LASER SAFETY
激光安全

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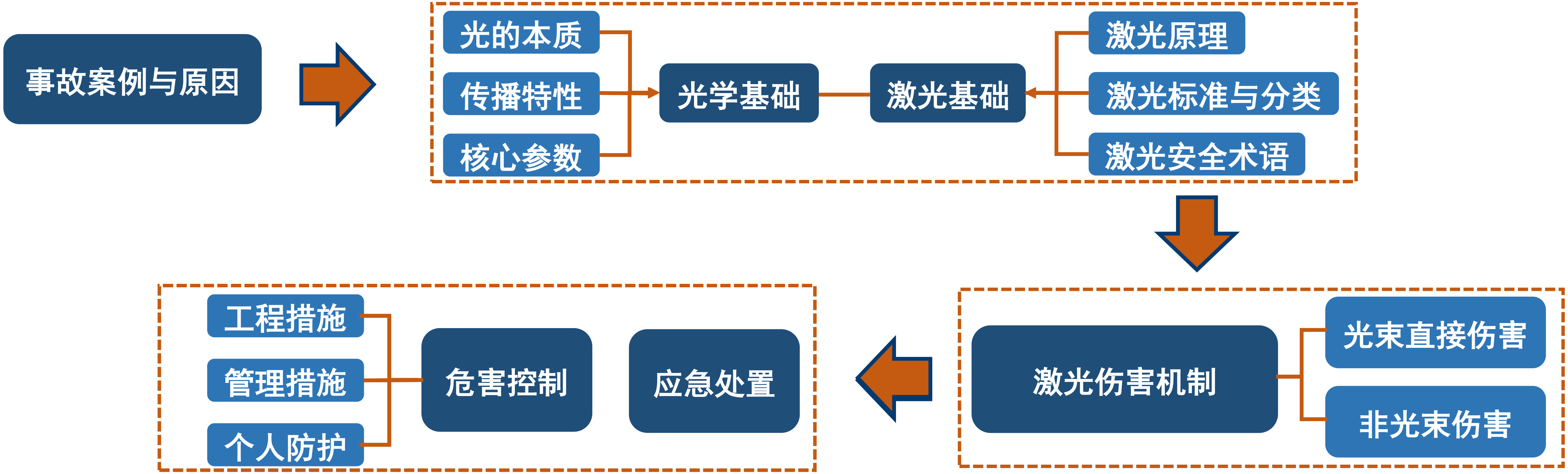
Course Structure
课程结构



Case Studies
事故案例

Laser Incident Description

On Thursday November 19, 2015, LANL postdoc received an eye injury from a reflected, non-visible laser beam (Class 4, pulsed, wavelength 800 nanometer). The setup is configured to split the laser output into two work areas in which qualified operators conduct research experiments. During this incident, the laser output beam was being projected to both experimental work areas, although only one experimental area was actively being used. The second laser beam directed to the second work area was blocked by an inappropriate device (Plexiglas, reflective, non-normal incidence) that reflected substantial portion of the beam toward the first setup. In preparation for the measurements, worker stepped on the stepstool and decided to remove the laser goggles to better see the micrometer readings which were difficult to see due to insufficient lighting. Immediately, he noticed a flash of light in his eye. The operator quickly replaced the laser eye-wear and then, using an infrared viewer, located a stray laser beam being reflected from the plexiglas beam block.

The operator did not think he had sustained any injury and continued working. Later that day, however, he noticed a blurry spot in the vision of his left eye. He notified his supervisor on Friday morning, November 20, 2015, and was taken by CINT management to Sandia National Laboratories (SNL) medical facility for evaluation. SNL Medical did not find any abnormalities, but referred the operator to a local ophthalmologist for further evaluation. Further evaluations by the ophthalmologist on November 21 and November 23 identified a small spot of inflammation near the fovea on the retina in his left eye. The ophthalmologist stated that this spot would most likely heal on its own and that the blurry spot on the operator's vision would go away. A follow-up visit was scheduled. The employee was released back to work without restrictions.

Los Alamos NATIONAL LABORATORY EST.1943

NNSA

一名博士后在实验中因不当操作受伤

当时激光分束到两个工作区（仅一个在用），他为看清读数摘下激光护目镜，被反射的4类不可见激光（800nm）伤到左眼。起初他未察觉异常，次日左眼出现视物模糊。

- Insufficient communication between users of shared laser beam – second beam was active when not in use
- Selection of inappropriate material (reflective surface, susceptible to laser damage) and position for the beam block
- Operator of the second setup had not verified safety conditions (blocking stray reflections) after modifying the setup (changing/blocking the beam path)
- Limited illumination impaired visibility of the instrumentation readings
- Operator removed laser protective eyewear

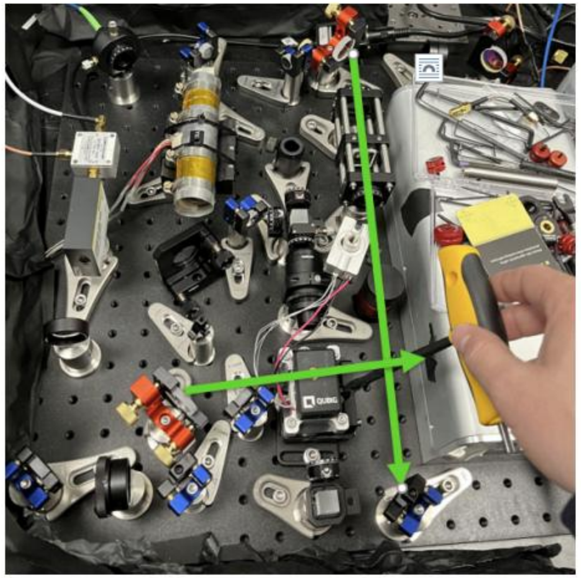
某厂电工在维护 4 类激光设备时手动装靶标校准激光镜，左手两指被意外激活的 2500 W激光灼伤，设备急停后伤者送医。

On August 30, 2011, during the performance of preventative maintenance for a 2,000 hour run time on a Class IV laser, a Specific Manufacturing Capability (SMC) electrician received second degree burns to the middle and ring fingers on his left hand. The qualified electricians were in the process of aligning the mirrors on a Laser Optics Telescope when the event took place. In preparing to align the mirrors, the electricians selected the program parameters, as instructed in the procedures. They verified the settings within the program and proceeded to install a target by hand into the required location to take a paper shot. This procedure tests the alignment of the laser beam to ensure it is reflecting properly off the mirrors. To activate the invisible beam a technician then steps outside of the nominal hazards zone boundary and, using both hands, turns the key and pushes the button on the hand held pendant. When placing the target into place, the electrician's left hand came into contact with an unexpected, unfocused energized 2,500 watt beam and was burned. The high power was immediately turned off by the maintenance Person in Charge and the laser was placed in a safe configuration. The electrician was taken to Central Facilities Area medical and was treated for the burns to his fingers and was released to SMC with restrictions. Further investigation is required to determine why the beam was energized.

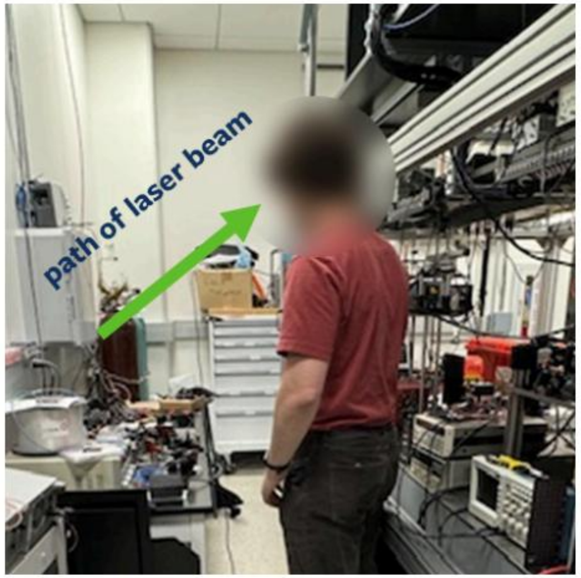
Case Studies
事故案例

A researcher of UC berkeley walking towards an optical table was expossed to a laser beam that reflected off a hex ball driver tool. The direct cause of the incident was the insertion of a ball driver tool with a reflective surface into the path of the 0.02 W continuous wave beam (420 nm), which reflected the laser beam into the eye of a nearby researcher. The laser user was not adequately trained and lacked experience with building an optical layout with an active beam present, including appropriate laser safety beam management.

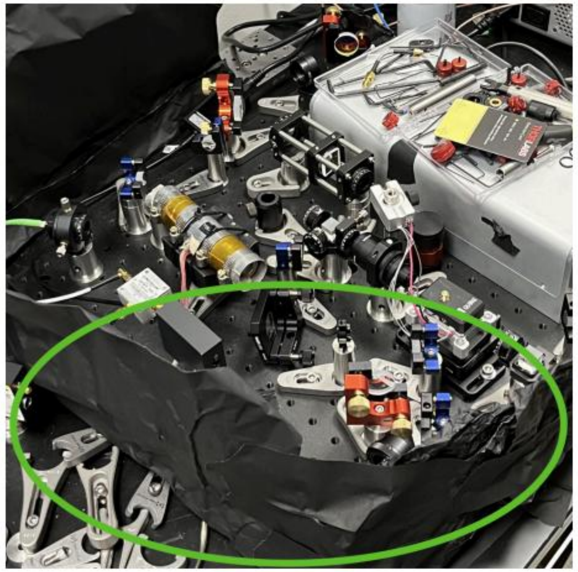
加州大学伯克利分校一名研究人员走向一个光学工作台，暴露在工具反射的激光束下。该事件的直接原因是研究人员将一个带有反光表面的球头螺丝刀工具插入了 0.02 W 连续波光束的路径中，这导致激光束反射到了附近一名研究人员的眼睛里。该激光使用者没有接受过充分的培训，并且在存在活跃光束的情况下搭建光学装置方面缺乏经验，其中包括适当的激光安全光束管理。



Tool in beam path



Approx. location of researcher struck by specular reflection



Low beam curb/barrier

Case Studies
事故案例

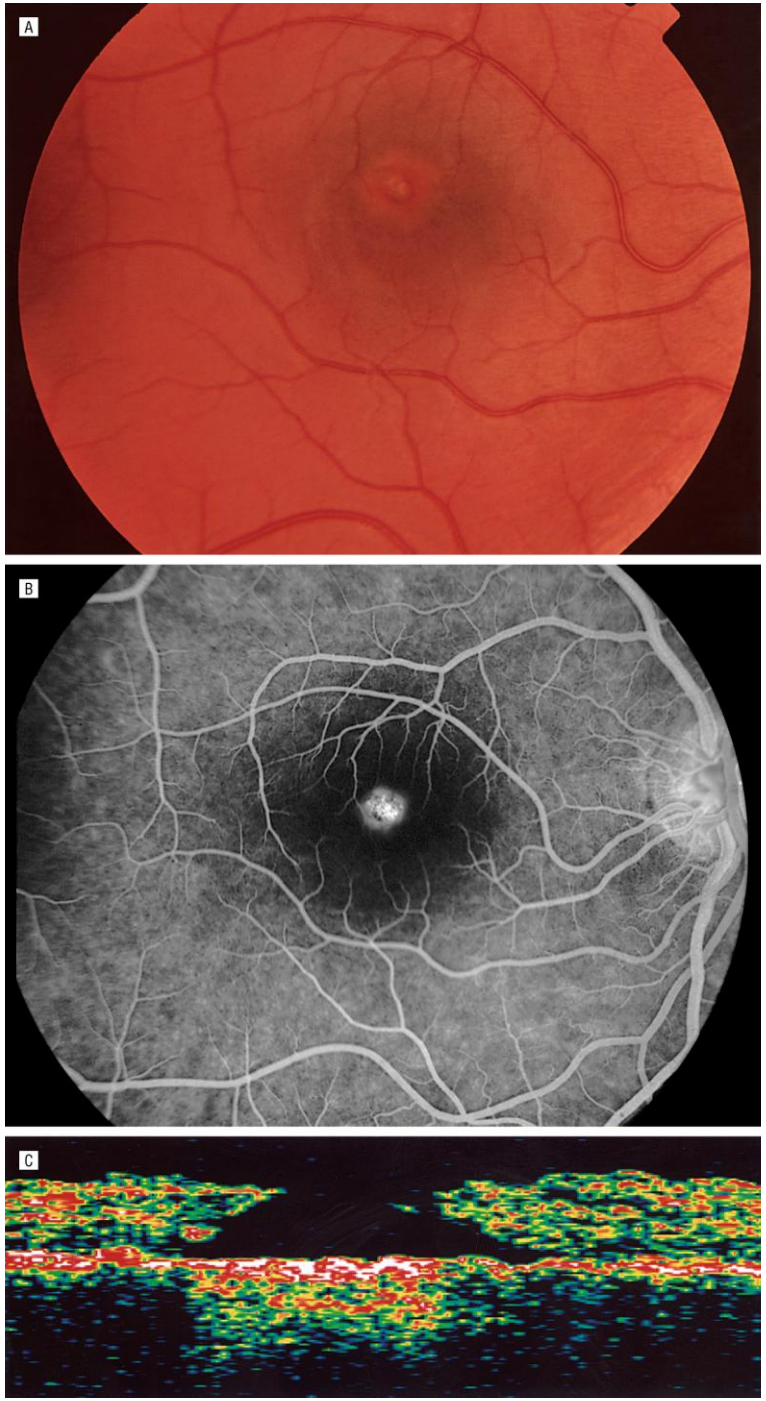
A case of severe accidental laser-induced eye injury in a 20-year-old technician

Despite having received laser safety training and reading warning labels, he deliberately stared at the output of a laser rangefinder, resulting in immediate vision loss in his right eye (partial improvement occurred 5 minutes later).

一名20 岁男性技术员严重意外激光致眼损伤病例。该技术员虽接受过激光安全培训且阅读过警示标识，仍故意直视激光测距仪的出光口，随即出现右眼视力丧失。

Corneal burn-rabbit due to photo ablation

Large retinal burn from 1W blue laser



Mainster MA, Stuck BE, Brown J. Assessment of Alleged Retinal Laser Injuries. Arch Ophthalmol. 2004.

Factors of Laser Hazards
激光事故原因

THE NUMBER OF INCIDENTS

The previous in-depth laser incident summary report of approximately November, 1994 reported 272 incidents [6]. This number has now increased in December of 1996 to a total of 330. The division of these incidents is shown in Table 1.

Table 1

The division of 330 incidents in the period: 1964-1996

Period	No. Yrs	Number of Incidents
1964 - 1976	13	32
1977 - 1986	10	151
1987 - 1996	10	147
	33	330

The new total, therefore, represents an increase of 58 incidents over the two years period. It is significant that not all of those 58 incidents occurred in the 1995-1996 period. In that period, only 32 "new" incidents were recorded. Thus, *26 incidents were belatedly reported during this period for years prior to 1965*. This is not an uncommon factor: e.g.learning of incident details many years following the event (sometimes after litigation involving the incident has been effected).

Table 2

Laser Accident Summary of 330 Incidents

	TOTALS	Align	Univ/ Lab	Bystnd	Other Cause	Equip Cause
EYE INCIDENTS						
No Eyewear Used:	134	44 18--	13 --18* 3--	11 -- 3*	38	7
		62	34	14	38	7
Eyewear Use Unspecified:	75	13 2--	3 ------	4 ---2*	44	9
	209	15	3	6	44	9
Eyewear Malfunction						
- Eyewear Failure:	4	1	1		2	
- Improper Choice:	5	2--	-- 2*		3	
- Improper Fit:	2	2				
	11	5	3		5	
Total Exposure Incidents:	**220**	**82**	**41**	**20**	**86**	**16**
No Eye Injury recorded:	21	2 2--	1 -- 2*	4	12	
	21	4	3	4	12	
Total Eye Exposures:	**241**	**86**	**44**	**24**	**98**	**16**
SKIN INCIDENTS						
Injury Reported:	45(1)	8	1	3	23	10
No injury reported	1					
Total Skin Exposures:	**46**	**8**	**1**	**3**	**24**	**10**
NON-BEAM INCIDENTS						
Fire	16(1)		2-- 1	1*< ------ 1	------ 8	-- 2* 3
Electrical			1*<			1*<
- Shock:		1	1--	------	------	-- 1*
- Shock:	7		2		1	2
- Death:	5	1	2		2	-
	12	2	5		3	3
Embolism						
- Non lethal:	1				1	
- Death:	3				3	
Equipment Failure	7					
- No injury reported	3				10	1
Other (Misc.)	1				1	
Total Non-Beam:	**43**	**2**	**7**	**1**	**26**	**8**
TOTAL INCIDENTS:	***330***	***96***	***52***	***28***	***148***	***34***

* Indicates incidents shared in two groups.

(1) There are 8 fire/skin combinations included in Skin total. The actual Fire total: 24.

ILSC 1997/567

- 眼部事故（占比约 73%）： 共 241 起，是最主要的激光事故类型
- 皮肤事故（占比约 14%）： 共 46 起
- 非光束事故（占比约 13%）： 共 43 起

ILSC1997/567 Laser incidents: A review of recent events

Factors of Laser Hazards
激光事故原因

- 对准过程中意外的眼睛暴露
- 未使用可用的眼部防护装备
- 设备故障
- 高压处理方法不当
- 未对辅助危害采取防护措施
- 设备维修后恢复不当
- 护目镜选择错误或护目镜失效
- 使用过程中意外的眼睛 / 皮肤暴露

SOR 2005-01

SPECIAL OPERATIONS REPORT: LASER SAFETY

U.S. Department of Energy

Office of Corporate Performance Assessment

February 2005 www.eh.doe.gov/paa

Background

Laser accidents continue to occur across the DOE Complex. Seven laser accidents were reported in the Occurrence Reporting and Processing System (ORPS) over the past 5 years that resulted in eye exposures to six people. None of those injured was wearing the laser eye protection that is essential when working with high-energy laser systems. The purpose of this report is to examine the root causes and the corrective actions taken in response to these events; to evaluate the extent to which DOE laser safety requirements comply with ANSI Z136.1-2000, *American National Standard for Safe Use of Lasers* (*Safe Use of Lasers*); and to provide laser safety performance expectations.

Lasers are used in the conduct of many DOE missions. There are several thousand laser systems in use, and more than 2,000 of these systems are Class 3B or 4. Furthermore, it is expected that the use of lasers will continue to increase with expanded future applications. Lasers are grouped into four classes based on their power and thus their potential for causing either injury or fires from direct exposure to the beam or reflections from diffuse reflective surfaces. The table below lists the four classes and describes the power of lasers in each class.

ILSC1997/567 Laser incidents: A review of recent events

PRELIMINARY ANALYSIS

The ANSI Z136.1 Standard "For the Safe Use of Lasers has indicated that the laser related incidents generally fall into one (or more) of the following major incident categories [1]:

* Unanticipated eye exposure during alignment.
* Available eye protection not used.
* Equipment malfunction.
* Improper methods of handling high voltage.
* No protection for ancillary hazards.
* Improper restoration of equipment following service.
* Incorrect eyewear selection eyewear failure.
* Accidental eye/skin exposure during use.

Optics Basic Knowledge
光学基础知识

The Nature of Light——Electromagnetic Radiation
光的本质——电磁辐射

Light, Electromagnetic Radiation, is a form of energy whose behavior is described by the properties of both waves and particles.

光，即电磁辐射，是一种能量形式，具有波粒二象性。

Photon's energy is:

$$E = hv = \frac{hc}{\lambda}$$

where

E- Energy

h- Planck's constant

ν- Frequency

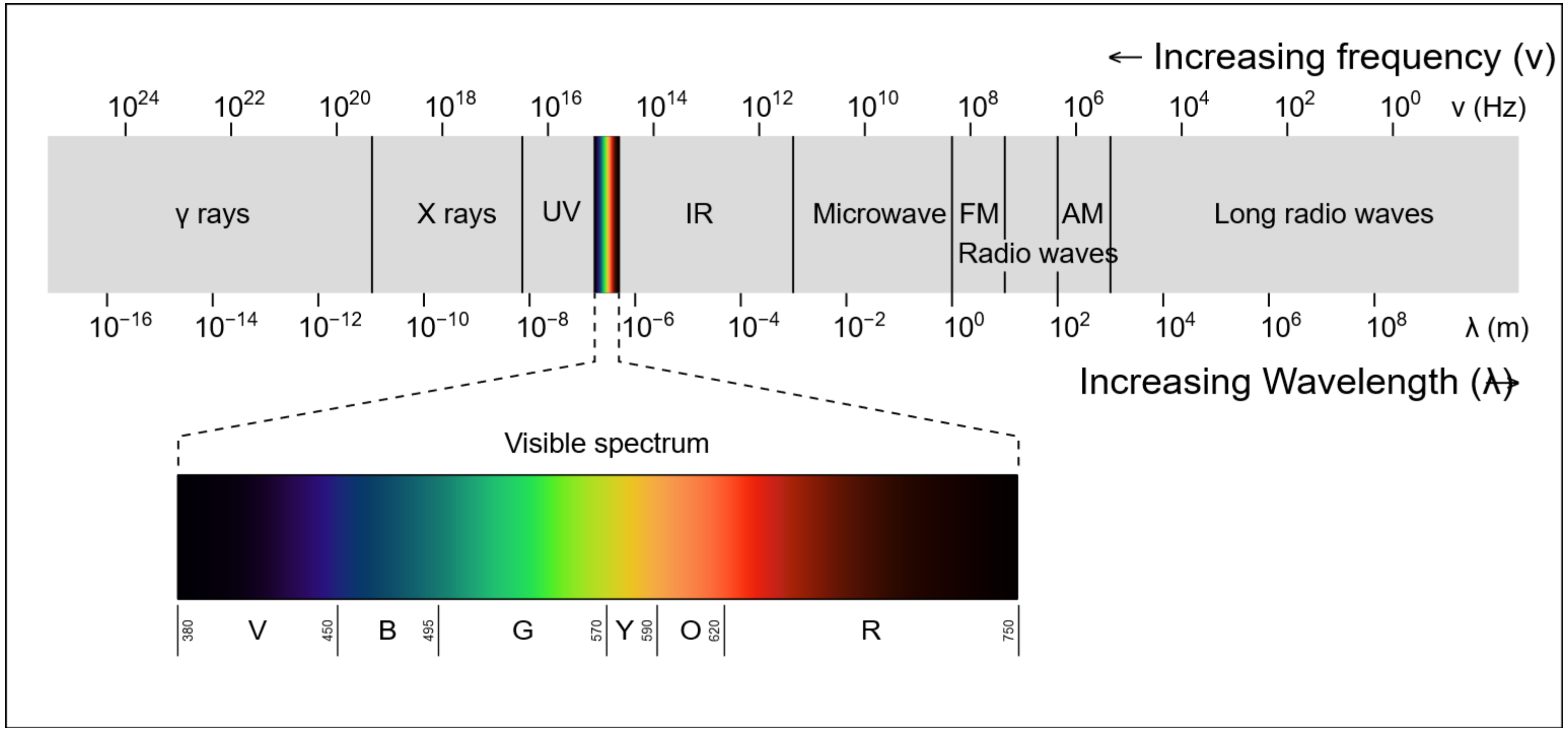
λ- Wavelength

c- Speed of light

The energy of a photon is inversely proportional to its wavelength

波长越短，能量越高

Electromagnetic Spectrum (Source: Zedh. Wiki)



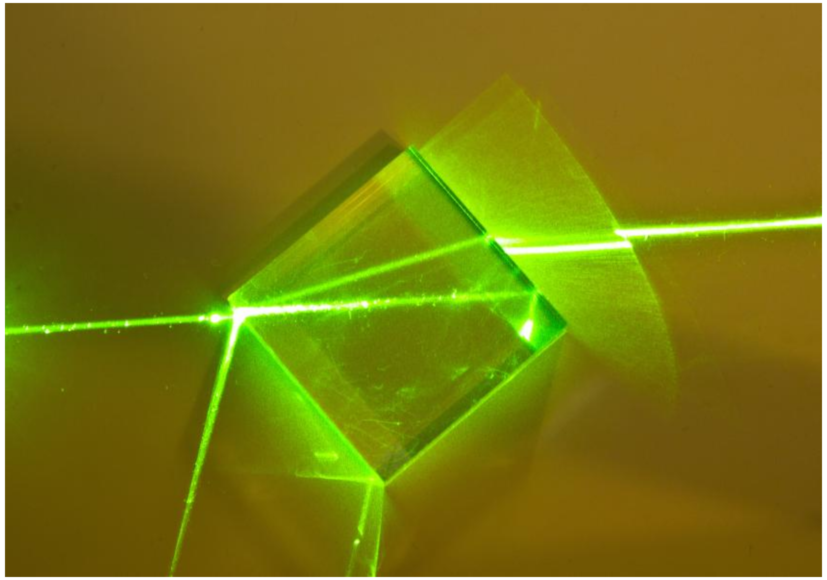
Optics Basic Knowledge
光学基础知识

Propagation Characteristics of Light
光的传播特性

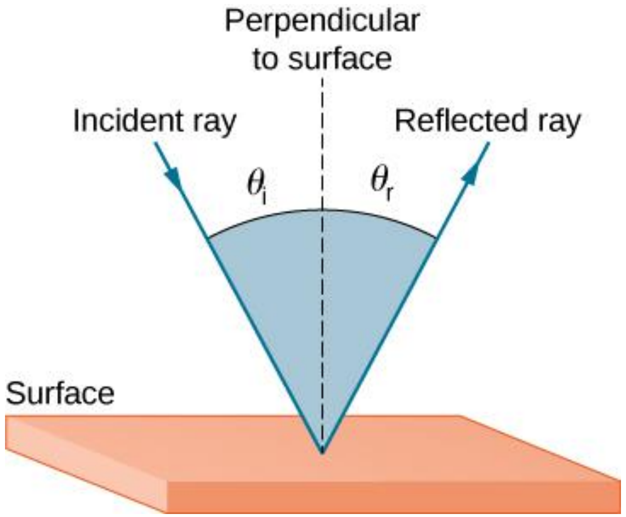
Since light moves in straight lines, changing directions when it interacts with materials. Two laws govern how light changes direction when it interacts with matter:

光沿直线传播，且在与物质相互作用时会改变传播方向，其方向改变遵循两大定律：

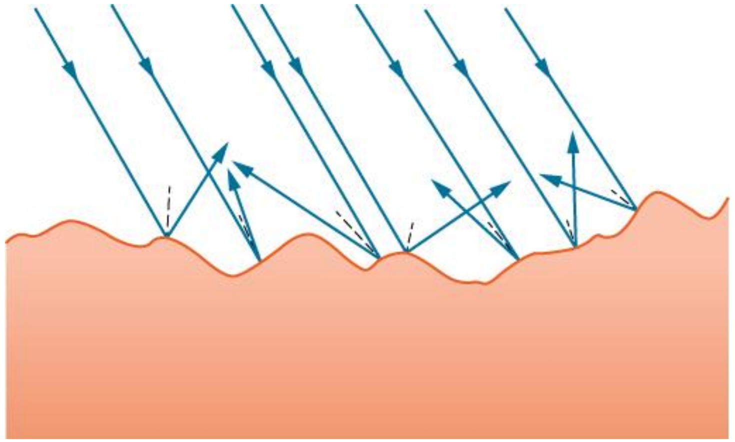
- Law of Reflection——light bounces off matter.
  反射定律适用于光从物质表面反射的情况
- Law of Refraction——light passes through matter.
  折射定律适用于光射入不同介质的情况



Law of Reflection



Specular Reflection



Diffuse reflection

(Source: John Breen. *"Advanced Analytical Chemistry 1"* Providence College.)

The degree of beam deflection depends on both the incident angle and the magnitude of the velocity change. For a given incident angle, a greater reduction in wave velocity results in a greater refraction.

光线的偏折程度取决于入射角及其波速变化的程度。当入射角固定时，波速降低得越多，折射效应越显著，折射角的变化也越大。

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

n_1 and n_2 are the indices of refraction for media 1 and 2.

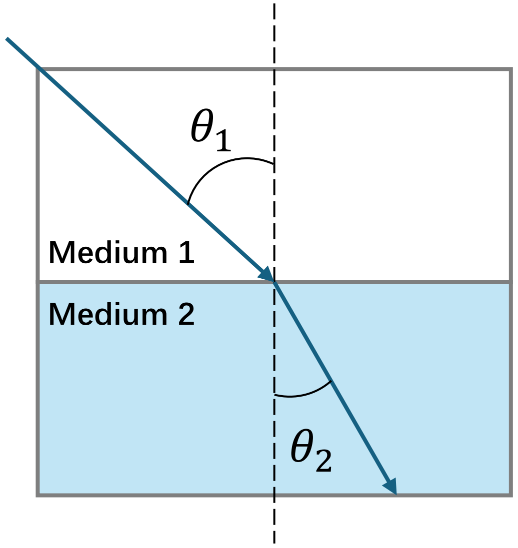
θ_1 and θ_2 are the angles between the rays and the perpendicular in media 1 and 2.

- In physics, attenuation is the gradual weakening of light intensity as it propagates through a medium. The main cause of light attenuation is **absorption** by the medium. Absorption occurs when matter captures a photon's energy, converting it into internal energy (e.g., heat)

  在物理学中，衰减是指光在介质中传播时，其强度逐渐减弱的现象。光衰减的主要原因是介质的吸收。**吸收**是指物质捕获光子能量，并将其转化为自身内能 (如热能) 的过程。
- **Scattering**, another key attenuation mechanism, is the redirection of light in multiple directions due to particles or inhomogeneities in the medium.

  除吸收外，**散射**是另一种关键的衰减机制，即光因介质中的颗粒或不均匀性而向多个方向偏转的现象。

Law of Refraction



Optics Basic Knowledge
光学基础知识

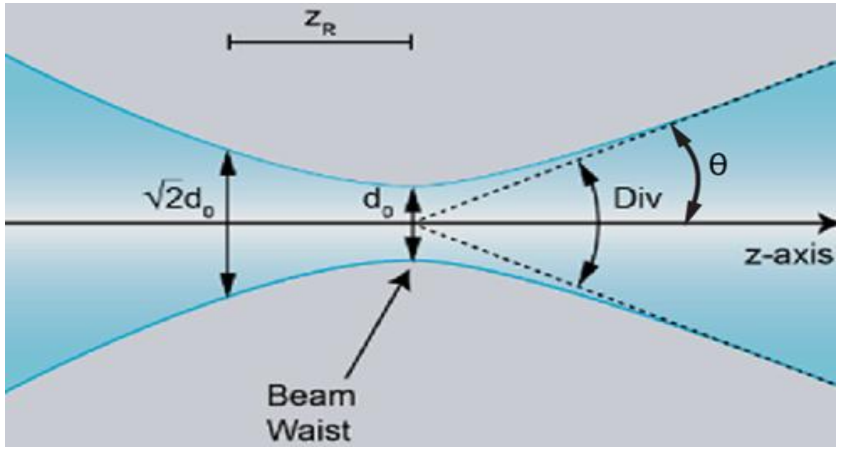
Basic Parameters of Light
光的核心参数

- Energy: The total quantity of energy carried by light. Unit: Joule (J)
  能量：光所携带的总能量。其单位是焦耳 (J)。
- Power: The rate at which light energy is transmitted, defined as energy transferred per unit time. Unit: Watt (W) = J/s.
  功率：光能量传递的速率，即单位时间内传输的能量。其单位是瓦特 (W)。
- Power Density: The power incident per unit area of a light beam's cross-section. Unit: W/cm^2 or mW/cm^2
  功率密度：光束在单位截面积上所承载的功率。其单位是 W/cm^2 或 mW/cm^2
- Beam Half-Divergence Angle: A key parameter quantifying the collimation and directionality of a light beam. A smaller divergence angle results in a more concentrated beam, a longer propagation distance, and a slower attenuation of its power density.
  光束发散角：衡量光束准直性与方向性的关键参数。发散角越小，则光束能量越集中，传播距离越远，其功率密度的衰减也越慢。

Formula for Half-Divergence Angle of a Gaussian Beam are:

$$\theta = \frac{\lambda}{\pi \omega_0} \quad \text{(rad)}$$

θ - beam divergence
λ - wavelength
ω_0 - beam waist

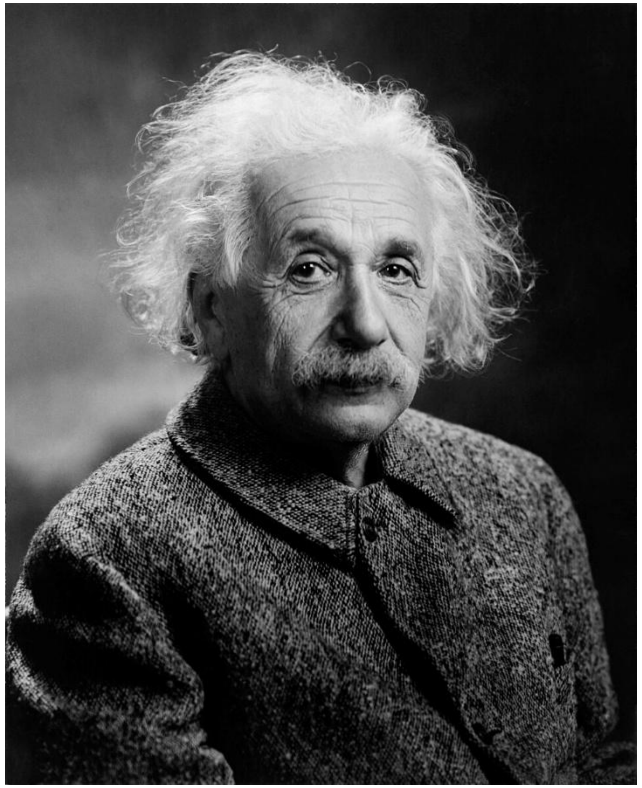


What is LASER？
什么是激光

Definition of Laser
激光定义

LASER ＝ Light Amplification by Stimulated Emission of Radiation

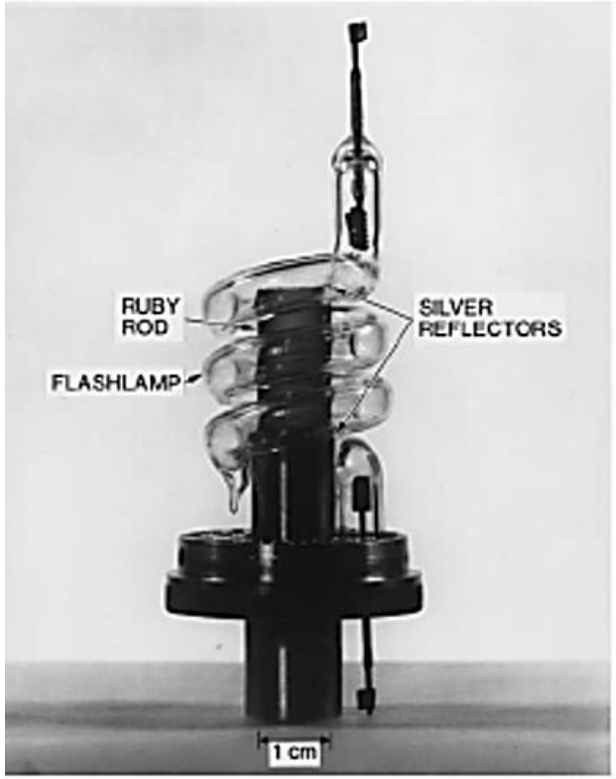
“激光”意为“受激辐射的光放大”



Albert Einstein

He published “**On the Quantum Theory of Radiation**“ in1917, laying the theoretical groundwork for the laser.

(Source: Wikipedia)



Theodore Maiman’s first laser

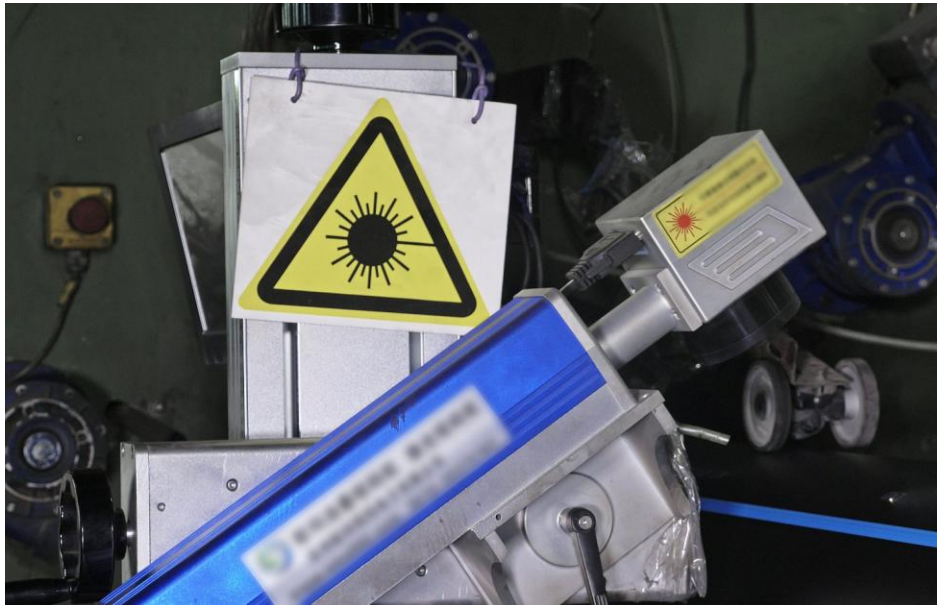
Maiman behind a larger ruby laser, handed out at the Hughes press conference announcing the laser, initially many thought this was the first laser in the world.

(Source: Hecht, Jeff. *"Short history of laser development." Optical engineering 49.9 (2010))*

What is LASER ?
什么是激光

Laser V.S. Ordinary Light
激光与普通光

- A laser is a device that generates coherent light through the process of stimulated emission.
  激光器是一种通过受激辐射过程产生相干光的装置。
- The output of a laser, laser light, is characterized by its monochromaticity, directionality, and coherence.
  激光器输出的激光，其特性为单色性、方向性和相干性。
- A laser system refers to the complete integrated setup, encompassing the laser itself along with all necessary electrical, mechanical, and optical components.
  激光系统指完整的集成装置，包含激光器本身以及所有必需的电气、机械和光学部件。

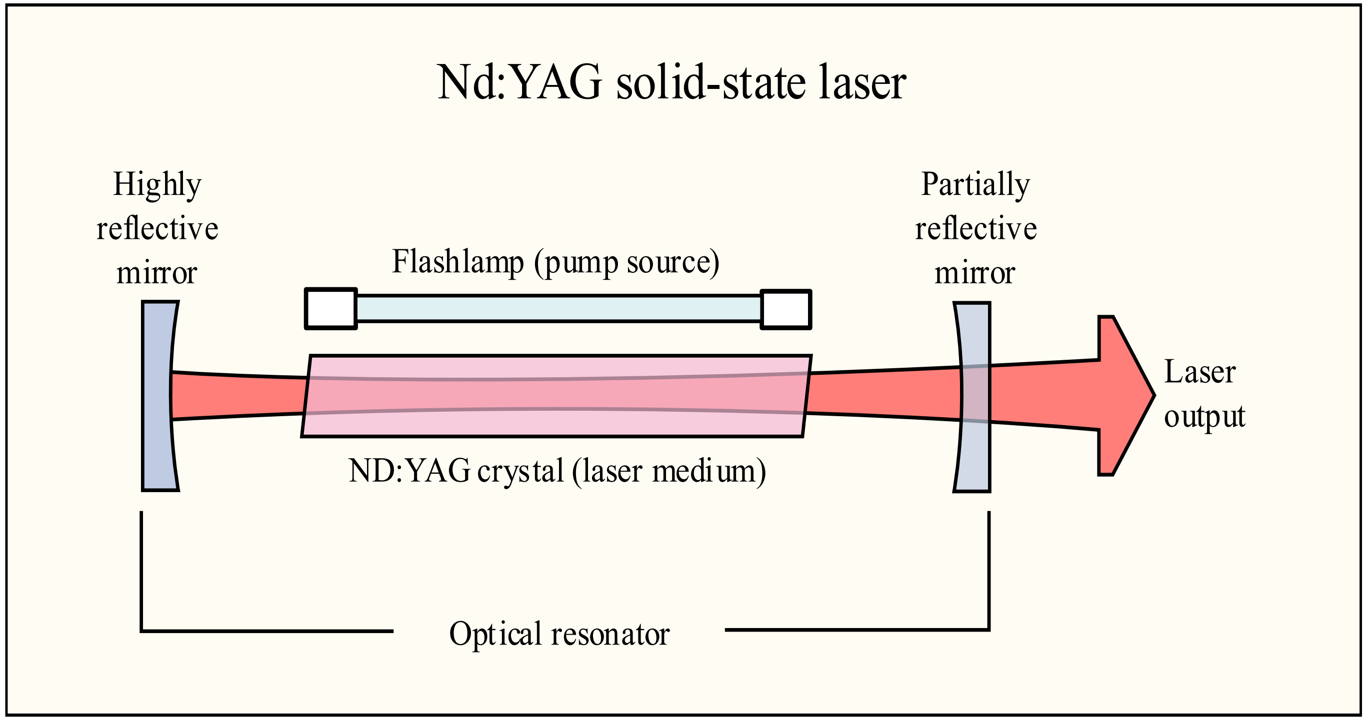


Characteristic 特性	Laser 激光	Ordinary Light 普通光
Monochromaticity 单色性	Single wavelength 单一波长	Mixed multiple wavelengths 多波长混合
Directionality 方向性	Extremely small divergence angle 发散角极小	Large divergence angle 发散角大
Coherence 相干性	Consistent phase 相位一致	Disordered phase 相位混乱

Laser Construction
激光器组成

- The three essential components of a laser are the gain medium, the pump source, and the optical cavity.
  激光器由三个基本部分构成：激光介质 (增益介质) 、泵浦源和光学谐振腔。
- Gain Medium: solid, liquid, gas.
  激光介质：固体、液体、气体
- Pump Source Mechanisms: Optical pumping (e.g., flashlamp, diode), Electrical pumping (e.g., electric discharge, current injection.
  泵浦源机制：光学泵浦 (如：闪光灯、二极管) 、电泵浦 (如气体放电、电流注入)
- The optical cavity contains a completely reflective mirror and a partially reflective mirror.
  光学谐振腔包括一面全反射镜和一面部分反射镜。

Component 组成	Function 功能
Gain Medium 激光介质	Generates stimulated emission 产生受激辐射
Pump Source 泵浦源	Provides energy 提供能量
Optical Cavity 光学谐振腔	Amplifies the laser beam 实现光束放大



(Source: Lakkasuo. Wikipedia)

Common Applications of Laser
激光的常见应用

Material Processing & Manufacturing
材料加工与制造

- Using laser energy to precisely alter materials: shaping, joining, removing, or modifying properties.
  利用激光能量对材料进行精确加工，实现成形、连接、去除或性能改性。

- **Specific Types and Applications 具体类型及应用：**
  Thermal Processing: Cutting, Welding, Selective Laser Melting
  热加工：切割、焊接、选择性激光熔化
  Photochemical Processing: Stereolithography Apparatus
  光化学加工：立体光固化成形

RBMS Workshop 雕刻机

Common Applications of Laser
激光的常见应用

Scanning Detection & Imaging Category
扫描探测与成像类

- Capitalizing on laser properties (directionality, high brightness, coherence), this technique scans an object point-by-point or line-by-line to detect interaction signals (reflection, scattering, fluorescence), enabling the reconstruction of morphological, structural, or compositional images.

  利用激光的方向性、高亮度和相干性，以逐点或逐线扫描的方式，探测激光与物质相互作用后产生的信号 (反射、散射、荧光)，进而构建出物体的形貌、结构或成分图像。

- **Specific Types and Applications 具体类型及应用：**

  Morphology Scanning: Lidar, Confocal Profiler
  表面形貌扫描与测距：激光雷达、共聚焦形貌仪
  Optical Imaging: Confocal Microscope, Multiphoton Microscope
  光学成像：共聚焦显微镜、多光子显微镜

MCPF Lab 奥林巴斯激光共聚焦显微镜

AAM Lab
FreeScan Combo激光手持三维扫描仪

Common Applications of Laser 激光的常见应用

Component and Structural Analysis Category 成分与结构分析类

- The laser acts as an excitation source. It probes a material's intrinsic properties—such as elemental composition, molecular structure, and crystal structure—by detecting the characteristic "fingerprint" signals generated during laser-matter interaction.

  激光作为"激发源"，通过探测激光与物质相互作用产生的特征"指纹"信号，来解析物质的元素组成、分子结构与晶体结构等内在属性。

- **Specific Types and Applications 具体类型及应用**

  Laser Spectroscopy: Raman Spectroscopy, Laser-Induced Breakdown Spectroscopy)

  激光光谱：拉曼光谱、激光诱导击穿光谱

MCPF Lab 显微共焦激光拉曼光谱仪

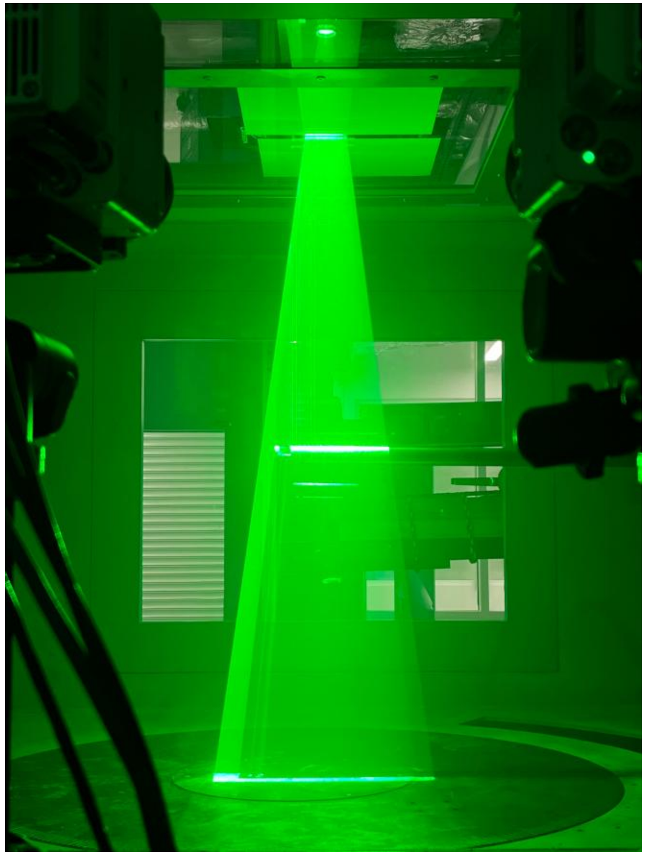
Common Applications of Laser
激光的常见应用

Particle and Fluid Measurement Category
颗粒与流体测量类

- These are optical measurement methods based on the interaction of laser light with tracer particles in a fluid, enabling the quantification of flow fields or particle properties.
  通过分析激光与流体中示踪粒子的相互作用，来测量流场的动力学参数或颗粒的物理特性。

- **Specific Types and Applications 具体类型及应用：**
  Flow Field Measurement: Particle Image Velocimetry, Laser Doppler Velocimetry
  流场测量：粒子图像测速法、激光多普勒测速法
  Particle Size Analysis: Laser Diffraction, Dynamic Light Scattering)
  粒度分析：激光衍射法、动态光散射法

LFT激光粒度仪



BioIERF PIV激光器粒子图像测速

Laser Types
激光种类

- Lasers are categorized according to their gain medium, with major types including solid-state, gas, semiconductor, and liquid lasers.
  激光器根据其介质的类型进行分类，主要种类包括固态、气体、半导体、液体激光等。

Solid-State	Gas	Semiconductor	liquid
Nd: YAG	Nitrogen	Gallium Arsenide (GaAs)	Rhodamine 6G
Er: Glass	Helium Cadmium	Gallium Aluminum Arsenide	Coumarin C30
Erbium: YAG	ArF、KrF	…	…
Holmium: YLF	XeCl、Xef		
Chromium Sapphire	HeNe		
Ti: Saph	HF		
Alexandrite	CO、CO_2		
…	Neon–Copper Vapor		
	Gold Vapor		

Laser Safety Standard
激光安全标准

IEC 60825-1

Edition 3.0 2014-05

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

GROUP SAFETY PUBLICATION
PUBLICATION GROUPÉE DE SÉCURITÉ

Safety of laser products –
Part 1: Equipment classification and requirements

Sécurité des appareils à laser –
Partie 1: Classification des matériels et exigences

INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

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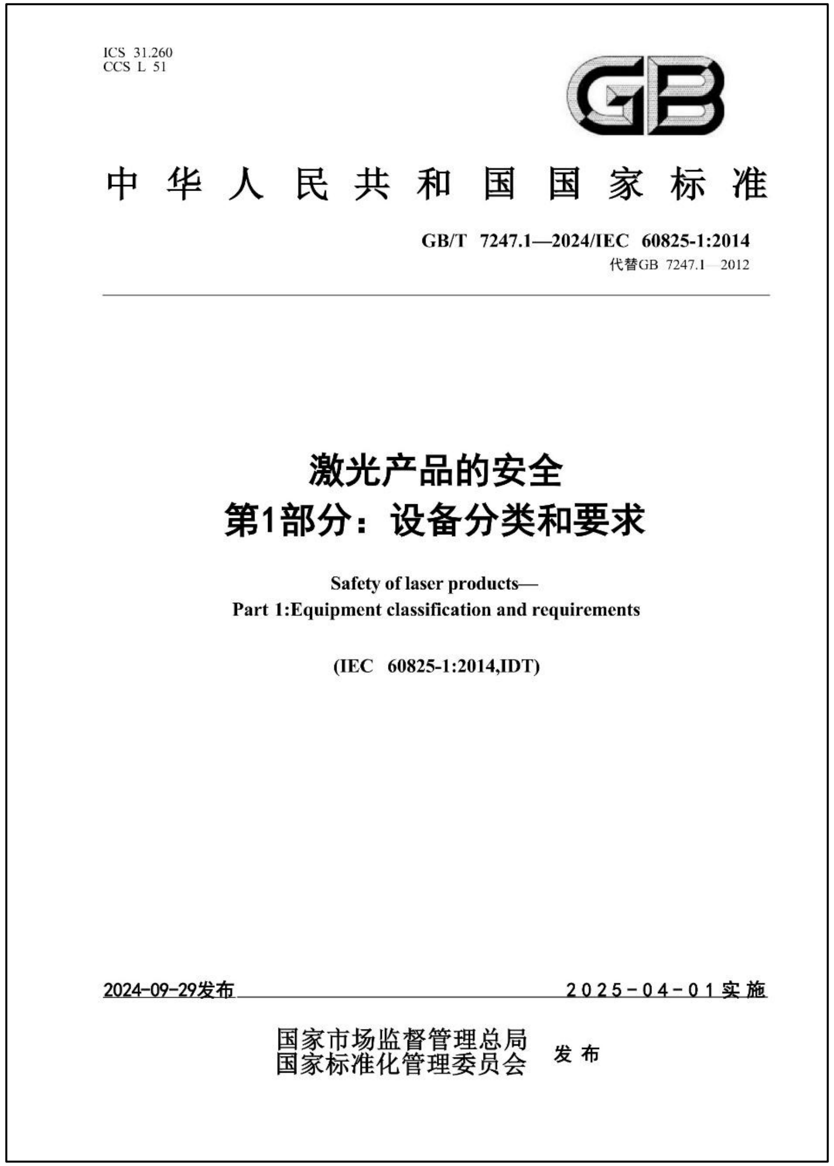
- International Electrotechnical Commission
  国际电工委员会
- It is the primary backbone of classification throughout most of the world.
  它是世界上大部分激光分类的基础。
- Emphasis on "Product Classification and Basic Safety Requirements"
  强调 "产品分类与基本安全要求"

(IEC) 60825-1

Safety of Laser Products

Part 1: Equipment Classification and Requirements

Laser Safety Standard
激光安全标准



ICS 31.260
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中 华 人 民 共 和 国 国 家 标 准

GB/T 7247.1—2024/IEC 60825-1:2014
代替GB 7247.1—2012

激光产品的安全
第1部分：设备分类和要求

Safety of laser products—
Part 1:Equipment classification and requirements

(IEC 60825-1:2014,IDT)

2024-09-29发布　　2025-04-01实施

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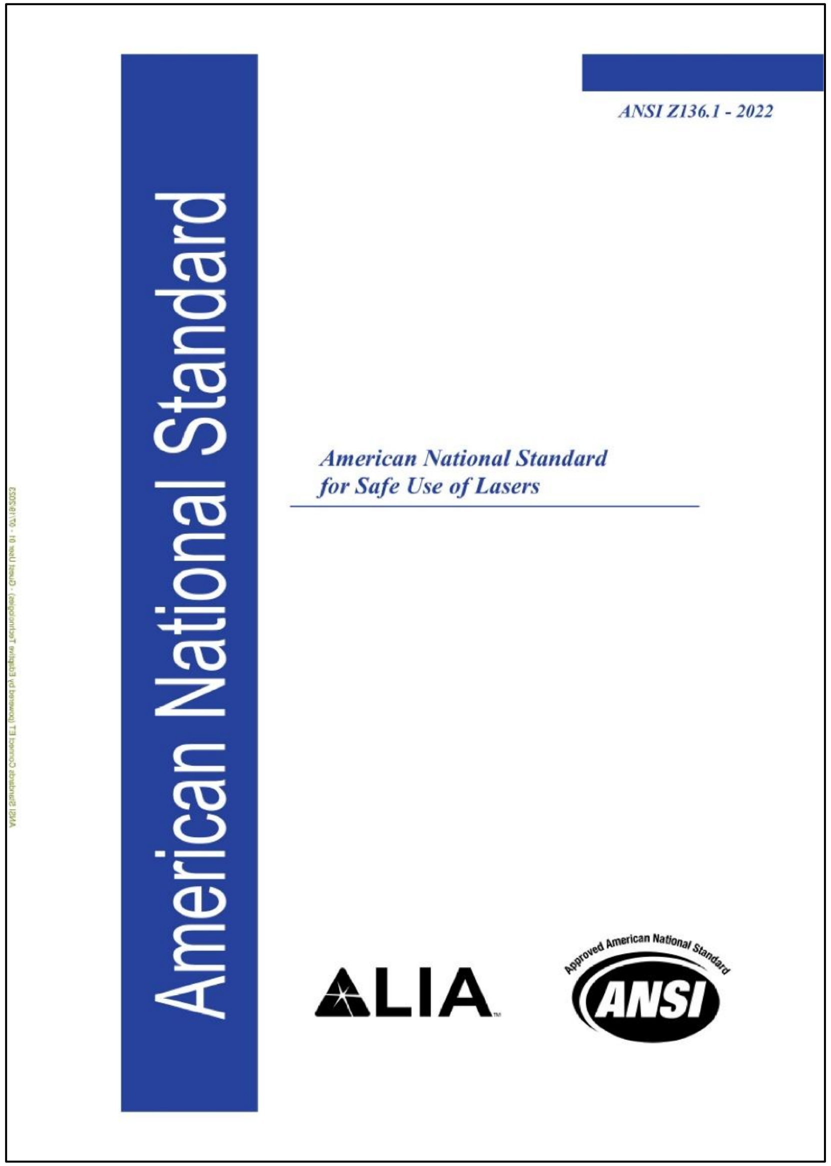
国家标准化管理委员会　发布

- Standardization Administration of the People's Republic of China
  中国国家标准化管理委员会
- GB/T-7247.1——2024 Edition Equivalently Adopts IEC 60825-1:2014
  GB/T-7247.1——2024 版等效采用 IEC 60825-1:2014标准

GB/T 7247-1
激光产品的安全
第1部分：设备分类和要求

Laser Safety Standard
激光安全标准



- American National Standards Institute
  美国国家标准协会
- Laser safety in use within the United States—covering settings such as laboratories and industrial environments—is largely consistent with the IEC standard classification system, though there are differences in details.
  美国境内激光使用安全，包括实验室、工业等场景，与 IEC 标准分类体系基本一致，但细节有差异。
- It places greater emphasis on "safe use," with more detailed requirements for operating procedures and personnel training.
  更强调 "安全使用"，对操作流程和人员培训要求更细致。

ANSI Z136.1
American National Standard for Safe Use of Lasers

Laser Safety Terminology
激光安全术语

- **Accessible Emission Limit (AEL) 可达发射极限**

  The maximum accessible emission level permitted within a particular laser hazard class.
  在特定激光危险等级内允许的最大可达发射水平。

——— ANSI Z136.1-2022

- **Application Scenarios 应用场景**

The fundamental criterion for laser classification 激光分级的基本判据:

Determining a laser's hazard class (1, 1M, 2, 2M, 3R, 3B, 4) by comparing its output power/energy against the AEL thresholds defined by the standard.

通过对比激光器的输出功率/能量与标准定义的AEL阈值，确定其危险等级 (1, 1M, 2, 2M, 3R, 3B, 4)

A key parameter for compliance testing 合规性测试的关键参数:

Ensuring that a laser product's accessible emission does not exceed the AEL of its designated class during manufacturing and acceptance testing.

在生产和验收测试中，确保激光产品的可达发射量不超过其指定等级的AEL。

Laser Safety Terminology
激光安全术语

- **Maximum Permissible Exposure (MPE) 最大允许照射量**

The level of laser radiation to which an unprotected person may be exposed without adverse biological changes in the eye or skin.

未防护人员受到激光照射后，眼或皮肤不会产生不良生物变化的激光辐射水平。

——— *ANSI Z136.1-2022*

- **Application Scenarios 应用场景**

Basis for selecting laser protective equipment 选择激光防护镜的核心依据：

The MPE value is used to calculate the minimum required Optical Density (OD) of laser safety goggles for a given laser wavelength and power, ensuring that the incident radiation on the eye is attenuated to a level below the MPE.

根据激光的波长、功率，结合 MPE 计算所需防护镜的OD 值，确保到达眼睛的辐射量被衰减至 MPE 以下。

The benchmark for establishing a Nominal Hazard Zone (NHZ) 确定标称危害区域 (NHZ) 的基准：

The MPE is used to calculate the distance from the laser source beyond which the exposure is safe, thereby defining the boundaries of the hazardous area where controls are mandatory.

MPE 用于计算激光源以外的安全距离，从而确定需要实施管控的危险区域边界。

Laser Safety Terminology
激光安全术语

- **Intrabeam Viewing 光束内视**

All viewing conditions whereby the eye is exposed to the direct or specularly reflected laser beam in contrast to viewing of diffuse reflections.

眼睛暴露于直射光束或镜面反射的激光辐射下的任何观察情形。

——— *ANSI Z136.1-2022*

- **Risk Implications 风险警示**

The most hazardous exposure scenario 最危险的暴露情形：

Intrabeam viewing allows laser energy to be focused to a tiny spot on the retina, which can cause instantaneous and often irreversible tissue damage, even with relatively low-power beams.

光束内视会使激光能量聚焦于视网膜上的一个极小点，即使功率较低，也可能瞬间造成不可逆的组织损伤。

A primary safety prohibition 安全规范的首要禁令：

Laser safety protocols strictly prohibit intrabeam viewing of **Class 3B and 4 lasers**. This includes **never** intentionally looking into the direct beam or its reflections from mirror-like surfaces.

激光安全规程规定严禁对**3B类及4类激光**进行光束内视。这包括**绝对不可**有意直视直射光束或其镜面反射光。

Laser Hazard Classification
激光危害分级

Basis for Laser Classification
激光分级的依据

- Laser classification is mainly based on the Accessible Emission Limit (AEL) and the interaction characteristics between lasers and the human body. The specific basis includes the following four points:
  激光分级主要依据可达发射限值及激光与人体的相互作用特性，具体依据包括以下 4 点：

01

AEL　可达发射极限

Classification is achieved by comparing a laser's output against predefined AEL thresholds.
通过将激光的输出与预定义的AEL阈值进行比较，从而确定其等级。

02

Output Parameters　输出参数

AEL values are calculated differently for various emission durations and patterns. This ensures that specific hazards of pulsed and continuous-wave (CW) lasers are appropriately reflected in their class.
针对不同的发射持续时间与模式，AEL 值的计算方法不同。这确保了脉冲激光和连续激光的特定危害能恰当地体现在其等级中。

03

Wavelength　波长

Wavelength determines which tissue is primarily at risk. This directly influences the Maximum Permissible Exposure (MPE), which in turn sets the AEL for each hazard class.
波长决定了主要受威胁的组织，这直接影响最大允许照射量 (MPE) 的数值，而 MPE 又是设定各级别 AEL 的基础。

04

Potential for Optically　光学辅助观察

The use of optical instruments (e.g., microscopes, lenses) can elevate the effective hazard, which is a consideration in the classification rules.
使用光学仪器 (如显微镜、透镜) 可能会增加实际危险，这也是分级规则中的一个考量因素。

How to do a Laser Grading Judgment
如何对激光进行分级?

01 Determine laser wavelength
确定激光波长

02 Measure accessible emission power/energy (≤AEL?)
测量可达发射功率 / 能量（是否≤AEL? ）

03 Check optical aid impact (exceed MPE with telescope?)
检查光学辅助观察影响（用望远镜是否超 MPE? ）

04 Confirm class against classification table
对照分级表确定类别

Laser Hazard Classification
激光危害分级

Classification & Its Potential Hazards
分级及其潜在危害

- **Class 1：** Laser products that emit radiation in the wavelength range from 302.5nm to 4000 nm， which are safe during use, including long-term direct intrabeam viewing, even when exposure occurs while using telescopic optics.
  1类：发射波长范围为 302.5nm~4000nm 的激光产品，在使用过程中，即使长时间直接光束内视、使用望远光学仪器观察，仍然是安全的。

- **Class 1M：** It is safe during use, including long-term direct intrabeam viewing, but eye injury may occur with exposure to telescopic optics.
  1M类：在使用中包括裸眼长时间直接光束内视是安全的，但使用望远光学仪器观察可能造成眼损伤。

- **Class 2：** Laser products that emit visible radiation in the wavelength range from 400 to 700 nm, which is only safe for instantaneous exposures (0.25s) , but can be hazardous for deliberate staring into the beam.
  2类：发射波长范围为400nm~700nm可见辐射，仅瞬间照射 (0.25s) 是安全的，但刻意注视激光束可能有危害。

- **Class 2M：** Laser products that emit visible laser beams, which are safe for naked eye exposure only for short periods. But eye injury may occur with exposure to telescopic optics.
  2M类：激光产品发射可见激光束，仅对裸眼短时照射是安全的。但使用望远光学仪器观察可能造成眼损伤。

(**M classes** usually apply to expanded or diverging beams)

——GB/T 7247.1-2024、IEC 60825-1：2014

Laser Hazard Classification
激光危害分级

Classification & Its Potential Hazards
分级及其潜在危害

- **Class 3R：** The emission radiation of laser products may exceed the MPE under direct intrabeam viewing, but the risk of damage is relatively low in most cases.
  3R类： 激光产品发射的辐射，在裸眼直接光束内视时可能超过MPE，但大多数情况下伤害风险相对较低。

- **Class 3B：** Laser products for which intrabeam ocular irradiation (including accidental short exposures) is generally harmful. Viewing diffuse reflections is normally safe.
  3B类： 激光产品发生光束内视 (包括意外短时照射) 通常对眼部有害，漫反射观察一般是安全的。

- **Class 4：** Both intrabeam viewing and skin exposure are dangerous, and viewing diffuse reflections can be dangerous. Such lasers also often cause fires.
  4类： 光束内视 (眼部) 和皮肤照射均有危险性，漫反射观察也可能有危险。这类激光器还可能引发火灾。

(**“R”** is derived from reduced, or relaxed, requirements: reduced requirements both for the manufacturer & the user.)

——GB/T 7247.1-2024、IEC 60825-1：2014

Laser Hazard Classification
激光危害分级

Why Classify Lasers?
为什么要对激光分级

- The laser hazard classification system serves as a universal language for hazard communication. Its necessity is evident for three key stakeholders:
  激光危险分级体系是传递危险信息的通用语言。其必要性对于以下三个关键相关方至关重要:

It quantifies the inherent hazard potential of a laser product, forming the basis for global regulatory compliance.
它量化了激光产品的固有危害潜力，是全球合规性认证的基础。

Manufacturers

It is the primary determinant for the stringency of control measures.
它是确定控制措施严格程度的首要依据

SO

It allows for the instant recognition of risk level.
它允许直观地识别风险等级

Users

Beam-Related Hazards
光束直接伤害

Damage to the eyes
激光对眼睛的伤害

- **Cornea 角膜**

  The transparent bulge on the front of the eye, which is the primary refracting structure of the eye.

  眼球前部的透明隆起，是眼睛的主要屈光结构。

- **Lens 晶状体**

  Lens is moveable/re-shapeable by the ciliary muscles and serves as the dynamic focus for the eye.

  晶状体可通过睫状肌调节形状，是眼睛的动态聚焦结构。

- **Retina 视网膜**

  The visual receptors (rods and cones) are located in the retina.

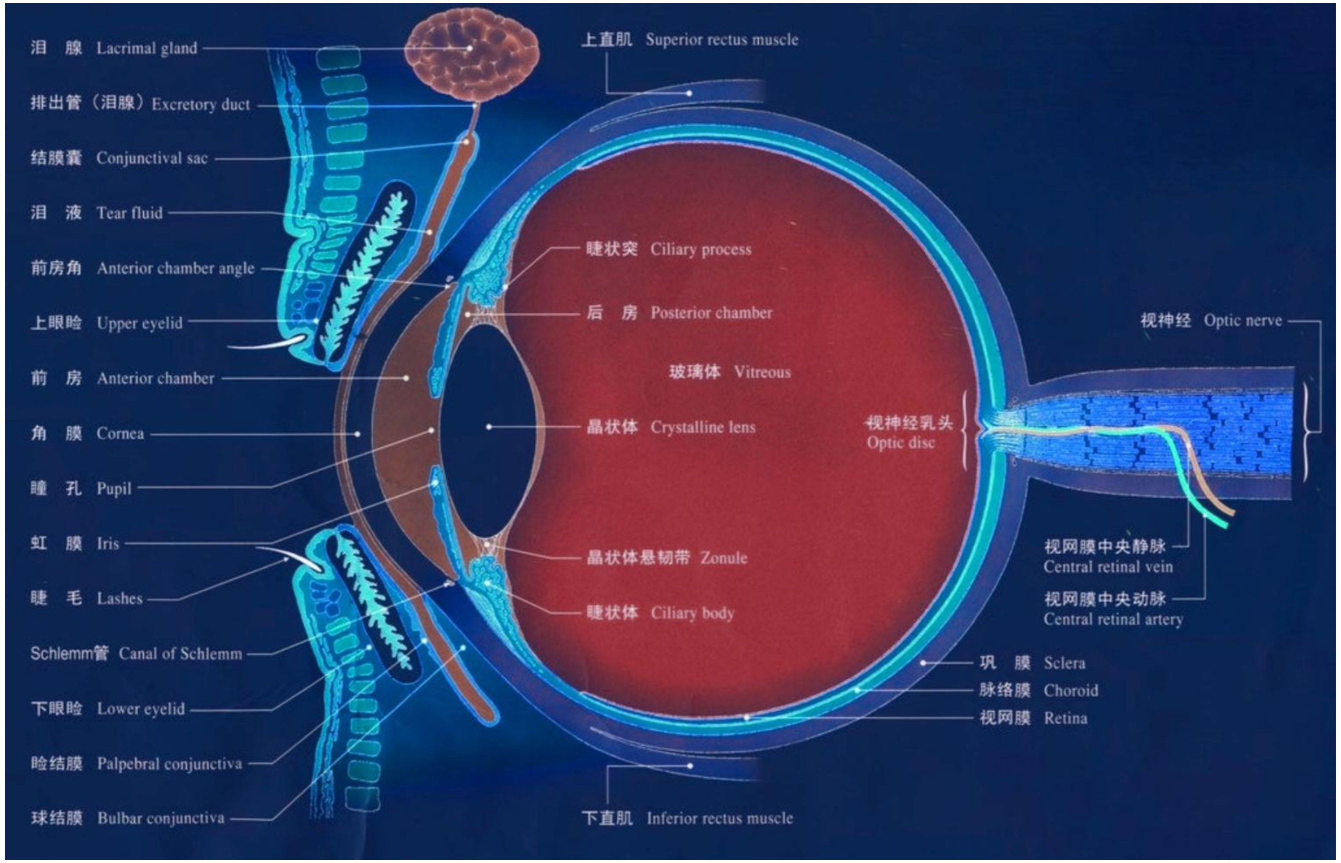
  视网膜含视杆细胞和视锥细胞，是视觉感知的基础。

- **Iris/Pupil 虹膜/瞳孔**

  The iris/pupil serves as the variable aperture for different light levels and can change in size.

  虹膜/瞳孔的大小会随光照强度变化。

Typical Sizes of Pupil			
Daylight	2mm	**Indoor**	3mm
Dark adapted	7mm	**Dilated**	8mm



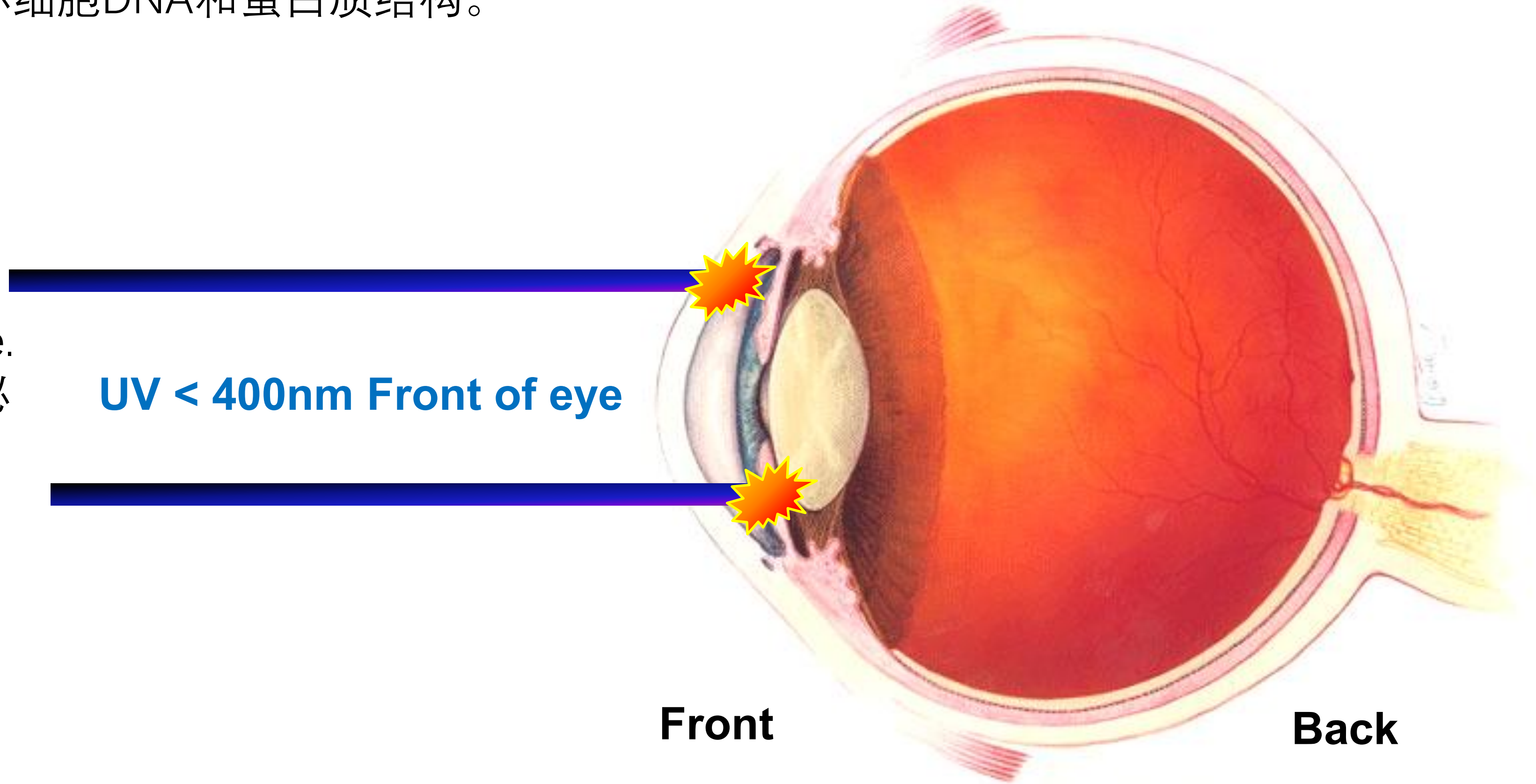
Beam-Related Hazards
光束直接伤害

Damage to the eyes——Ultraviolet (180nm-400nm)
对眼睛的伤害——紫外波段

- **Affected areas 损伤部位：**
  Cornea, Conjunctiva, Lens 角膜、结膜、晶状体

- **Damage mechanism 损伤机制：**
  Laser-induced damage is primarily due to photochemical effects, which disrupt cellular DNA and protein structures.
  该波段的损伤以光化学效应为主，破坏细胞DNA和蛋白质结构。

- **Specific harm 具体伤害：**
  Photophobia accompanied by surface redness, tearing, conjunctival discharge, corneal surface exfoliation and stromal haze.
  畏光，伴随眼表充血、流泪、结膜分泌物增多、角膜表层剥脱及基质混浊。



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Beam-Related Hazards
光束直接伤害

Damage to the eyes——Visible & Near IR (400nm-1400nm)
对眼睛的伤害——可见-近红外波段

- **Affected areas 损伤部位：**

  Retina (Laser of this wavelength can be focused onto the **retina** through the cornea and lens, amplifying the energy density hundreds of times.)

  视网膜 (此波段激光可通过角膜和晶状体聚焦于视网膜，使能量密度放大数百倍。)

- **Damage mechanism 损伤机制：**

  Thermal effects & Photochemical effects

  热效应和光化学效应

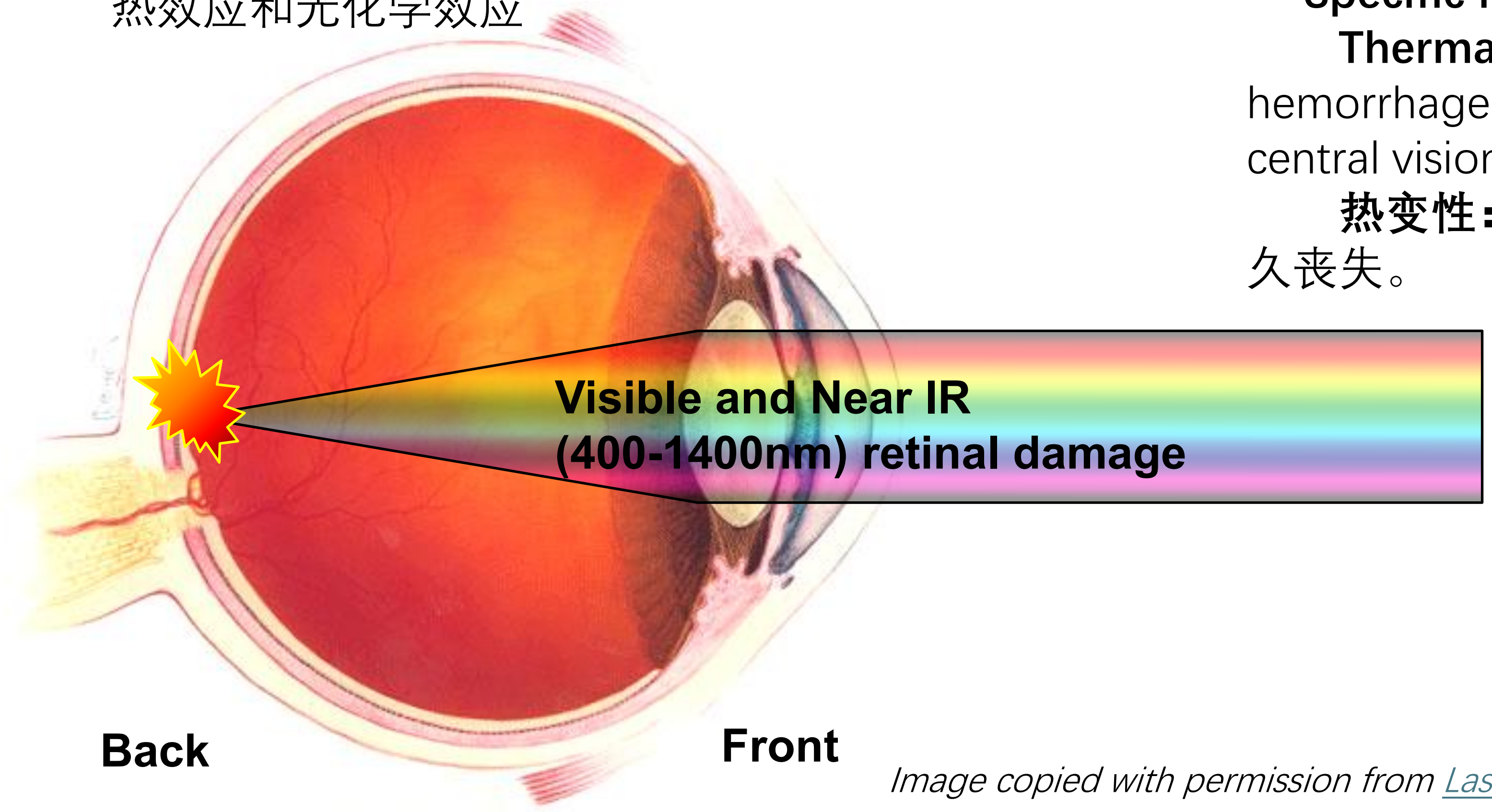
- **Specific harm 具体伤害：**

  Thermal denaturation: Retinal coagulation, hemorrhage and retinal tears leading to permanent loss of central vision.

  热变性： 视网膜凝固、出血、裂孔，导致中心视力永久丧失。

  Photochemical damage: Apoptosis of retinal pigment epithelial cells, with prolonged exposure triggering chronic vision deterioration.

  光化学损伤： 视网膜色素上皮细胞凋亡，长期暴露引发慢性视力恶化。



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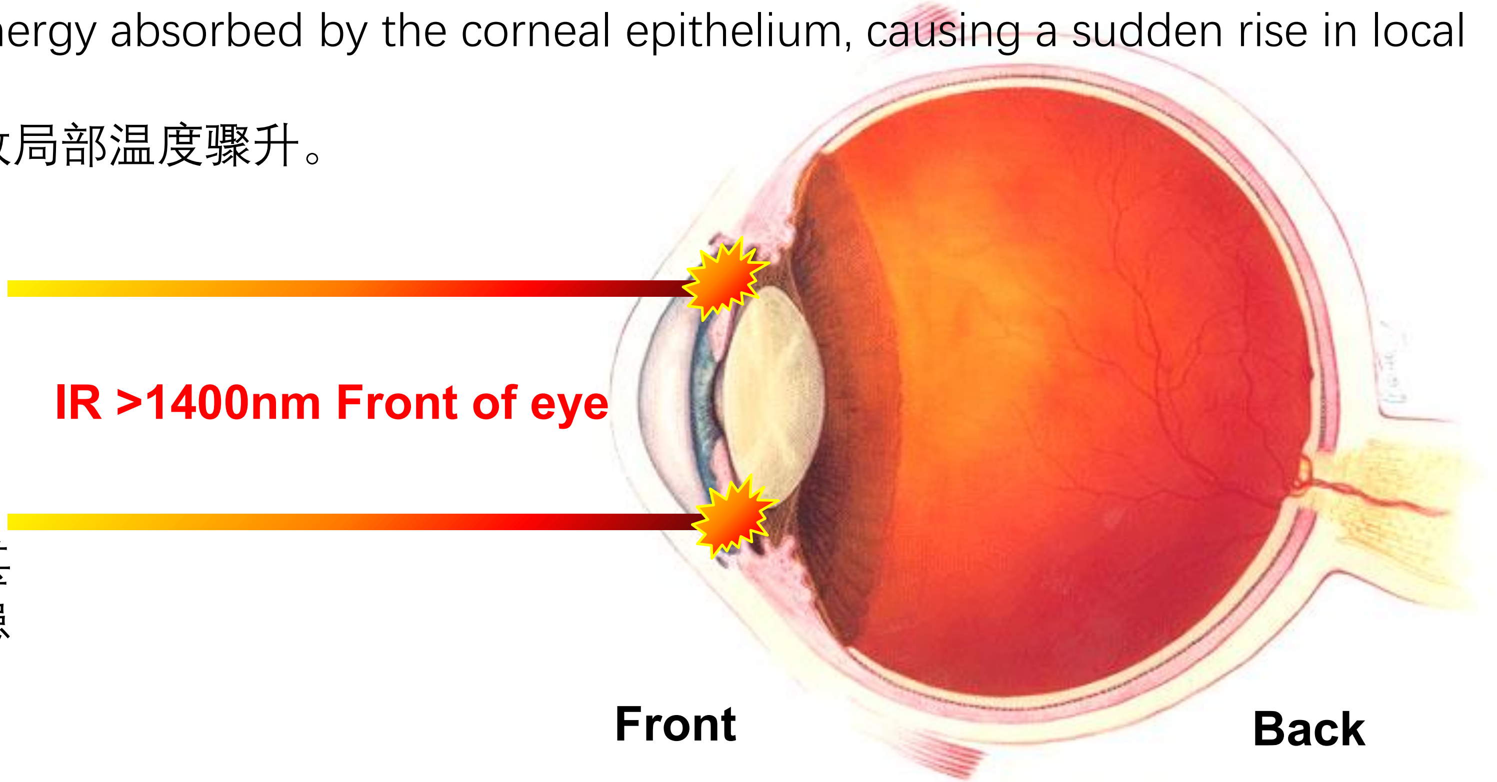
Beam-Related Hazards
光束直接伤害

Damage to the eyes——Infrared (1400nm-1000μm)
对眼睛的伤害——红外波段

- **Affected areas 损伤部位：**
  Cornea, Conjunctiva, Eyelids (This wavelength laser cannot penetrate to the retina)
  角膜、结膜、眼睑 (此波段激光无法穿透至视网膜)

- **Damage mechanism 损伤机制：**
  The thermal effect predominates, with laser energy absorbed by the corneal epithelium, causing a sudden rise in local temperature.
  热效应为主，激光能量被角膜上皮吸收，导致局部温度骤升。

- **Specific harm 具体伤害：**
  Corneal epithelial burns, high-intensity exposure may cause eyelid burns or even corneal perforation. Prolonged exposure may damage the lens and increase the risk of cataracts.
  角膜上皮灼伤，高强度暴露可引发眼睑烧伤甚至角膜穿孔。长期暴露可能损伤晶状体，增加罹患白内障风险。



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Beam-Related Hazards
光束直接伤害

Damage to the skin
对皮肤的伤害

- **Visible to Infrared 可见-红外波段 (400nm-1000μm)**

The biological effects of irradiation of the skin by lasers operating in the visible and IR regions is considerably less than exposure of the eye, as skin damage is usually reparable or reversible.

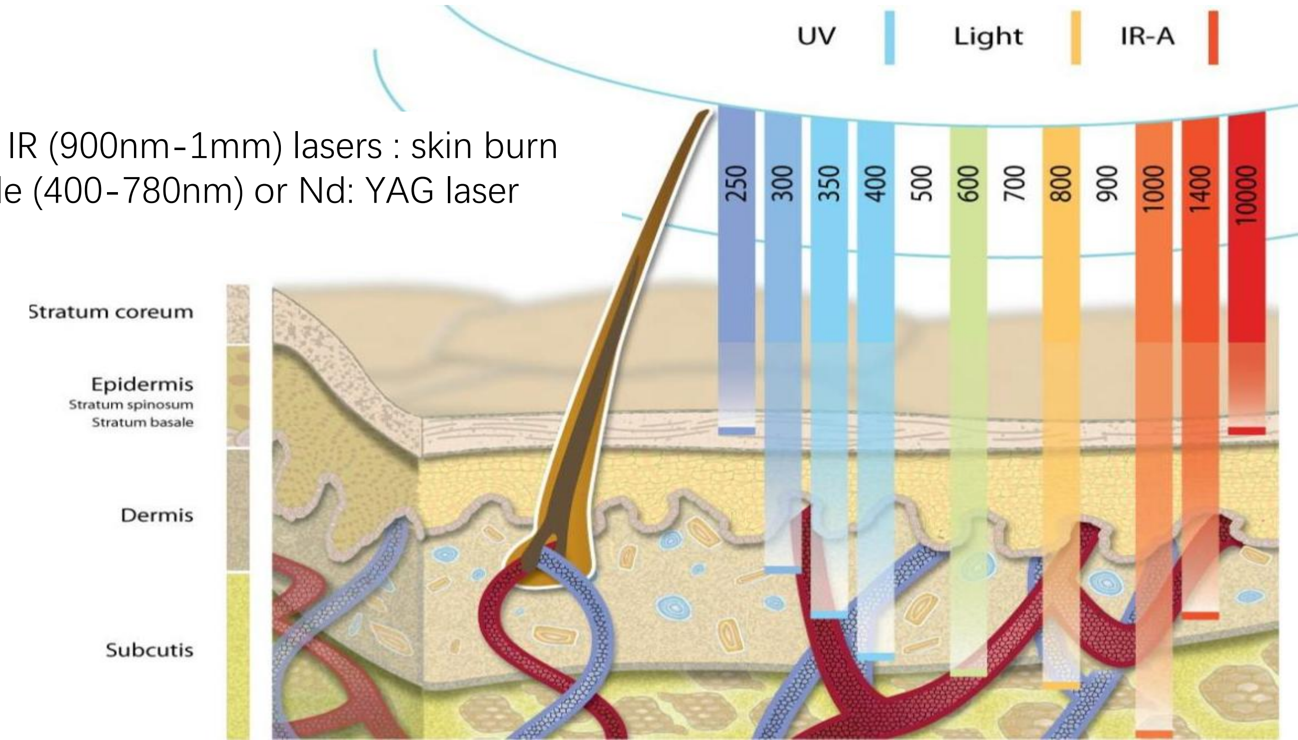
在可见光和红外区域工作的激光对皮肤照射的生物学影响，远小于对眼睛的照射。因为皮肤损伤通常是可逆的。

- **Ultraviolet 紫外波段 (180nm-400nm)**

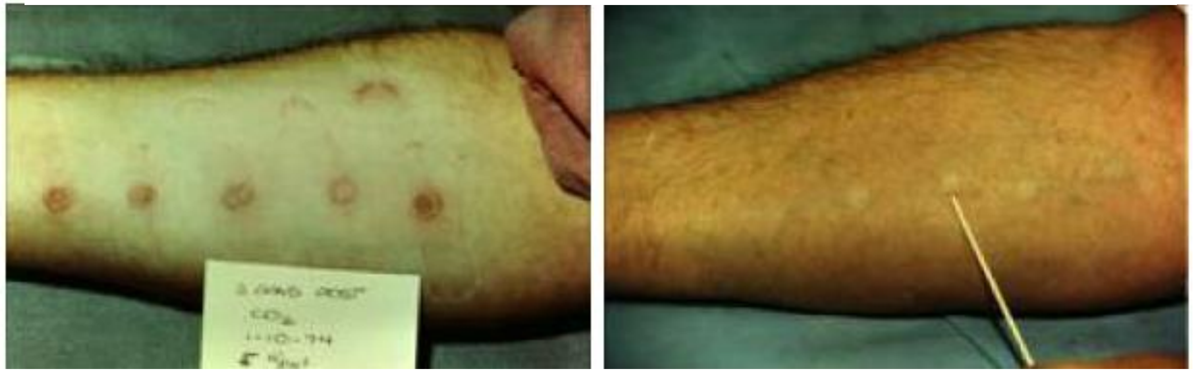
200-250nm UV is absorbed by stratum corneum, 250-320nm UV is most injurious to skin, 320-400nm UV darkens pigment. UV exposure is also associated with an increased risk of developing skin cancer and premature aging of the skin.

200-250nm UV能被角质层吸收，250-320nm UV对皮肤伤害最大，320-400nm UV致色素加深。紫外暴露也会增加皮肤癌风险及皮肤过早老化问题。

CO_2/ IR (900nm-1mm) lasers : skin burn
Visible (400-780nm) or Nd: YAG laser



Twenty year evaluation of CO_2 laser (5 W/cm^2. 1 sec. at 10,600 nm) exposure of human skin.



Beam-Related Hazards
光束直接伤害

Factors Influencing Laser Injury Severity——Wavelength
影响激光伤害程度的因素——波长

- The wavelength directly influences the penetration depth and absorption efficiency of laser energy within human tissues, determining the target organs affected and the mechanism of injury.
  波长直接影响激光在人体组织中的穿透深度和吸收效率，决定了受损伤靶器官及其对应的伤害机制。

Wavelength	Primary Injury Organs	Injury Mechanism	Core Risk Characteristics
UV (180-400nm)	Cornea, Conjunctiva; Skin	Photochemical effect	**Eyes:** Corneal damage, cataracts **Skin:** Erythema, blisters, long-term carcinogenic effects
Visible – NIR (400nm-1400nm)	Retina Skin surface	Photochemical effect Thermal conduction effect	**Eye：** Retinal coagulation & tears **Skin:** Thermal burns, pigmentation disorders
IR (1400nm-1000μm)	Cornea, Eyelids; Deep layers of the skin	Thermal conduction effect	**Eye：** Corneal edema, ulceration **Skin：** Deep tissue burns, thermal stress

The wavelength of 400-1400nm is the most dangerous area to the retina.
400-1400nm为 “视网膜危险区”
The main damage due to UV and IR is the eyes’ surface and skin.
紫外和远红外激光主要损伤眼表和皮肤

Beam-Related Hazards
光束直接伤害

Factors Influencing Laser Injury Severity——Exposure Intensity
影响激光伤害程度的因素——暴露强度

- Exposure intensity is a quantitative indicator of laser energy or power, directly determining the severity of harm, with core indicators including;
  暴露强度是激光能量或功率的量化指标，直接决定伤害的轻重程度，核心指标包括：
- **Radiant Exposure (H) 辐照量——Damage mechanisms where the total accumulated energyis the critical factor**

The total optical energy delivered per unit area (J/cm²). A higher H value indicates a greater cumulative dose of energy absorbed by tissue.

单位面积上接收的总光能量。H值越高表示组织吸收的累积能量剂量越大。

常用于脉冲激光

Photochemical Effects 光化学效应	Chronic damage from prolonged exposure to lower power levels (e.g., UV-induced skin erythema, cataract formation). 长期暴露于较低功率密度导致的慢性损伤 (例如，紫外线引起的皮肤红斑、白内障的形成) 。
Extended Exposure 长时间暴露	Aggravated thermal damage as energy builds up over time (e.g., retinal lesions). 由于能量随时间累积而加重的热损伤 (例如，视网膜灼伤) 。

- **Irradiance (E) 辐照度——Damage mechanisms where the rate of energy delivery(power) is the critical factor.**

The optical power incident per unit area (W/cm²). A higher E value indicates a more intense, instantaneous power flux absorbed by tissue per unit time.

单位面积上接收的光功率。E值越高，表示组织单位时间内吸收的瞬时功率通量越强。

常用于连续激光

Thermal Effects 热效应	Instantaneous burns caused by rapid temperature rise (e.g., corneal ablation, skin burns). 因温度急剧升高导致的瞬时灼伤 (例如，角膜灼蚀、皮肤烧伤) 。
High-Power Lasers 高功率激光	Rapid tissue vaporization, cutting, or penetration. 导致组织快速汽化、切割或穿透。

Beam-Related Hazards
光束直接伤害

Factors Influencing Laser Injury Severity——Propagation Mode
影响激光伤害程度的因素——传播方式

- The propagation modes of lasers determine the routes of human exposure to laser radiation, with varying risk levels for different modes.
  激光的传播方式决定人体接触激光的途径，不同方式的风险等级不同。

- **Direct Viewing/Intrabeam Viewing 直射**
  It is the most dangerous propagation mode.风险最高的传播方式。

- **Specular Reflection 镜面反射**
  The intensity and directionality of the reflected beam are largely preserved. Its damage risk is almost equivalent to direct viewing. 反射光束的强度和方向性基本保持不变，其伤害风险与直接照射几乎等效。

- **Diffuse reflection 漫反射**
  Close-range diffuse reflection of Class 4 lasers may still cause the eye or skin exposure dose to exceed the MPE, resulting in eye discomfort, skin burns, and even fires.
  4级激光的近距离漫反射仍可能使眼睛或皮肤暴露剂量超过MPE，导致眼睛不适，皮肤烧伤，甚至火灾。

Beam-Related Hazards 光束直接伤害

Factors Influencing Laser Injury Severity——Exposure Ways 影响激光伤害程度的因素——暴露方式

- The angle of incidence refers to the angle between the laser beam and the normal to the surface of human tissue. It affects injury severity by altering energy distribution.
  入射角是指激光束与人体组织表面法线的夹角，它通过改变能量分布影响伤害。
- **Perpendicular incidence (0°) 垂直入射:**
  The beam projects the smallest area, resulting in the highest energy density per unit area and the most severe injury;
  光束投射面积最小，单位面积能量密度最高，伤害最严重。
- **Oblique incidence (θ>0°) 非垂直入射:**

The beam coverage area increases with the angle of incidence, reducing the energy density per unit area and lowering the risk of injury. However, if the total laser energy is high, the expanded coverage area may result in a larger injury zone.

光束投射面积随入射角增大而扩大，单位面积能量密度降低，伤害风险随之降低；若激光总能量较高，扩大的投射面积可能导致损伤范围增大。

- **Impact of optical observation aids 光学辅助观察的影响：**

Optical tools like telescopes or magnifying glasses can focus low-intensity lasers (e.g., Class 2M) onto smaller areas, significantly increasing energy density per unit area. This elevates ocular injury risk to Class 3B levels.

望远镜、放大镜等光学工具可将低强度激光 (如Class 2M) 的能量汇聚到更小区域，使单位面积能量密度显著升高，眼部伤害风险可提升至Class 3B水平。

Beam-Related Hazards
光束直接伤害

Factors Influencing Laser Injury Severity——Others
影响激光伤害程度的因素——其他

- **Continuous Wave (CW) vs. Pulsed Laser 连续波与脉冲波**

Pulsed lasers concentrate energy into short pulses, so their peak power is much higher than CW lasers with the same average power. Even with equal total energy, pulsed lasers can cause more severe thermal/mechanical damage; CW lasers mainly cause continuous thermal burns.

脉冲激光将能量集中在短脉冲内，相同平均功率下峰值功率远高于连续波激光。即使总能量相等，脉冲激光也会造成更严重的热或机械损伤；连续波激光主要引发持续热灼伤。

- **Threshold Duration 阈值时长**

Threshold duration is the boundary: exposure within the threshold reduces acute damage; beyond it, radiant exposure (H) increases, elevating chronic damage risk.

阈值时长是分界点：阈值内暴露可降低急性损伤；超过阈值后，辐照量 (H) 升高，增加慢性损伤风险。

Beam-Related Hazards
光束直接伤害

Factors Influencing Laser Injury Severity
影响激光伤害程度的因素

- Laser injury: Damage caused by a laser of specific wavelength, acting on human tissue at a certain intensity and incident angle, via a specific propagation mode, for a duration exceeding the threshold.
  激光伤害：特定波长的激光，以一定强度和入射角，通过某种传播方式，持续作用于人体组织至阈值时长后的损伤。

KEY CONCLUSION

- **Wavelength determines "which part gets injured"**
  波长决定 “哪个部位会受伤”
- **Radiant intensity & Exposure duration determines "how severe the injury is" and "whether the injury is reversible"**
  辐射强度和暴露持续时间决定 “损伤的严重程度” 以及 “损伤是否可逆”
- **Incident angle, operation mode, and propagation mode amplify or reduce injury risk by altering energy distribution and exposure pathways.**
  入射角、工作模式和传播方式通过改变能量分布和暴露路径来增加或降低损伤风险
- **Class 4 lasers are a "high-risk combination" of dangerous wavelength + high intensity + multiple propagation pathways, and they are the core target of laser safety prevention and control.**
  4 类激光器是 “危险波长 + 高强度 + 多种传播路径” 的 “高风险组合”，是激光安全防控的核心目标。

Case Studies
事故案例

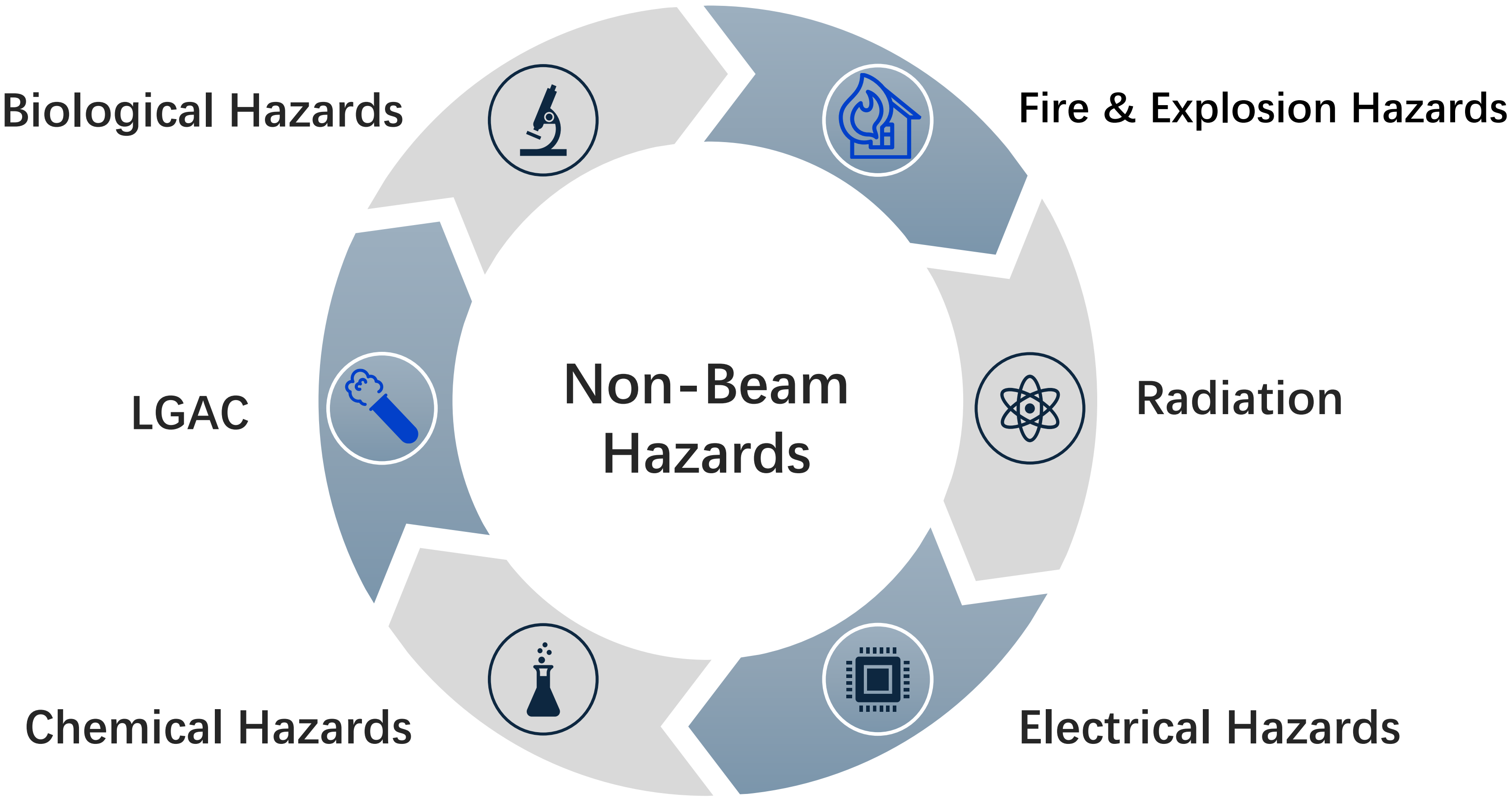
2023 年 9 月 14 日，因激光设备滤芯需更换，工作人员与设备操作工艺员将备用滤芯运至现场，对除尘器滤芯加水湿化时，11 时 32 分滤芯发生闪燃，明火被及时扑灭；13 时 30 分，工作人员与学习设备操作的人员将涉事中效净化箱移至车间通道，设备操作员随后到场；14 时许，设备操作员打开箱体后，相关人员向滤芯加水．14 时 02 分该净化箱发生爆炸。事故造成3人死亡，1人重伤。

Non-Beam Hazards (NBH) 非光束危害

Definition 定义

- Non-beam Hazards (NBH) refer to various hazards arising from system components, auxiliary processes, chemical, biological material interactions, or environmental factors during the entire lifecycle of laser systems, excluding direct laser beam exposure and reflections.

　非光束危害是激光系统全生命周期中，除激光束直接照射及反射外，由系统组件、辅助过程、化学品、生物材料交互或环境因素引发的各类危害。



Non-Beam Hazards (NBH)
非光束危害

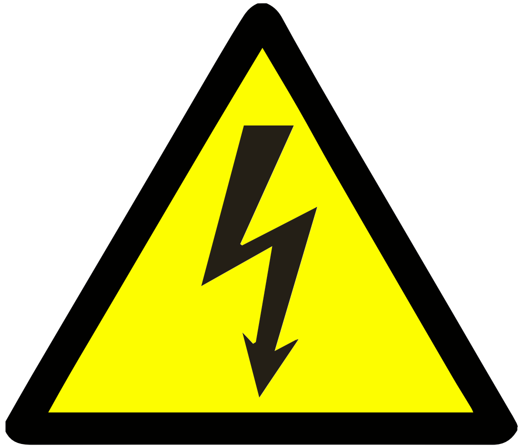
Electrical Hazards
电气危害

- **Electrical hazards 电气危害**

It represent the most common and significant non-beam hazard associated with all classes of laser systems. The primary risks include electric shock, fire from resistive heating, and ignition of flammable materials by electrical sparks. These hazards predominantly originate from high-voltage components (e.g., laser power supplies, capacitors), improper grounding, or equipment failure.

电气危害是激光系统中最常见、最严重的非光束危害。主要风险包括电击、电阻加热引发的火灾，以及电火花引燃易燃材料。这些危害主要源于高压组件 (如激光电源、电容器) 、不当接地或设备故障。

Electric Shock **电击**	Contact with exposed live conductors operating at potentials of 50 volts or above can result in electric shock.The severity can range from a perceptible tingle to severe injury, cardiac arrest, or electrocution. This risk is highest during installation, maintenance, and servicing activities.
Resistive Heating **电阻加热引发的火灾危险**	Current flow through conductors generates heat due to electrical resistance. In cases of poor connections, overloading, or component failure, excessive heat can accumulate.This can lead to insulation melting, component deformation, and ultimately, ignition of surrounding materials, causing an electrical fire.
Ignition of Flammable Materials **易燃材料的引燃**	Electrical arcs or sparks from faulty equipment can act as an ignition source for flammable gases, vapors, or dusts in the laboratory environment.A critical specific hazard involves high-voltage energy storage capacitors, which can retain a lethal charge long after being powered down. If not properly discharged, they may pose a shock hazard and potentially cause an energetic discharge that can ignite materials.



Non-Beam Hazards (NBH)
非光束危害

- **Fire Hazards 火灾**

Class 4	• Present a definitive fire hazard. Combustible enclosure materials, wire insulation, and plastic components can be ignited upon exposure to the direct, reflected, or scattered beam. 构成明确的火灾隐患。当可燃的外壳材料、电线绝缘层和塑料部件接触到直射、反射或散射光束时，可能被引燃。
Class 3B	• Under certain conditions, such as when beams interact with flammable gases, solvents, or materials, Class 3B lasers can also initiate fires. Unprotected flammable materials are particularly vulnerable to ignition from unintentional exposure to high-intensity reflected beams. 在特定条件下，例如当光束与易燃气体、溶剂或材料相互作用时，3B级激光器也可能引发火灾。未受保护的可燃材料尤其容易因意外暴露于高强度反射光束而被引燃。

Surgical fires: nightmarish "never events" persist

Lauren Vogel [1]

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PMCID: PMC5790565 PMID: 29378876

A surgeon activates a laser to shrink the tumour in a woman's trachea. There's a sudden flash and flames erupt inside the patient, choking her with smoke and burning the branching tree of airways from her larynx to her lungs. After three weeks in intensive care, the woman sues for malpractice. The laser hit the inflatable cuff around a tube delivering anesthetic gases and 100% oxygen. Expert witnesses attest that the fire could have been prevented if the anesthesiologist had followed best practices and used the lowest possible oxygen concentration, usually between 30% and 40%.

Vogel L. Surgical fires: nightmarish "never events" persist. CMAJ. 2018 Jan 29;190(4):E120.

Non-Beam Hazards (NBH)
非光束危害

Explosion
爆炸

- Explosion 爆炸:

High-Pressure Components 高压组件	• Arc lamps, flashlamps, and capacitors can rupture or explode violently due to mechanical failure, electrical overstress, or improper operation. 弧光灯、闪光灯和电容器可能因机械故障、电应力过高或操作不当而破裂或剧烈爆炸。
Target Interactions 靶材相互作用	• The laser beam can cause certain target materials to vaporize rapidly or undergo thermal stress, leading to ejection of molten particles or shattering of the target, posing a projectile hazard. 激光束可能导致某些靶材迅速汽化或承受热应力，造成熔融颗粒飞溅或靶材破裂，产生抛射物危害。
Chemical Lasers 化学激光器	• Reactant chemicals and pressurized lasing gases used in some laser systems may have inherent explosive properties. 某些激光系统中使用的反应物化学品和加压激光气体可能具有固有的爆炸性。
Ancillary System Hazards 辅助系统的危害	• Laser processing of materials can generate combustible dusts. If accumulated in ventilation systems, these dusts can be ignited by a spark or the laser beam itself, leading to a dust explosion. 材料激光加工可能产生可燃性粉尘。若在通风系统中积聚，这些粉尘可能被电火花或激光束本身引燃，导致粉尘爆炸。

Non-Beam Hazards (NBH)
非光束伤害

Laser Generated Air Contaminants (LGAC)
激光产生的空气污染物

- When laser beams interact with matter, they can produce a complex mixture of airborne hazardous materials known as Laser-Generated Air Contaminants (LGAC). The quantity, chemical composition, and toxicity of these contaminants are highly dependent on the target material, the presence of any cover or assist gases, and the laser beam's irradiance and exposure time.

当激光束与物质相互作用时，会产生复杂的空气传播有害物质混合物，称为激光产生的空气污染物。这些污染物的数量、化学成分和毒性高度依赖于靶材、是否存在保护气或辅助气体，以及激光束的辐照度和曝光时间。

Particulate Matter **颗粒物**	• Metallic fumes (e.g., from cutting metals) and fine soot. 金属烟雾 (例如，来自金属切割) 和细微烟尘。
Chemical Vapors Gases **化学蒸汽和气体**	• Toxic and carcinogenic compounds released from heated or vaporized materials. 材料受热或汽化释放出的有毒和致癌化合物。
Biological Aerosols **生物气溶胶**	• Airborne particles generated from the interaction with human or animal tissues, which may include bioaerosols, cellular debris (both viable and non-viable), bacteria, fungi, and viruses. This is a significant hazard in laser surgery. 与人体或动物组织相互作用产生的空气传播颗粒，可能包括生物气溶胶、细胞碎片 (存活和非存活的) 、细菌、真菌和病毒。这是激光手术中的一个重大危害。

Non-Beam Hazards (NBH)
非光束伤害

Gas Hazards
气体危害

- Laser systems often utilize gases that pose significant chemical and physical hazards, including toxicity (e.g., chlorine, fluorine), corrosivity (e.g., hydrogen chloride), flammability, and high pressure.
  激光系统常使用具有显著化学和物理危害的气体，包括毒性 (如氯气、氟气)、腐蚀性 (氯化氢)、易燃性及高压。
- Cryogenic fluids/gas used for cooling lasers or detectors present two primary hazards
  用于激光器或探测器冷却的低温液体 (气体) 主要有两大危害:

Cold Contact Burns 接触性冻伤

Skin or eye contact with cryogenic fluids or gas can cause severe frostbite injuries

皮肤或眼睛接触低温液体或气体，可导致严重的冻伤损伤。

Asphyxiation Risk 窒息风险

In confined or poorly ventilated spaces, the rapid evaporation and expansion of these fluids can displace oxygen, creating an oxygen-deficient atmosphere capable of causing unconsciousness or death.

在密闭或通风不良的空间内，这些液体的迅速蒸发和膨胀会取代氧气，形成缺氧环境，可能导致昏迷或死亡。

风险提醒 Level of Risk

氧含量比例 Oxygen Scale

6%	12%	16%	19.5% — 23%	> 23%
Death	Unconscious	Fast breathing, increased heart rate, drowsiness & nausea	**Normal, safe oxygen levels**	Increase fire risk
死亡	无意识	呼吸急促，心率加快，嗜睡和恶心	正常范围，安全范围	火灾风险大

When O_2 sensor alarm is being heard, DO NOT Enter (Exit immediately). Inform relevant staff or call security control center 8833 0110, and wait until it is safe to enter.

当听到氧气探测仪报警后，不要进入，立即离开。通知相关工作人员，或拨打保安控制中心电话8833 0110，待确认安全后，方可进入。

Non-Beam Hazards (NBH)
非光束伤害

Laser Dye Hazards
激光染料危害

- **Risks of Dyes Themselves 染料本身风险**

Laser dyes are complex fluorescent organic compounds that form the lasing medium for dye lasers when mixed with specific solvents. Some dyes are highly toxic or carcinogenic, requiring special care during replacement.

激光染料是复杂的荧光有机化合物，与特定溶剂混合后形成染料激光的激光介质，部分染料具有高毒性或致癌性，更换时需特别小心。

- **Solvent-Related Risks 溶剂相关风险**

Dimethyl sulfoxide (DMSO) is commonly used as a solvent for cyanine dyes and can promote dye penetration into the skin. If no alternative solvent can be found, personnel must wear low-permeability gloves when contact with the solvent may occur.

二甲基亚砜 (DMSO) 常用作花青染料的溶剂，其会促进染料渗透皮肤，若无法更换其他溶剂，操作人员接触时需佩戴低渗透性手套。

- **Storage and Leak Handling 储存与泄漏**

Dye lasers containing at least 100 milliliters of flammable liquid must comply with relevant NFPA standards. Dye pumps and reservoirs should be placed in secondary containment vessels to minimize leakage and spills; dye preparation must be conducted in a laboratory fume hood, and related waste must be disposed of in accordance with regulations.

含有至少 100 毫升易燃液体的染料激光器需符合 NFPA 相关标准，染料泵和储液器应放置在二次密闭容器中以减少泄漏和溢出；染料制备需在实验室通风橱中进行，相关废弃物需按规定处理。

Non-Beam Hazards (NBH)
非光束伤害

Non-Beam Hazards of Common Laser——Excimer Lasers
常见激光的非光束伤害——准分子激光

- **Basic Characteristics 基础特性**

UV band, typically 193 nm (ArF), 248 nm (KrF) and 308 nm (XeCl).Pulsed operation with pulse widths in the nS to mS range. While pulse energy is high, the average power is relatively low.A reactive gas mixture comprising a noble gas and a halogen gas. Lasing action is initiated by a high-voltage electric discharge.

主要集中在紫外波段，典型波长为 193 nm、248 nm和308 nm。脉冲运行，脉冲宽度在纳秒到微秒级；脉冲能量高，但平均功率相对较低。工作介质通常为惰性气体与卤素气体组成的混合物，通过高压放电激发产生激光。

- **Application Scenarios 使用场景**
  Medical Field, Semiconductor Industry, Material Processing.
  医疗领域、半导体行业、材料加工
- **Non-Beam Hazards 非光束伤害**
  Toxic Gas Hazards 有毒气体危害
  Electrical Hazards 电气危害
  LGAC 激光产生的空气污染物

Non-Beam Hazards (NBH)
非光束伤害

Non-Beam Hazards of Common Laser——HeNe Laser
常见激光的非光束伤害——氦氖激光

- **Basic Characteristics 基础特性**

  Primarily emits in the red visible spectrum at 632.8 nm. Other, less common wavelengths include green (543 nm) and infrared (1152 nm).Continuous wave, some of the lowest power lasers in common use.A mixture of helium and neon gases within a sealed glass tube, excited by a low-voltage DC power supply.

  主要发射可见红光，波长为 , 632.8 nm。其他较少见波长包括绿光 (543 nm) 和红外 (1152 nm) 。连续波运行；功率较低，通常为 0.1~10 mW。密封玻璃管内的氦氖混合气体，由低压直流电源激发。

- **Application Scenarios 使用场景**

  Alignment and Positioning, Optical Demonstrations and Education, Low-Power Sensing and Scanning.

  对准与定位、光学演示与教育、低功率传感与扫描

- **Non-Beam Hazards 非光束伤害**

  Minor Electrical Hazards 轻微电气危害

  Mechanical Hazards 机械危害

  Visual Interference 视觉干扰

Non-Beam Hazards (NBH)
非光束伤害

Non-Beam Hazards of Common Laser——Argon Laser
常见激光的非光束伤害——氩气激光

- **Basic Characteristics 基础特性**

Emits on multiple lines in the visible spectrum, with the strongest typically at 488 nm (blue) and 514.5 nm (green). Some models can also emit ultraviolet (UV) lines.Primarily continuous-wave (CW). Output power can range from hundreds of milliwatts to over 20 watts for large-frame systems.Uses high-purity argon gas excited by a high-current DC discharge or RF excitation. High-power models require efficient water cooling to manage substantial waste heat.

在可见光波段存在多条谱线，最强谱线通常为488 nm (蓝光) 和514.5 nm (绿光) 。部分型号也可发射紫外谱线。主要为连续波。输出功率可从数百毫瓦至超过20瓦 (大型系统) ，采用高纯度氩气，通过大电流直流放电或射频激励激发。高功率型号需要高效的水冷系统来处理大量的废热。

- **Application Scenarios 使用场景**

Medical Field, Industrial and Scientific Research, Biotechnology.
医疗领域、工业与科研、生物技术

- **Non-Beam Hazards 非光束伤害**

Electrical Hazards 电气危害
Thermal Hazards 热危害
LGAC 激光产生的空气污染物
UV Collateral Radiation 紫外附带辐射

Non-Beam Hazards (NBH)
非光束伤害

Non-Beam Hazards of Common Laser——CO_2 Laser
常见激光的非光束伤害——二氧化碳激光

- **Basic Characteristics 基础特性**

Primary output at 10.6 micrometers (μm) in the far-infrared (FIR) region, invisible to the human eye. A secondary line exists at 9.6 μm.Available in both continuous-wave and pulsed modes. CW powers range from watts to over kilowatts. Pulsed versions can deliver energies up to joules level.A gas mixture of CO_2, N_2, and He excited by DC or RF discharge. Efficient cooling (often water-based) is critical to manage the substantial heat generated.

主输出波长为远红外波段的 10.6 微米，人眼不可见。次要谱线为 9.6 μm。支持连续波和脉冲两种模式。连续波功率从瓦级到千瓦级以上。脉冲激光的能量可达焦耳级。工作物质为CO_2、N_2和He的混合气体，通过直流或射频放电激发。高效的冷却 (通常为水冷) 对于管理产生的巨大热量至关重要。

- **Application Scenarios 使用场景**

Industrial Processing; Medical Field; Scientific and Environmental Applications

工业加工、医疗领域、科研与环境应用

- **Non-Beam Hazards 非光束伤害**

Fire Hazards 火灾危害
Thermal Hazards 热危害
LGAC 激光产生的空气污染物
Electrical Hazards 电气危害

Non-Beam Hazards (NBH)
非光束伤害

Non-Beam Hazards of Common Laser——YAG Lasers
常见激光的非光束伤害——钇铝石榴石晶体激光

- **Basic Characteristics 基础特性**

The fundamental output is at 1064 nm in the near-infrared (NIR) spectrum, which is invisible.Operates in continuous-wave (CW) with powers from W to kW, or in pulsed mode with pulse widths ranging from mS down to fS. Pulsed modes generate extremely high peak powers. Requires cooling, especially at high powers.

输出为近红外波段的 1064 nm，不可见。 在连续波下运行功率从瓦到千瓦；也可在脉冲模式下运行，脉冲宽度从毫秒到飞秒，脉冲模式可产生极高的峰值功率。需要冷却来散热，尤其是在高功率运行时。

- **Application Scenarios 使用场景**

Industrial Processing, Medical Field, Scientific Research, Defense and Aerospace

工业加工、医疗领域、科研领域、国防与航空航天

- **Non-Beam Hazards 非光束伤害**

Electrical Hazards 电气危害
Thermal Hazards 热危害
Laser-Induced Plasma Radiation 激光诱导等离子体辐射
Mechanical Hazards 机械危害

Hazard Control Approaches 危害控制措施

Engineering Controls 工程措施

- **Protective Housing 防护外壳**

  Enclose laser equipment to prevent access to hazardous laser radiation; equipped with interlocks to terminate laser emission when opened.

  封装激光设备，防止接触有害激光辐射；配备联锁装置，打开时终止激光发射。

- **Interlocks 安全联锁**

  Fail-safe interlocks for removable protective housings, service access panels, and entryways to cut off laser power when safety barriers are breached.

  用于可移除防护外壳、维修检修面板和入口的失效安全联锁，在安全屏障被破坏时切断激光电源。

- **Viewing windows & display screens 观察窗与显示屏幕**

  Equipped with filters or attenuators to ensure transmitted laser radiation is below the MPE; made of materials resistant to laser-induced damage.

  观察窗和显示屏幕：配备滤光片或衰减器，确保透射激光辐射低于MPE,采用抗激光损伤材料制成。

Hazard Control Approaches
危害控制措施

Engineering Controls
工程措施

- **Laser protective barriers and curtains 激光防护屏障和幕帘**

  Used as boundaries of the Nominal Hazard Zone (NHZ) to attenuate direct or scattered laser radiation to safe levels.

  作为标称危险区域 (NHZ) 的边界，将直射或散射激光辐射衰减至安全水平。

- **Beam path control 光束路径控制**

  Enclose beam paths, use beam stops to terminate stray beams, and avoid beam paths at eye level; install baffles to prevent errant beams.

  封装光束路径，使用光束阻挡器终止杂散光束，避免光束路径处于人眼高度；安装挡板防止光束偏移。

Hazard Control Approaches
危害控制措施

Engineering Controls
工程措施

- **Area warning devices 区域警示装置**

  Visible and audible warning devices to alert personnel when lasers are operating or about to start.

  可见和可听警示装置，在激光运行或即将启动时提醒人员。

- **Entryway controls 入口控制**

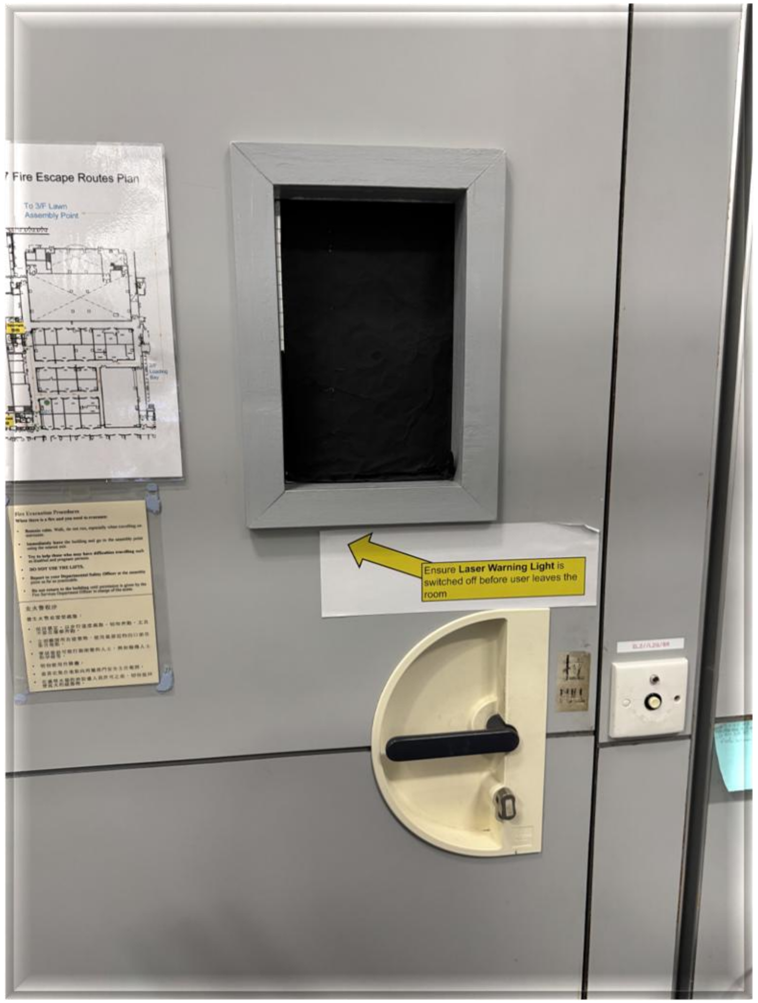
  For Class 4 lasers, use non-defeatable or defeatable entryway interlocks, pressure-sensitive mats, or light curtains to restrict unauthorized access.

  针对 4 类激光，使用不可规避或可规避的入口联锁、压敏垫或光幕，限制未经授权的进入。

- **Emergency stop devices 紧急停止装置**

  Clearly marked and easily accessible devices to deactivate lasers immediately in emergency situations.

  标识清晰、易于操作的装置，在紧急情况下立即停用激光。



Hazard Control Approaches
危害控制措施

Administrative controls
管理措施

Risk assessment 风险评估 01

- Conduct comprehensive risk assessments for laser systems, considering normal operation, foreseeable faults, maintenance, and service scenarios.

对激光系统进行全面的风险评估，考虑正常运行、可预见的故障、维护及检修场景。

Laser Controlled Area 激光控制区域 02

- Establish LCAs for Class 3B and 4 lasers, with clear boundaries, warning signs, and access control.
- implement temporary LCAs during maintenance.

为 3B 类和 4 类激光器建立激光控制区域（LCAs），设置清晰的边界、警告标志和出入控制。在维修期间设置临时管控。

Authorized personnel 授权人员 03

- Restrict laser operation, maintenance, and service to trained and authorized individuals.
- Prohibit unauthorized personnel from accessing laser-controlled areas.

仅限经过培训和授权的人员进行激光操作、维护和检修。设置清晰的边界、警告标志和出入控制。禁止未经授权人员进入激光控制区域。

SOP 标准操作规程 04

- Develop written SOPs for laser operation, maintenance, alignment, and service.
- Specify safety requirements and hazard mitigation measures.

制定激光操作、维护、校准和服务的书面标准操作规程。明确安全要求和减少危险的措施。

Hazard Control Approaches
危害控制措施

Administrative controls
管理措施

Warning Signs & Labels
警示标识与标签
05

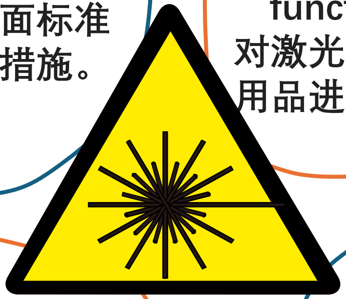
- Affix clear warning labels on laser equipment, protective housings, barriers, and LCAs, indicating laser class, wavelength, power, and safety precautions.

制定激光操作、维护、校准和服务的书面标准操作规程。明确安全要求和减少危险的措施。

Maintenance & Inspection
维护与检查
06

- Implement regular maintenance and safety inspections for laser guards, interlocks, warning devices, and PPE to ensure functionality.

对激光防护装置、联锁装置、警告装置和个人防护用品进行定期维护和安全检查，以确保其功能正常。



Education and Training
教育与培训
07

- Provide specialized training for operators, maintenance personnel, and SOs on laser hazards, control measures, and emergency response.

对操作人员、维护人员和安全管理人员进行激光危害、控制措施和应急响应的专门培训。

Records Keeping
记录保存
08

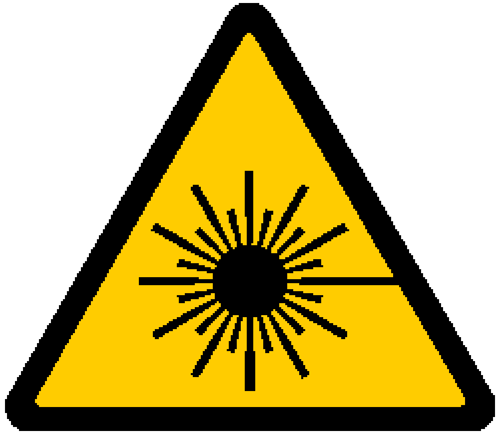
- Maintain records of training, risk assessments, maintenance inspections, incidents, and equipment certifications.

维护培训、风险评估、维修检查、事故和设备认证记录。

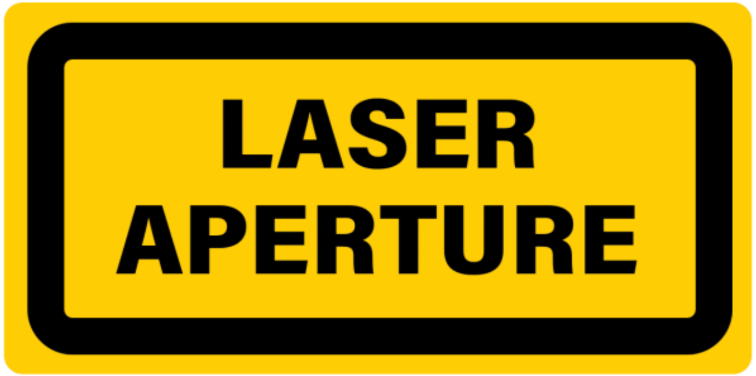
Hazard Control Approaches
危害控制措施

Administrative controls
管理措施

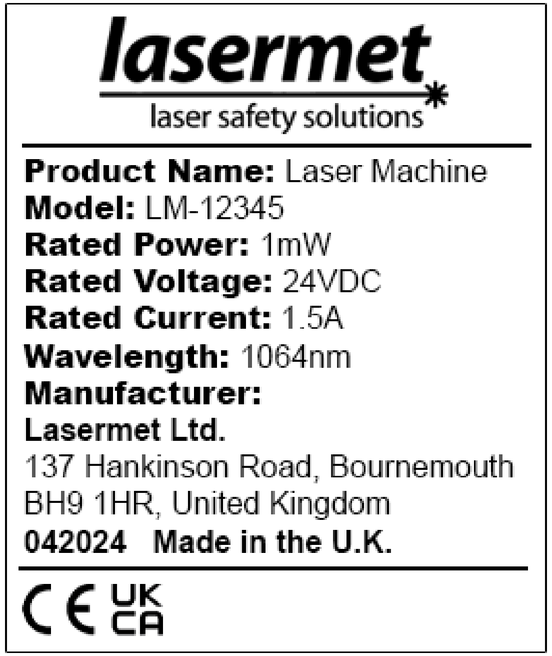
WARNING TRIANGLES



APERTURE LABELS



PRODUCT INFORMATION LABELS

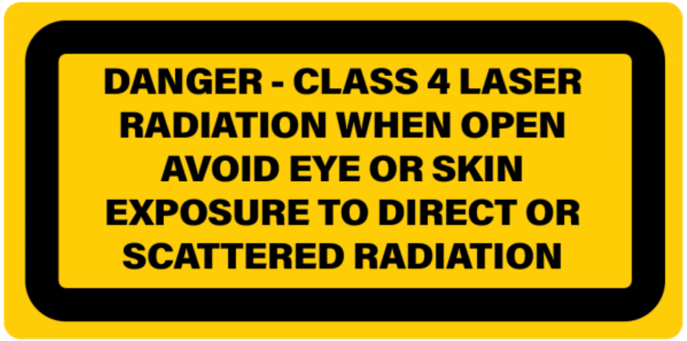


CLASSIFICATION LABELS

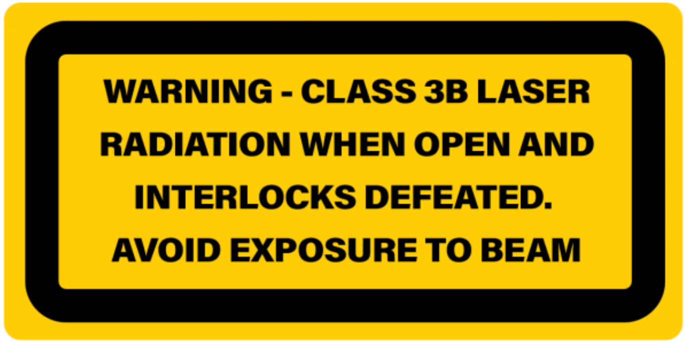
Hazard Control Approaches
危害控制措施

Administrative controls
管理措施

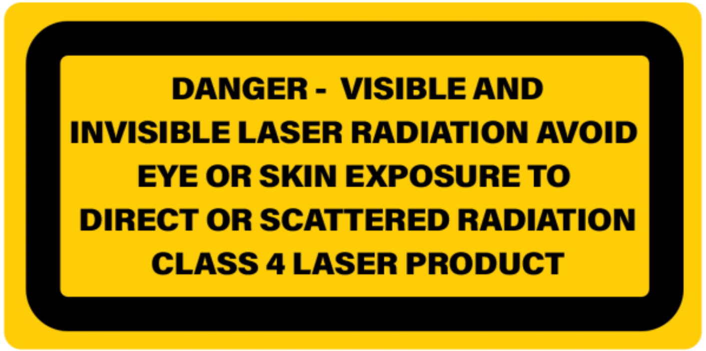
PROTECTIVE HOUSING LABELS



INTERLOCKED HOUSING LABELS



"INVISIBLE" OR "VISIBLE AND INVISIBLE" RADIATION WARNINGS



Hazard Control Approaches
危害控制措施

Personal protective equipment
个人防护装备

- While engineering and administrative controls are the primary safeguards, appropriate Personal Protective Equipment (PPE) serves as a critical last line of defense against laser radiation and associated hazards.
  尽管工程控制和管理控制是主要防护措施，但合适的个人防护装备是抵御激光辐射及相关危害的最后一道关键防线。

- **Laser Protective Eyewear: The Primary Defense**
  激光防护眼镜：首要防护

Select eyewear with a sufficient Optical Density (OD) at the specific laser wavelength(s) in use to reduce beam exposure to below the Maximum Permissible Exposure (MPE) limit.

所选眼镜必须在所用激光的特定波长上具有足够的光密度，以确保将辐照量降至最大允许照射量以下。

Ensure a comfortable fit that provides coverage from all potential exposure angles (side, front, and reflected beams). All eyewear must comply with relevant laser safety standards.

确保舒适贴合，并能防护所有潜在的暴露角度(侧面、正面及反射光束)。所有眼镜必须符合相关的激光安全标准。

Hazard Control Approaches
危害控制措施

Personal protective equipment
个人防护装备

Comply to ANSI Z136.1, EN 207, GB 30863 etc.

- ANSI Z136.1
- EN207: Personal eye-protection equipment - Filters and eyeprotectors against laser radiation (laser eye-protectors)
- GB 30863 个体防护装备 眼面部防护 激光防护镜

Table 1 — Scale numbers (maximum spectral transmittance and resistance to laser radiation) of the filters and/or eye-protectors against laser radiations

Scale number	Maximum spectral transmittance at the laser wavelength	Power (E) / energy density (H) for testing the protective effect and resistance to laser radiation in the wavelength range								
		180 nm to 315 nm			> 315 nm to 1 400 nm			> 1 400 nm to 1 000 µm		
		For test condition/pulse duration in seconds (s)								
		D ≥ 3×10^{4}	I, R 10^{-9} to 3×10^{4}	M < 10^{-9}	D > 5×10^{-4}	I, R 10^{-9} to 5×10^{-4}	M < 10^{-9}	D > 0,1	I, R 10^{-9} to 0,1	M < 10^{-9}
	$\tau(\lambda)$	E_D W/m²	$H_{I,R}$ J/m²	E_M W/m²	E_D W/m²	$H_{I,R}$ J/m²	H_M J/m²	E_D W/m²	$H_{I,R}$ J/m²	E_M W/m²
LB1	10^{-1}	0,01	3×10^{2}	3×10^{11}	10^{2}	0,05	$1,5 \times 10^{-3}$	10^{4}	10^{3}	10^{12}
LB2	10^{-2}	0,1	3×10^{3}	3×10^{12}	10^{3}	0,5	$1,5 \times 10^{-2}$	10^{5}	10^{4}	10^{13}
LB3	10^{-3}	1	3×10^{4}	3×10^{13}	10^{4}	5	0,15	10^{6}	10^{5}	10^{14}
LB4	10^{-4}	10	3×10^{5}	3×10^{14}	10^{5}	50	1,5	10^{7}	10^{6}	10^{15}
LB5	10^{-5}	10^{2}	3×10^{6}	3×10^{15}	10^{6}	5×10^{2}	15	10^{8}	10^{7}	10^{16}
LB6	10^{-6}	10^{3}	3×10^{7}	3×10^{16}	10^{7}	5×10^{3}	$1,5 \times 10^{2}$	10^{9}	10^{8}	10^{17}
LB7	10^{-7}	10^{4}	3×10^{8}	3×10^{17}	10^{8}	5×10^{4}	$1,5 \times 10^{3}$	10^{10}	10^{9}	10^{18}
LB8	10^{-8}	10^{5}	3×10^{9}	3×10^{18}	10^{9}	5×10^{5}	$1,5 \times 10^{4}$	10^{11}	10^{10}	10^{19}
LB9	10^{-9}	10^{6}	3×10^{10}	3×10^{19}	10^{10}	5×10^{6}	$1,5 \times 10^{5}$	10^{12}	10^{11}	10^{20}
LB10	10^{-10}	10^{7}	3×10^{11}	3×10^{20}	10^{11}	5×10^{7}	$1,5 \times 10^{6}$	10^{13}	10^{12}	10^{21}

The symbols D, I, R and M relative to the test conditions are explained in Table 4.

Hazard Control Approaches
危害控制措施

Personal protective equipment
个人防护装备

Selection, Storage and Maintenance of Laser Protective Eyewear
激光防护眼镜的选型、保存与保养

- Matching with Wavelength & Power
  匹配波长与功率
- Determination of Optical Density
  匹配光密度
- Ergonomic Design and Fit
  人体工学舒适性

- Suitable Storage Environment
  适宜的保存环境
- Proper Storage Containers
  适宜的储存容器
- Avoidance of Cross-Contamination & Misuse
  避免交叉污染和误用
- Preservation of Labeling Information
  标签信息的保存

- Regular Cleaning Procedures
  定期清洁
- Routine Inspection and Testing
  例行检查及测试
- Handling of Deteriorated Eyewear
  处理老化眼镜

Selection

Storage

Maintenance

Hazard Control Approaches
危害控制措施

Personal protective equipment
个人防护装备

- **Hand Protection: Laser-Rated Gloves**
  手部防护：激光防护手套
  Use gloves for safety, which are impervious to flame-retardant.
  使用符合激光安全等级的手套，其应具有阻燃性。

- **Facial Protection: Laser Safety Face Shields**
  面部防护：激光防护面罩
  Use laser safety face shields to protect the entire face from intense scattered radiation, plasma flash, and flying debris generated during material processing.
  使用激光防护面罩保护整个面部，以阻挡强烈的散射辐射、等离子体闪光及材料加工过程中产生的飞溅物。

Hazard Control Approaches
危害控制措施

Personal protective equipment
个人防护装备

- Do not wear clothes with metallic or highly reflective fabrics — they may reflect laser and raise accidental injury risk.
  忌穿金属质感、高反光面料的衣物
- Avoid wearing metal accessories (e.g., necklaces, bracelets, earrings) — metal may reflect laser and cause burns when heated.
  忌佩戴项链、手链、耳环等金属饰品

Emergency Response
应急处置

- **Eye burn 眼部灼伤**
  Shut down laser immediately, remove goggles 立即停止激光，移除防护镜
  Bring laser parameters (wavelength, power) to hospital 携带激光参数(波长、功率) 就医
  Inform doctor of "laser-induced eye burn" 告知医生 “激光眼部灼伤”

- **Fire 火灾**
  Turn off laser power + cylinder valve 关闭激光电源 + 气瓶阀门
  Use CO_2, dry powder extinguisher (no water for electrical fire) 用 CO_2、干粉灭火器扑救(禁止用水灭电气火灾)
  Evacuate personnel, call fire department 疏散人员，拨打火警电话

- **Others 其他事故**
  May refer to the emergency guidelines of the LHSD.
  可参考LHSD应急指南

In Laser Safety, Little Mistakes Can Have Big Consequences

Eye injuries are an integral part of the history of lasers, but with a cultural change among experimentalists, that need not be the case.

Reference
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