Measurement of the speed of light by laser pulse

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Introduction

Once upon a time, many scientists were trying to figure out the speed of light, such as Galileo's lanterns experiment in 1638, Fizeau's toothed wheel experiment in 1849, and Foucault's rotating mirror experiment in 1862…etc. However, the speed of light is too fast to measure in a short distance. Thanks to modern electronic technology, we can generate a short laser pulse to measure the speed of light in short distance. We hope that we can measure the speed of light as precise as possible.

Set up & Experimental details

There are two parts in our experiment, diode laser and photo detector which is connected with oscilloscope (Fig.1) . The driving circuit generate a current pulse to make laser emitting laser pulse. Detector receive the laser pulse. When we change the distance between reference point and detector , the time delay will change. Once we know the distance difference and time difference, we can calculate the speed of light.

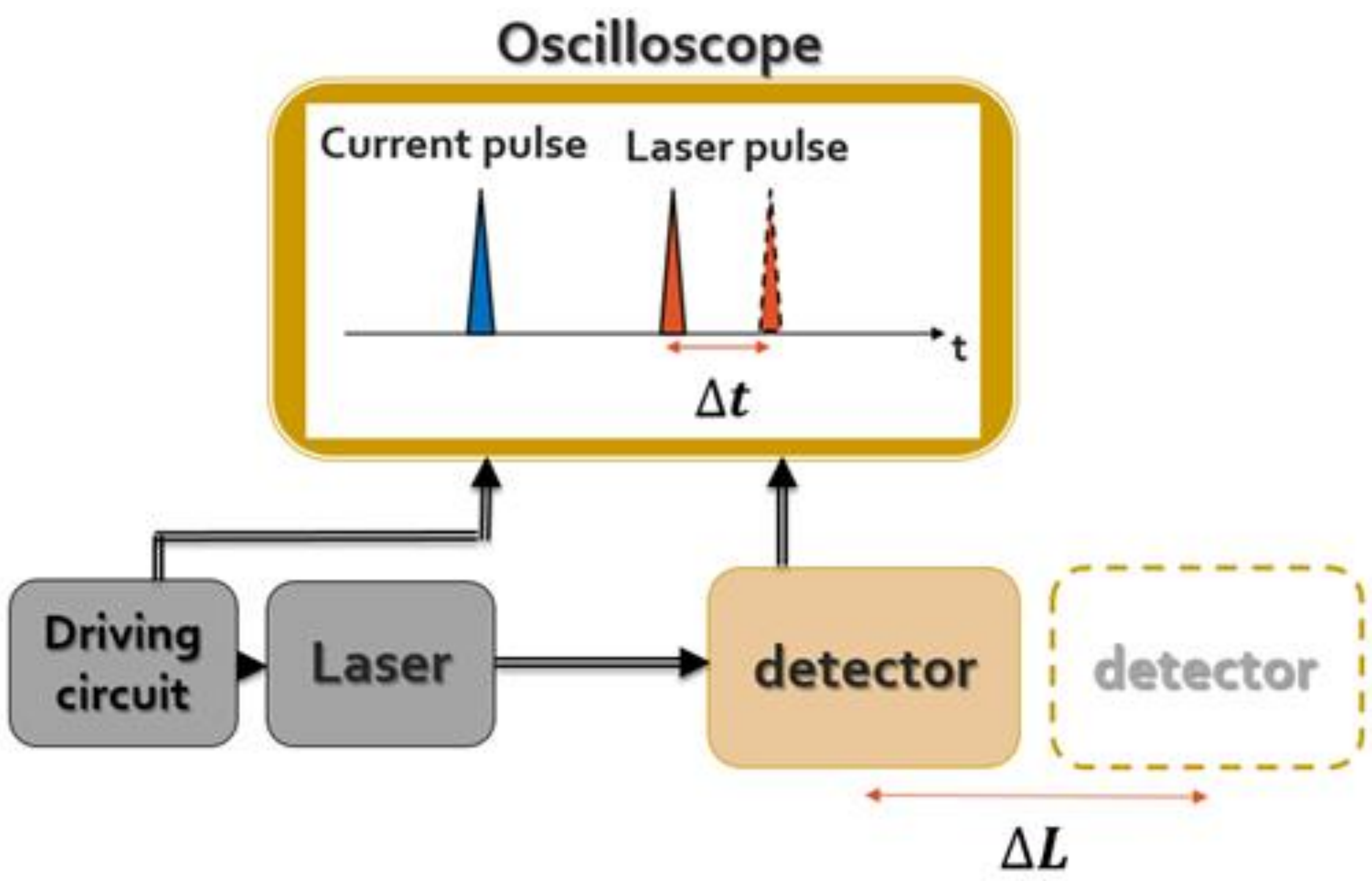

Fig.1 : Diagram of experiment set up

We switch the gain of avalanche pulse generator[1] generating a short current pulse[2] to generate a laser pulse. In this driving circuit, the avalanche of 2N3904 makes this circuit generate a short current pulse.

The detector circuit is made of a Low-pass filter and a photodiode. Owning to increase the response time of photodiode for nanosecond laser pulse, it is necessary to apply reverse bias on the photodiode to reduce its junction capacitance.

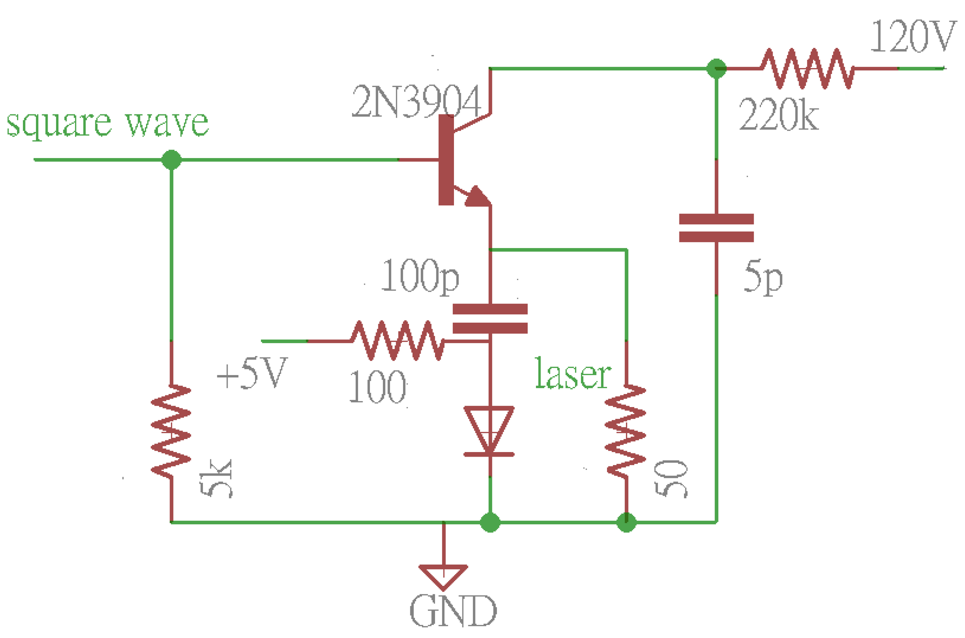

Fig.2 : The laser driving circuit (Avalanche pulse generator)

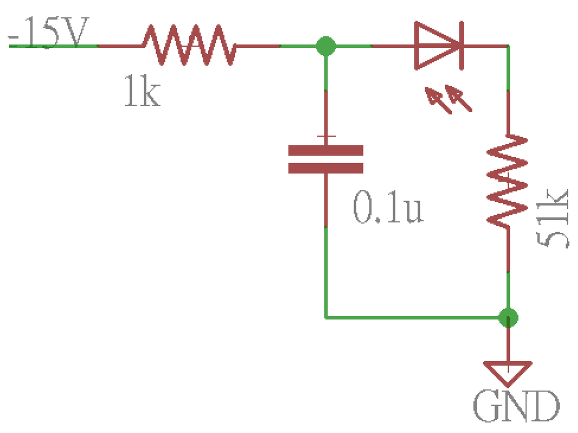

Fig.3 : Detector circuit (photodiode with reverse bias)

We set a reference point on the optical table and use block gauges to change the distance between detector and laser. On the oscilloscope, we can observe two signals which have time delay. One signal comes from laser circuit and the other is from detector. We get the different time difference by moving the detector. Also, we record the time and distance difference data of each position to calculate the speed of light.

Fig. 5 : laser diode

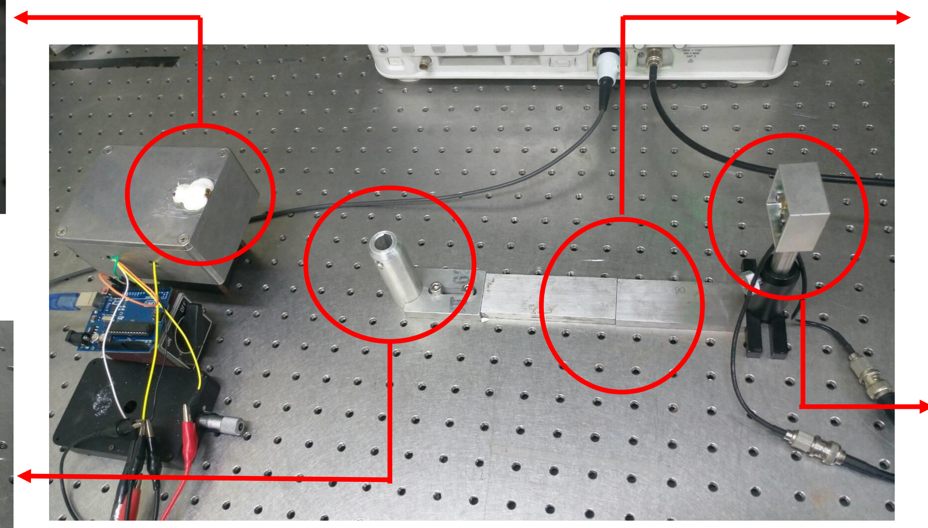

Fig.4 : The experimental set up

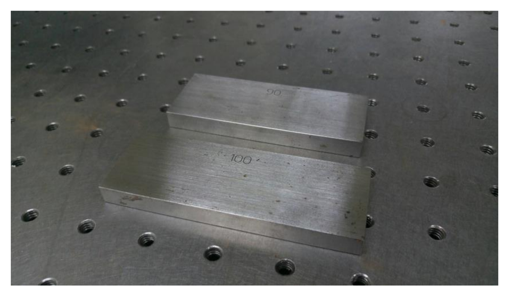

Fig. 6 : block gauge (size : 90 mm and 100mm)

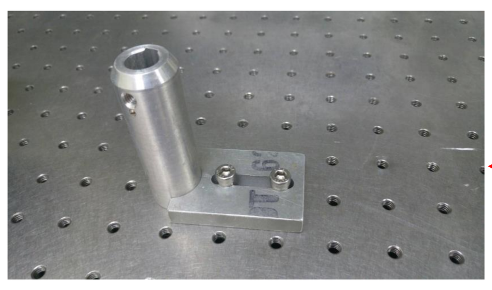

Fig. 7 : reference point

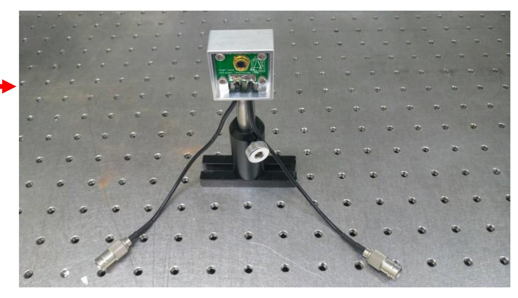

Fig. 8: detector (photodiode)

Result & Discussion

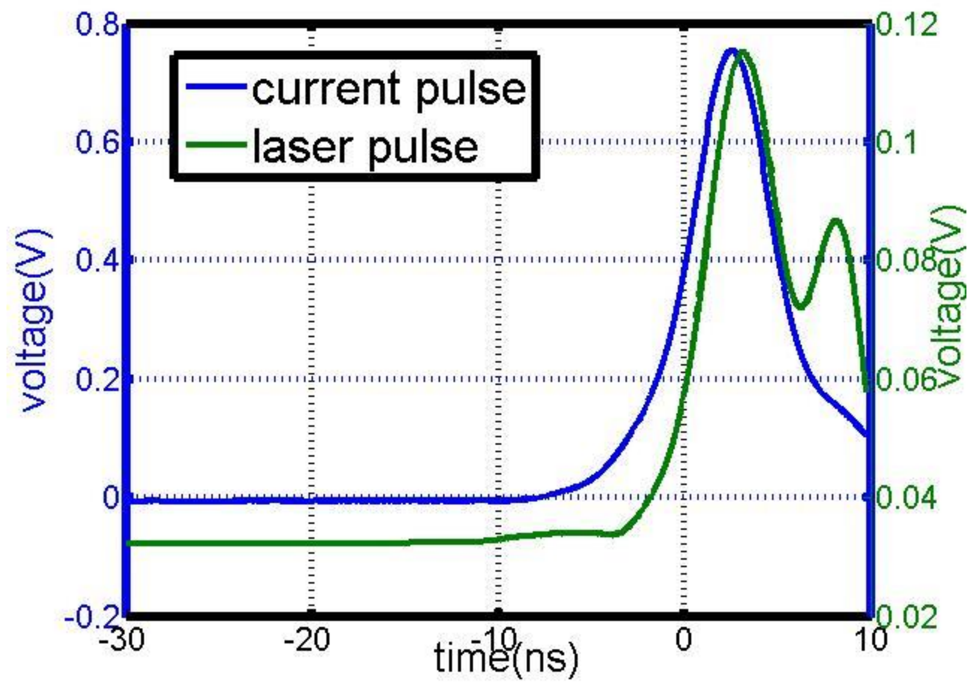

Fig. 9 : Comparison of two signals' time difference (the current pulse has 10X attenuation and laser pulse is reversed. This waveform is be averaged 128 times)

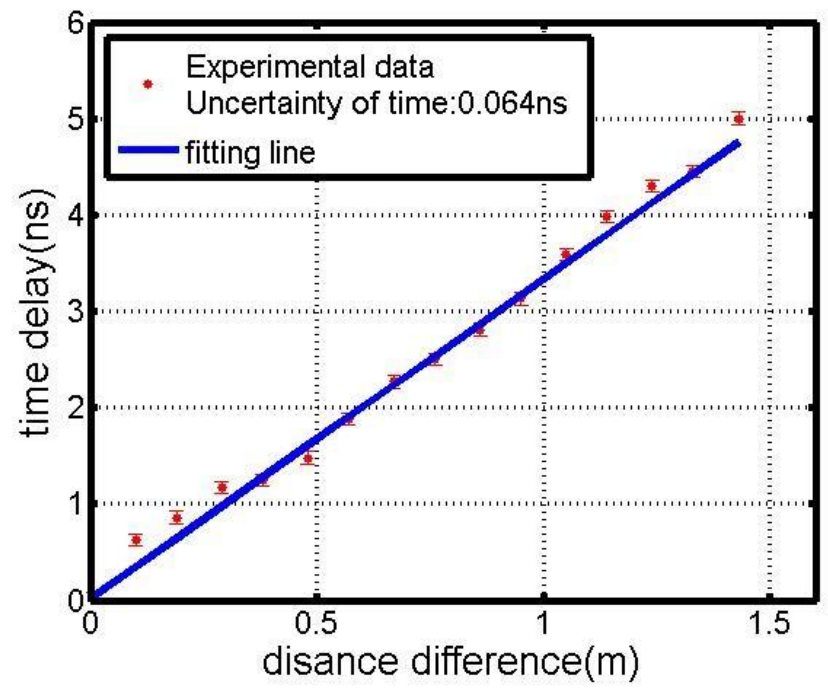

Fig. 10 : The experimental data and fitting line ($t = (3.288 \pm 6.64 \times 10^{-2})x + 0.0112$) (the sampling of the oscilloscope lead to the uncertainty of the time delay.)

The rise time of current and laser pulse are about $5\,ns$ (Fig. 9), this benefits the determination of timing. Once if the oscilloscope has sampling error of the waveform, the fast rising edge will reduce the error of time. From our result (Fig. 10), we can see that the time delay is linear relation with the distance difference. The inverse of its slope is the speed of light that we measured is about :

$$\boldsymbol{v} = (\mathbf{3.004} \pm \mathbf{0.006}) \times \mathbf{10^8} \text{ m/s}$$

(The distance difference is three significant digits and we use the oscilloscope(DSO-X 2022A) of 2GSa/s, that means the time delay is three significant digits. Thus, the speed of light is also three significant digits.)
Because the uncertainty of the time delay (σ_t) and speed (σ_c) is positive correlation, we can calculate and obtain the uncertainty of the speed by :

$$\sigma_c{}^2 = \frac{\sigma_t{}^2}{(b^4)N\langle(x_i - \bar{x})^2\rangle}$$

(where b is the slope in Fig.10, and $N = 20$ means that we measure 20 times on one point)
The speed of light in air is (the refractive index of the air is about n=1.000277) :

$$\boldsymbol{c} = \mathbf{2.997} \times \mathbf{10^8} \text{ m/s (to three significant digits)}$$

1. The time difference varies slightly when we measured at one point. It is the main error for our experiment.
2. The propagation direction of laser beam is not parallel to optical table, so the distance difference error caused from the tilted laser beam.

Conclusion

1. The project teach us that we can measure the speed of light by short laser pulse circuit (rising time is about $5\,ns$) in short distance (within 1.5 m). Finally, The speed of light that we measurement is $(3.004 \pm 0.006) \times 10^8$ m/s.
2. The scale of distance and time are so small that the numbers of the significant digits are only three in our experiment and let our measurement be not precise. However, it is possible to solve this problem by using time-pulse-height circuit, so the random error can be reduced by average.

Reference

[1] https://www.rp-photonics.com/gain_switching.html

[2] https://www.elexp.com/Images/Speed_of_light_with_650nm_diode_laser.pdf