform at 100 V input voltage.

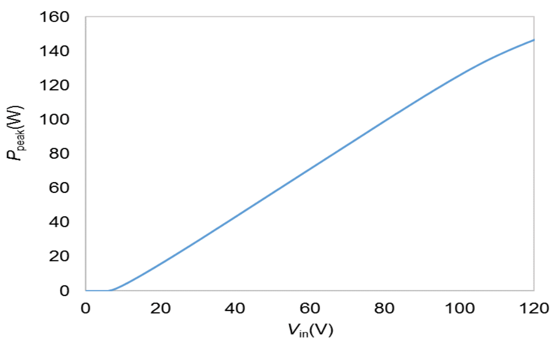

Fig. 4-4. Relationship between input voltage and maximum output power.

The current resonant drive circuit is characterized by short pulse widths and high output, but the current cannot be measured correctly because of the resonant waveform. When a shunt resistor is attached to the main current loop to sense the current, while the current is fluctuating, it is electromotive force because of the parasitic inductance of the shunt resistor itself. This is also true for the V_{FLD} measurement of LD. Due to the parasitic inductance of LDs, V_{FLD} cannot be measured correctly. Therefore, the actual measured waveform includes the effect of the electromotive force. In order to measure current and V_{FLD} correctly, it is important to measure in the range where the current does not fluctuate to avoid the influence of electromotive force due to shunt resistance and parasitic inductance of LD. Therefore, a circuit that outputs a square wave is necessary to accurately measure the current and V_{FLD}. In the area where the square wave current is constant, the electromotive component due to parasitic inductance becomes zero, so the current and V_{FLD} can be measured correctly.

5. Evaluation Board (Square Wave Circuit)

In order to measure the current and V_{FLD} correctly, ROHM also provides a square wave evaluation circuit (Square wave B-01).

A picture of the evaluation board is shown in Fig. 5-1.

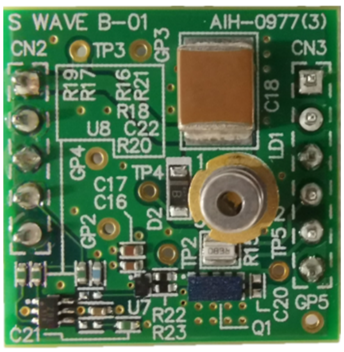

Fig. 5-1. Evaluation board Square wave B-01.

Actual measurement results

The model number of the measuring instrument used

Oscilloscope: DPO5204B (Tektronix)

Voltage probe (passive probe): TPP1000 (Tektronix)

Power Meter: S121C (THORLABS)

PD: DET025AL/M (THORLABS)

Function generator: 33250A (Agilent)

Fig. 5-2 shows the actual waveform at V_{in} of 50 V. The measurement sample is a 120 W ROHM product. This result shows that the T_p is about 50 ns and P_{peak} is 120 W. In addition, Fig. 5-2 shows that the measurement is not affected by parasitic inductance because the current and voltage are constant in some areas. (The surge voltage at the rising and falling edge is due to the parasitic inductance, as described above.) Fig. 5-3 shows the relationship between the optical output and V_{FLD} with respect to the current. This waveform was obtained with T_p of about 50 ns. If the T_p is longer, the optical output power may be lowered when compared with the same output current due to heat generation. In addition, the way of heat generation changes depending on the drive frequency and heat dissipation environment, so compare under the same conditions when comparing elements.

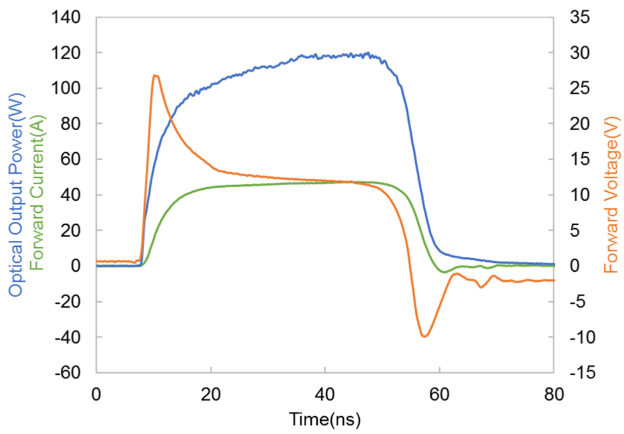

Fig. 5-2. Optical output waveform, forward current waveform and forward voltage waveform at 120 W optical output power.

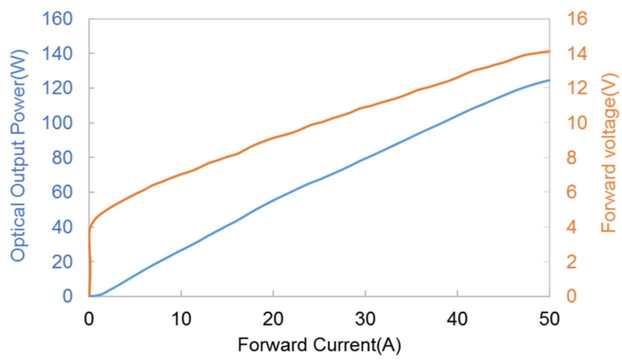

Fig. 5-3. Relationship between optical output power and forward voltage in relation to forward current.

In this circuit, as well as the resonant wave circuit, a diode is attached to the LDs for protection. If there is no diode for protection, a reverse surge voltage is generated in the LDs immediately after the circuit is turned off. Moreover, even after the reverse surge voltage, the voltage of the DC component continues to be applied to the LDs in the opposite direction, which may destroy the element. Attaching a protective diode makes it possible to control the reverse surge voltage and stabilize the voltage to almost 0 V even after the surge voltage is generated. For this reason, it is important to connect protective diodes in order to prevent the destruction of the LD elements, for details see Chapter 6, which compares the case with and without protective diodes using simulation.

6. Simulation Models and Demo Circuits

ROHM also provides the Spice Model to simplify the preliminary study.

Please refer to the following page for more information on how to use it and download the model.

https://www.rohm.co.jp/products/laser-diodes/high-power-lasers

ROHM's Spice model for LDs not only models the forward current, forward voltage drops, capacitance characteristics and leakage current characteristics, but also the optical output. This makes it possible to design circuits in a simulator and easily predict the optical output. (The optical output can be checked by using the OPT terminal of the optical output model. In this case, connect the GND terminal to GND. The optical output power unit is in V [volts] but multiply the output result by 1 A and convert it to W [watts].) However, this model is modeled on the assumption that the optical output waveform is the same as the forward current waveform, so if you want to make a more accurate calculation, please consider a different method.

Fig. 6-1 shows a comparison between the simulation results and the actual measurement results for each characteristic of ROHM's 120 W product. This result confirms that the simulation results are almost identical to the actual measurement results. The simulation results are shown in Fig. 6-2, using a demo circuit for the Resonant wave B-01 evaluation board. By using this circuit, we can confirm not only the optical output waveform but also the current that is difficult to measure in the resonant circuit because of inductance electromotive force.

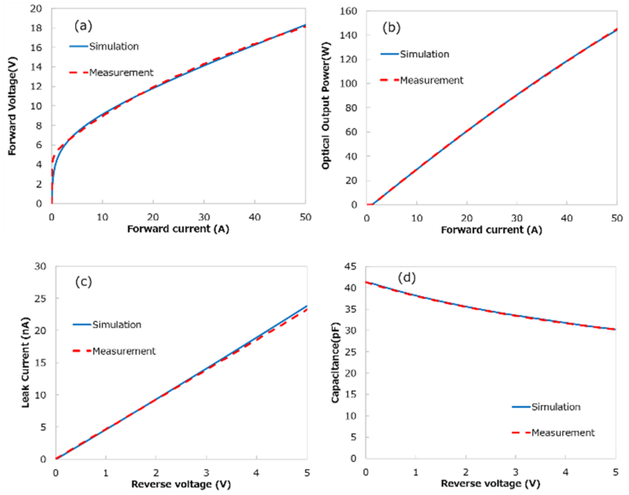

Fig. 6-1. Comparison of measured and simulated results (a) Forward voltage characteristics (b) Optical output characteristics (c) Leakage current characteristics (d) Capacitance characteristics.

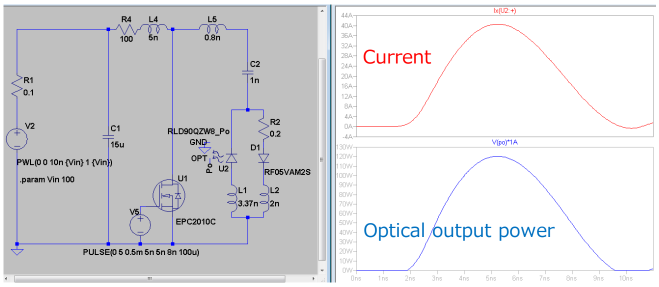

Fig. 6-2. Demo circuit for Resonant wave B-01.

About the demonstration circuit corresponding to Square wave B-01's circuit

Fig. 6-3 shows the simulation results of the voltage applied to the LDs with and without the protective diode. When we measure applied voltage of LD, the result includes the inductance components of LD, the actual voltage applied to the LD cannot be confirmed. In the simulation, the voltage directly applied to the LD elements is confirmed.

With the protection diode, as shown in Fig. 6-3, the voltage becomes close to zero immediately after switching. On the other hand, without the protection diode, the voltage is almost fixed at a negative voltage after switching. Under this simulation conditions, a voltage of about -20 V is applied, and the device is driven under conditions that continue to exceed the reverse voltage withstand voltage of -4 V. As a result, the possibility of element breakage will increase if a protective diode is not installed, so the installation of a protective diode is recommended.

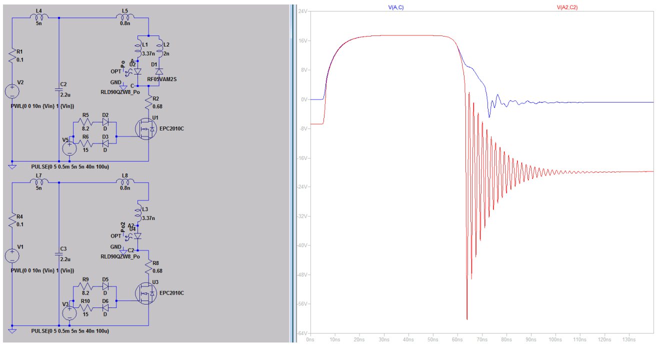

Fig. 6-3. Confirmation of the effect of the protection diode by Simulation.

7. References

*1 G. A. Howe, "Capabilities and performance of dual-wavelength Echidna® lidar," Journal of Applied Remote Sensing 9(1), 095979, Dec 2015

*2 Efficient Power Conversion Corp., “Optimizing PCB Layout,” 2019.

*3 J. Glaser, “High Power Nanosecond Pulse Laser Driver Using an GaN FET,” *PCIM Europe 2018 Proceedings*, 2

Notes

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