Experiments in Fluids 5, 141 – 144 (1987)

Experiments in Fluids

A pulsed light generator for high speed photography

W. Hiller, H.-M. Lent, G. E. A. Meier and **B. Stasicki**

Max-Planck-Institut für Strömungsforschung, Bunsenstr. 10, D-3400 Göttingen, F.R.G.

Abstract. A pulsed light generator for stroboscopic photography which makes use of LED's has been developed. The maximum light power which may be extracted from a single LED is approximately 1 Watt. The pulse repetition rate ranges up to 1 MHz and the length of the pulses is adjustable between 0.05 and 1 μs. The light emitted from the diodes is especially suited for the observation of phase objects by interferometric methods due to its pronounced coherence. Results of the electrical and optical performance of the generator are presented.

1 Introduction

Pulsed light sources are an effective tool for the visualization of transient states. Encouraged by the outstanding performance of an LED-stroboscope developed by Stasicki et al. (1984), it was decided to use LED-diodes for the generation of high intensity pulses suitable for photography.

In contrast to visual stroboscopic methods where the intensity of single flashes may be very weak, as periodic processes are observed, one also requires for a real time visualization a flash strong enough to adequately illuminate a frame of photographic film. From this requirement it becomes obvious that the maximum number of light pulses within a single series must depend on both the pulse frequency and the ratio between the power dissipation in the pulse mode and the permissible c.w. power dissipation of the LED's used.

2 Light source

2.1 General remarks

Among the various LED's which have been tested, the type USBR 5501 made by Stanley (Japan) seemed the best suited for our purposes. This LED gives a light output of nearly 5 mW at 50 mA d.c. The maximum c.w. power dissipation is 145 mW. The wave length of emission is 660 nm with a spectral width of 27 nm. The housing of the diode is equipped with an integrated lens which reduces the aperture of the light beam to approximately 10°. If the object to be illuminated is easily accessible one may install the diode without any additional optics. For many applications, however, it is better to couple the light from the diode by an optic fibre. Although one looses about 50% of the light power, other problems like matching the impedance of the diode to that of the power amplifier and forced cooling are more easily solved in this way. Moreover, by using optic fibres, objects become more uniformly illuminated and small light sources consisting of a bundle of fibres, each of which is connected to a diode, may be employed. In this case, the integrated lens is removed and a plastic fibre (core diameter ~1.5 mm) is attached in front of the light emitting chip by an epoxy resin. A very compact configuration is obtained if seven diodes are employed. A typical plot of the intensity distribution is displayed in Fig. 1.

Before discussing in detail the pulse mode operation of the diode, one should say something about the light power requirements. For the illumination of a single frame of a 16 mm film of type Kodak 2496 which is especially suited for our purpose, one needs roughly 0.05 μWs at an expo-

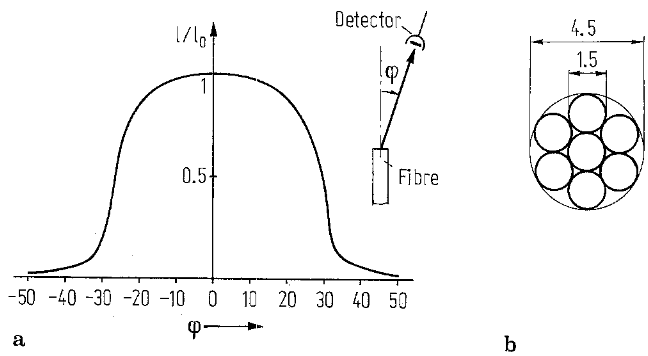

Fig. 1 a. Distribution of the azimuthal light intensity I/I_0 from a plastic monofibre coupled to an LED. Fibre length 1 m, core diameter ~1.5 mm. **b.** Assembly of 7 fibres to form a compact light source sure time of 0.5 µs. As only part of the light produced by the diode will arrive at the frame due to losses by beam forming and imaging processes, a factor of 5, which accounts for these losses in the case of a Mach-Zehnder-interferometer, will be used. Thus pulses of 0.5 Watt are required; this is about 100 times the c.w. power output of a single LED equipped with an optic fibre. From these considerations it also becomes clear that the light power requirements for the observation of large diffusively reflecting objects, where the loss factor may be some orders magnitude larger cannot be met.

2.2 *Pulse mode operation*

Pulses of constant voltage or of constant current are the two limiting cases for diode operation. As the resistance of the diode decreases with rising temperature, constant pulse voltage operation has the drawback that at low voltages the diode current will be very small, whereas at high voltages the diode is easily destroyed by a single pulse, since the current goes up to extremely high values. A second disadvantage of constant voltage operation is given when a series of high voltage pulses is generated and the diode may not return into its initial thermal state before the next pulse is released. Then, the temperature rises with each pulse until a new thermal equilibrium state is reached. During this time the intensity of single light pulses will also change, so that in many cases the illumination of the first frames within a series is very low. This behaviour which is discussed in detail by Hiller et al. (1985) is very pronounced if the diode is cooled with liquid nitrogen.

If, on the other hand, the diode is operated in the constant current pulse mode, the voltage drop across the diode will decrease within a single pulse and also within a series of pulses (as long as steady state is not reached). This means that the power dissipation will go down, too. Therefore, this type of operation is much less sensitive with regard to the adjustment of current pulse height. As the light output is roughly proportional to the pulse current and does not depend very sensitively on diode temperature, light pulses which are sufficiently constant for frame illumination are produced. Figure 2 is a typical plot of the dependence of the light output N_λ, the diode resistance R, and the mean voltage drop across the diode due on the current pulse height I_D, given for two different ambient temperatures. The pulse repetition frequency used in Fig. 2 is so low that the diode returns to its initial thermal state after each pulse. The light has been coupled from the diode by a plastic fibre of 1 m length and 1.5 mm in diameter. For pulse currents higher than those shown in Fig. 2, the light output increases further, then stays constant, and, for very high pulses, decreases again. The parametric values where this will occur differ from diode to diode. Nevertheless, from our own experience, pulse currents higher than 10 amps should be avoided. By cooling the diode with liquid nitrogen, the output light, but also the power dissipation, may be increased. For a pulse duration of 250 ns and pulse repetition rates up to 1 kHz, a light power of 1 Watt (for the fibre optic device) may be obtained.

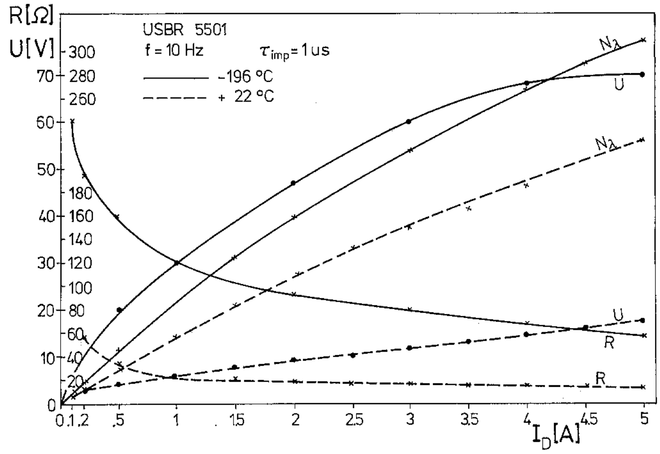

Fig. 2. Dependence of light output N_λ, diode resistance R, and voltage drop U across the diode on pulse current height I_D at two different temperatures. Pulse duration τ_{imp} is 1 µs

3 Setting of the pulse current

If a series of light pulses of given number, strength, and repetition frequency is to be generated, one has to take care that the LED is not destroyed by the dissipated power. A simple means for experimentally finding the limiting value of the current, is to measure the threshold voltage U_s of the diode. The necessary electric circuitry and the dependence of U_s on diode temperature for type USBR 5501 LED's are given in Fig. 3. As long as the diode does not undergo an irreversible degradation the threshold voltage will recover its initial value, when the diode is at its previous thermal state. Degradation is observed when the threshold voltage – while a current pulse is applied – reaches $U=0$. Therefore, one starts with moderate pulse currents and observes U, which becomes measurable about 100 ns after the end of a pulse. The U is extrapolated to the end of the current pulse. In order to be on the safe side, one generally adjusts the pulse current so that U does not fall below 0.4 V. When this limiting current is determined, the light power output is measured and the number of LED's necessary for a given requirement is estimated. When the illumination becomes insufficient it is best to employ current pulses as broad as possible, since the efficiency of the light output decreases with shorter flashes at fixed illumination.

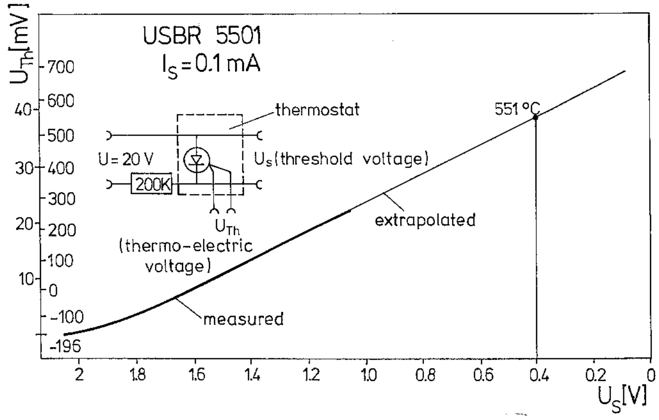

Fig. 3. Dependence of the threshold voltage U_s on diode temperature T_D for the diode USBR 5501. Threshold current 0.1 mA

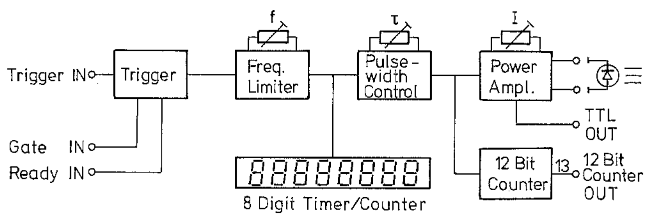

Fig. 4. Schematic diagram of the control unit

4 Control unit

The control unit, a schematic diagram of which is shown in Fig. 4, supplies the LED's with current pulses. Pulse height I_D and pulse width τ are adjustable in the range of $0 \leqq I_D \leqq 10$ A, and $0.05 \leqq \tau \leqq 1$ µs, respectively. Pulse voltage may, in the ranges, become as large as 200 V. The maximum repetition rate is 1 MHz. The control unit is triggered externally by a TTL input. The trigger stage is also equipped with a TTL gate, which may be set externally. The trigger pulses will pass only in the event that the gate is high. Moreover the trigger stage is equipped with a double synchronizing facility, which enables only the first trigger pulse, following an external ready signal, to release a current pulse. The trigger stage is followed by an adjustable frequency limiter as a protective circuit against an undesired high frequency trigger pulse series, which may destroy the LED's. After this stage the signals branch into an 8 digit counter where pulse repetition frequency, pulse repetition period, or pulse number is measured, and into the pulse length control. After the pulse length is controlled, the pulses branch once more into a 12 bit counter and into the power stage. The counter drives 12 LED's which display the state of the counter in a binary code. These diodes which are synchronous with the main flash light source driven by the power stage, may be imaged onto the film. This device serves as a flash enumerating system. The power stage employs V-MOS technique. For the shortest flash times it is advisable to connect the LED's directly to the output transistor. At room temperature approximately 18 V are needed to produce a current of 5 A. In this case 20 LED's can be driven synchronously. If the LED's are cooled with liquid nitrogen this number is reduced to 6. The power stage is equipped with a TTL output by which the width of the current pulses may be monitored.

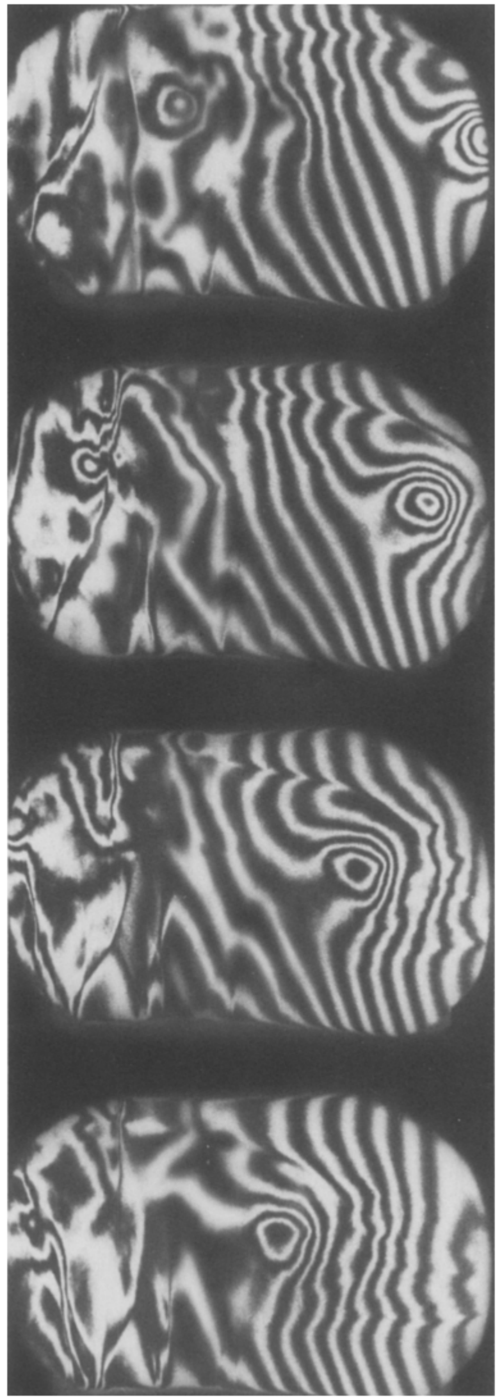

Fig. 5. Four subsequent interferograms of a Karman vortex street generated in a Laval nozzle flow. Time between frames 10^{-4} s, exposure time 1 µs, light source one USBR 5501 coupled to a monofibre. Flow direction from right to left

5 Examples of application

A proto-type of this light generator together with a drum camera has been used for the investigation of unsteady flow by means of a Mach-Zehnder-interferometer. The width of the flashes was 1 μs at a light power output of 250 mW. Pulse repetition frequency was 10 kHz; a single series consisted of about 200 frames. Film used was Kodak 2496. The size of a single frame is about 10.5×8 mm^2. For a light source one LED of type USBR 5501 coupled to a fibre was used. Figure 5 shows a series of 4 interferograms of the flow.

In many cases the evaluation of interferograms is performed by a computer. For this purpose the frames are fed into the computer via a TV camera. For single shots the interferograms may be directly imaged on the anode of the TV camera. As the sensitivity of the photoanode is much higher, even one LED OSBR 5501 at reduced current provides sufficient illumination.

References

Hiller, W. J.; Lent, H.-M.; Meier, G. E. A.; Stasicki, B. 1985: Ein schneller Lichtpulsgenerator hoher Leistung. Bericht 18/1985. Göttingen: Max-Planck-Institut für Strömungsforschung

Stasicki, B.; Hiller, W. J.; Meier, G. E. A. 1984: Hochfrequenz-Stroboskop mit LED-Lichtquelle. Tech. Messen 51, 217–220

Stasicki, B. 1984: Hochfrequenz-Stroboskop 839. Bericht 102/1984. Göttingen: Max-Planck-Institut für Strömungsforschung

Received April 18, 1986