Random Testing Reveals Excessive Power in Commercial Laser Pointers

Joshua Hadler,[1] Edna Tobares,[2] and Marla Dowell[1]

[1] *Quantum Electronics and Photonics Division, NIST, Boulder, CO 80305*
[2] *Office of Safety, Health and Environment, NIST, Gaithersburg, MD 20899*

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In random testing of 122 commercial laser pointers, we observed that 89.7 % of green pointers and 44.4 % of red pointers were not in compliance with the Code of Federal Regulations, producing laser power in excess of the limits allowed for within the CFR at one or more laser wavelengths. The measurement results are presented. In addition, we briefly describe an inexpensive test bed as well as physical mechanisms that could account for hazardous levels of laser pointer emissions.

Key words: Laser pointer, laser power, laser safety

I. INTRODUCTION

Recent manufacturing advances of solid-state diode lasers have led to brighter, cheaper handheld lasers. Demonstration lasers, also known as laser pointers, while once prohibitively expensive, are now commonplace at conferences, trade shows, and classrooms wielded by individuals unfamiliar with laser hazards. In 2010, as part of an expansion of the laser safety program at NIST, an effort was made to establish a compliance program for the use of laser pointers. This paper documents a study of laser power output as a function of wavelength for 122 randomly-sourced commercial laser pointers that were labeled as Class 3R and sold for demonstration purposes. The power measurements were made with an inexpensive measurement system capable of quick and accurate assessment of laser power. A review of the output characteristics of common laser pointers is presented for discussion.

II. LASER POINTERS, LASER CLASSIFICATION, AND THE CODE OF FEDERAL REGULATIONS

It is important to distinguish laser pointers for demonstration use from more powerful handheld Class 3B and Class 4 lasers.[1] While all of these products are commercially available, the emission from demonstration lasers is specifically regulated under the Code of Federal Regulations (CFR)[2,3] to not exceed the Class IIIa limit[1] of 5 mW maximum emission in the visible portion of the spectrum (400 nm to 700 nm wavelength); the CFR allows no infrared (IR) emission in demonstration lasers, so all IR emissions must remain below the Class 1 Accessible Emission Limit (AEL). For the purposes of this discussion, Class IIIa as used in the CFR, and Class 3R as used in commercial products complying with the ANSI standard[1] can be considered comparable. At 1064 nm, the Class 1 AEL is 1.92 mW. Class 3R visible lasers are considered a potential hazard only under extended or fixated viewing conditions.[1] For this laser classification, the human aversion response can still be relied upon to protect against potential injury. However, Class 3B and/or Class 4 lasers are capable of inducing injury from even momentary exposure (< 0.25 s).[1] In fact, the American Standard for the Safe Use of Lasers (ANSI Z136.1-2007) calls for the use of protective eyewear, designated laser control areas, laser hazard signage, as well as laser safety training for all Class 3B and Class 4 lasers, thereby prohibiting the use of these products for demonstration purposes by untrained users[1,4]. Confusion among consumers arises as Class 3B and Class 4 handheld laser products are often produced in an identical (or similar) structure as demonstration laser pointers and are sometimes advertised as ‘astronomy or military grade laser pointers.’ However, we emphasize that all the lasers tested in this study were specifically purchased as Class 3R devices.

III. EXPERIMENTAL DESIGN

To accurately and affordably characterize the output of these devices, we developed a measurement system[5] to quantify the emitted power in both visible and IR wavelengths for common red and green laser pointers. In addition to testing a large number of laser pointers from various NIST organizational units, we sourced laser pointers from multiple vendors identified in an internet search. All of the laser pointers tested were purchased as Class 3R handheld devices suitable for demonstration purposes.

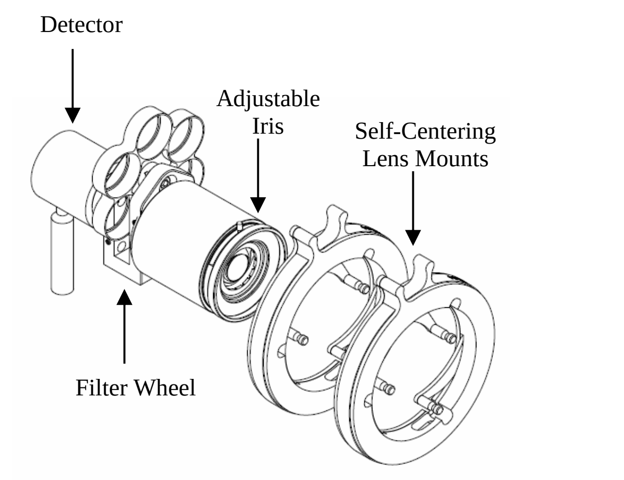

Figure 1. Schematic of test bed.. Filters and detector were calibrated at NIST.

A. Measurement System

The measurement system was designed to test red laser pointers and diode-pumped solid state (DPSS) green laser pointers. The system consisted of a commercial thermopile laser power meter and two bandpass optical filters. The purpose of the bandpass filters was to quantify the discrete emission contributions of the 808 nm pump wavelength and the 1064 nm fundamental wavelength of DPSS green lasers separately from the visible emission contributions. An adjustable aperture was used to contain the laser light around the output end of the handheld laser. Self-centering lens holders were used to ensure repeatable laser alignment. Both the power meter and bandpass filters were calibrated at NIST.[5,6] The expanded uncertainty of power measurements with this system was no greater than ± 5 %.[7] A schematic representation of the measurement system is shown in Figure 1. A more detailed description of the instrument design and calibration is published in Measurement Science and Technology[7].

B. Handheld Laser Device Measurements

After positioning a bandpass filter in front of the device, the laser was energized for 20 seconds. The filtered output power of the laser was recorded as the maximum value displayed on the power meter. This measurement was repeated for the second bandpass filter and, finally, for the full un-filtered beam. Each reading was corrected for the calibrated responsivity of the power meter at the corresponding power level; readings from measurements with the bandpass filters were corrected for the transmission of the bandpass filter. The corrected power output for the 532 nm laser line was then calculated by subtracting the sum of the IR components from the corrected value of the unfiltered measurement. For single-wavelength red laser pointers, only the power measured from the unfiltered beam was recorded. The measurement process is described in detail in Reference 7.

TABLE I Percentage of handheld demonstration lasers (also known as laser pointers) that exceeded the power emission limits of their product labels at one or more emission wavelengths. (*Note: Red laser pointers emit at a single wavelength).

Type of Laser Pointer	one wavelength	two wavelengths	three wavelengths	Total
Green	23.5 %	41.2 %	25.0 %	89.7 %
Red*	44.4 %	N/A	N/A	44.4 %

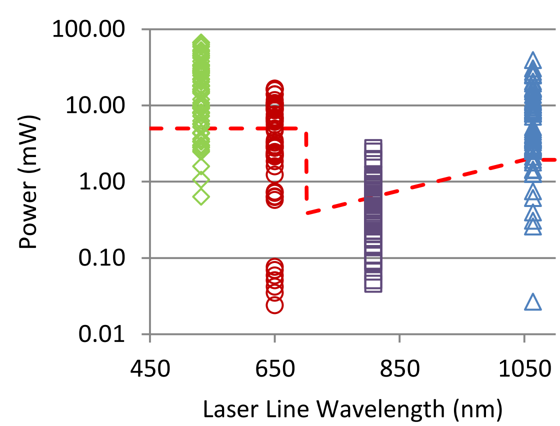

FIG 2: Measured spectral power distribution from 68 green handheld lasers (λ = 532, 808, and 1064 nm) and 54 red handheld lasers (λ ≅ 650 nm). The red dashed line corresponds to the AEL for demonstration lasers. Class IIIa for the visible wavelengths, and Class 1 for the IR wavelengths. All data points above the red dashed line correspond to devices that were incorrectly labeled as Class 3R or Class IIIa visible devices; these devices should not be used for demonstration purposes.

IV. RESULTS AND DISCUSSION

In total, we measured the output power of 122 devices that were labeled as Class 3R lasers and sold as laser pointers for demonstration purposes. Only 10.3 % of 68 green laser pointers were correctly labeled as Class 3R devices; 55.6 % of the 54 red laser pointers were correctly labeled as Class 3R devices. Of the devices tested, 52.4% exceeded the legal limit by at least a factor of 2 at one or more wavelengths. The highest measured power output was 66.5 mW. The results are summarized in Table I. The measured power distributions are shown in Figure 2:

We present a simplified view of laser pointer construction to explain the high incidence rate of mislabeled laser pointers.

A. Green Laser Pointer Construction

Green laser pointers are popular because they emit laser light very near the peak visual response of the human eye, such that even relatively low power levels can appear very bright. Most handheld green laser devices are based on DPSS technology, where an 808 nm pump laser diode is used to generate a 1064 nm fundamental in an Nd:YVO_4 or Nd:YAG crystal. The 1064 nm emission then propagates through a potassium titanyl phosphate (KTP) crystal to generate a second harmonic at 532 nm. The combined beams — 808 nm, 1064 nm and 532 nm — are then collimated by the lens of the laser. In an optimal design, proper alignment and materials selection will reduce the emission of the IR components to a minimum with an IR blocking filter placed at the output of the device to prevent any excessive IR emission. Based on the measured results, we hypothesize that many of the devices tested either used ineffective IR filters or none at all.

Proper alignment and quality materials are needed to generate efficient emission at the 532 nm laser line. Optimal pumping at 808 nm will generate the 1064 nm laser line using $Nd:YVO_4$ with a 60 % efficiency. Nonlinear harmonic generation through a KTP crystal typically has a maximum efficiency of 70 %. The combined maximum conversion efficiency from 808 nm pump light to 532 nm emission is approximately 42 %. Within a DPSS laser designed to emit 5 mW at 532 nm, the total optical power from the pump, fundamental and harmonic can be well over 20 mW. Sub-optimal construction methods in large scale manufacturing facilities, coupled with quality control limitations, may result in less efficient devices. As a result, sub-optimal devices would require even more optical power at the pump and fundamental wavelengths to generate 5 mW at 532 nm.

In Figure 3, the calculated power required at pump, fundamental and harmonic wavelengths is shown for optimal and sub-optimal device construction. Here we can see the effect that possible reductions in the total efficiency of the optical system of the DPSS laser generating a 5 mW 532 nm laser line can result in dramatically increased amounts of total optical power within the laser. Most notably, the 808 nm and 1064 nm laser lines are potentially

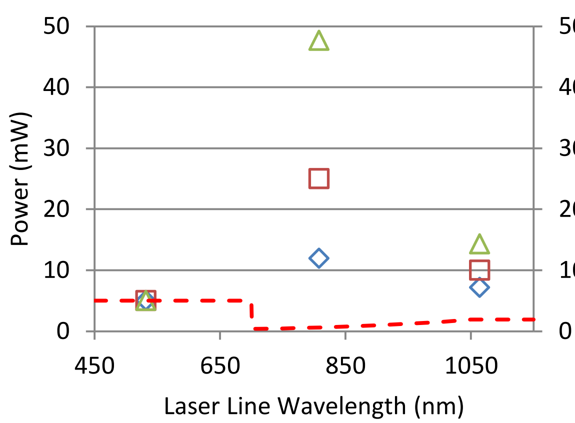

FIG 3: Calculated power required as a function of wavelength for hypothetical DPSS laser systems that result in 5 mW of laser power at the 532 nm laser line. The red dashed line corresponds to the maximum allowable emissions for laser pointers under the CFR. The blue diamonds correspond to laser power required to generate 5 mW at 532 nm of an optimized device exhibiting maximum conversion efficiency of infrared to visible light. The red squares (green triangles) correspond to sub-optimal devices with 20 % (30 %) reduction in maximum conversion efficiency.

more than 10 times in excess of the Class 1 AEL for the IR laser lines. Without adequate IR filtering, these IR wavelengths may propagate along with the visible 532 nm wavelength, thereby significantly increasing the effective hazard of the laser device.

B. Red Handheld Laser Construction

Recent advances in manufacturing have introduced laser pointers that incorporate vertical-cavity surface-emitting laser (VCSEL) diodes. VCSELs are popular for use in red laser pointers because of their high efficiency for emission around 650 nm as well as their production reliability.[8] A sampling of red VCSEL Class 3R laser pointers has revealed CFR compliance failures similar to those that were observed with the green DPSS laser pointers, such that 44 % of 54 devices tested exceeded the 5 mW Class 3R limit for laser pointers. Nearly half of those failed devices did so in excess of twice the legal limit.

VI. CONCLUSION

We observed a significant non-compliance rate among the labeling of both green and red laser pointers. The power output from 90 % of the green laser pointers and 44 % of red lasers pointers exceeded the CFR limits for laser pointers. Of both red and green devices tested, 52 % exceeded the power emission limits for a laser pointer by a factor of 2 or more. Our results indicate that there is a high probability that handheld lasers labeled as Class 3R devices and intended for use as laser pointers are in fact Class 3B handheld lasers. A smaller study conducted by the Federal Office of Metrology in Switzerland (METAS) reported comparable results.[9]

Our results raise numerous safety questions regarding laser pointers and their use. Although the documented reports of retinal damage incurred from laser pointers are still relatively scarce, the possibility for a permanent life-altering injury, the prolific ease of access, and the lack of proper safety awareness in the general public highlights the potential hazard of these devices. There are already a few well-documented cases of retinal injury incurred from hand-held laser products.[10-12] Going forward, increasing power levels — including the availability of Class 3B and Class 4 hand held lasers, some sold as ‘astronomy grade laser pointers’ — coupled with decreasing costs (~$10 is typical) will likely increase the proliferation of these devices among the general public. Therefore, it is reasonable to expect that without additional public awareness regarding the safe use of handheld lasers, laser-related injuries are likely to increase.

Institutions interested in ensuring safe use of laser pointers within their organizations could build a test-bed capable of expanded uncertainties of 10 % or lower using commercially available components similar to those used in this paper[5]. An off-the-shelf measurement system – relying on commercial components traceable to the International System of Units in place of NIST calibration procedures[5,6,7] – would have identified 97 % of the noncompliant laser pointers found in this study.

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