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Application of laser technology in textiles

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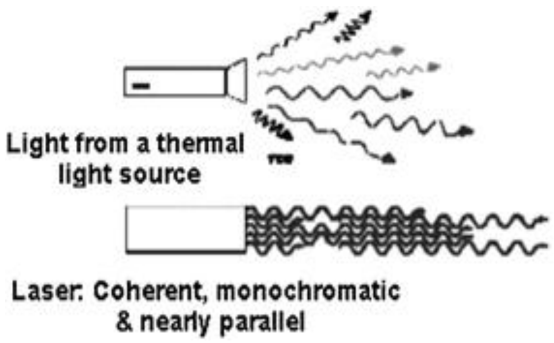
Abstract
Laser is an energy source, whose intensity and power can be precisely controlled. Laser can help to cut a variety of objects ranging from flexible fabric to rigid and strong metal. *LASER* is *light amplification by stimulated emission of radiation*. The most widely used unit to express the wavelength of a laser is in nanometer (nm). Laser light emitted from a laser has four fundamental characteristics: Intensity, Coherency, Mon chromaticity, Collimation which distinguish it from natural light. Lasers are being classified into four classes and some subclasses depending on their wavelength and maximum output power. This classification is based on the severity of the damage to a person when exposed to laser. These classes can be from 1 to 4. In the classes' 1–4 laser, there are the sub-classes 1M, 2M, 3A and 3B. Lasers have paved their way in the several sections of textile industry such as cutting, engraving, mass customization, bar code scanning etc. Laser equipment are becoming widely popular in textile, leather and garment industries due to the advantage of accuracy, efficiency, simplicity and the scope of automation. In garment production, it can be applied onto different products ranging from home textiles to fashion accessories. The old laser equipment were difficult to run, cumbersome and hard to maintain. However, the modern equipment are easy to operate, simple to learn and easy to maintain. Furthermore, the earlier equipment had several safety issues and they needed replenishment of gasses at regular intervals. The garment production units should take the advantage of applying laser in the post multi-fibre agreement regime to produce more competitive products.

Keywords: Laser, radiation, Mon chromaticity, mass customization

1. Introduction
Laser is an energy source, whose intensity and power can be precisely controlled. Laser is an electromagnetic radiation, produced by the atoms due to energy states are changed in some *materials. The* atoms promoted to higher energy states emit laser in the form of light by the process known as "stimulated emission". Subsequently, this laser is being amplified in a suitable lasing medium with the help of mirrors. The final laser delivers from the equipment as a stream similar to light. The colour of the laser depends on its wavelength. The most widely used unit to express the wavelength of a laser is in nanometre (nm).
Laser light emitted from a laser has four fundamental characteristics: Intensity, coherency, monochromaticity and collimation,
Which distinguish it from natural light. A high energy concentration per unit area of the beam is present in the laser. A laser beam can be of very high intensity with 1–2 mm of beam diameter and an output power of some milliwatts (mW).



It can be observed that the ordinary light (from a thermal source) is incoherent, i.e., light waves are generated at different times and propagate in all possible directions randomly. However, laser is coherent as shown in the figure due to the waves are in phase while they propagate. Ordinary light is composed of all the colours in the visible region, but laser light is of a single colour or monochromatic. The coherent nature in addition to the Monochromaticity results in highly collimated laser. As all the waves propagate in same phase in parallel lines, there is almost no divergence as observed in light. This property of laser helps in achieving high intensity even after travelling a long distance. The energy concentration of the beam can be increased by manifold when the beam is focused as a point with the help of optical lens.

Classification of Laser

Laser classification based on hazards: Lasers are being classified into four classes and some subclasses depending on their wavelength and maximum output power. This classification was based on the severity of the damage to a person when exposed to laser. These classes can be from 1 to 4. In the classes' 1-4 laser, there are the sub-classes 1M, 2M, 3A and 3B.

Table 1: The new system for laser classification

Laser class	Features
Class 1	The Class 1 laser is the safest under normal use. These lasers may pose a risk when viewed with a telescope or microscope of sufficiently high aperture
Class 1M	The Class 1M laser is safe during normal use. However, when passed through a magnifying device such as a microscope can pose hazard. A laser falls in this class if the power that can pass through the pupil of a naked eye is lower than the Accessible Emission Level (AEL) for Class 1
Class 2	A Class 2 laser is the visible-light laser (400–700 nm). It is safe as the blink reflex will limit the exposure time lower than 0.25 sec. However, intentional holding of the blink reflex could lead to potential eye injury. Several measuring instruments and laser pointers are based on Class 2
Class 2M	This class laser is safe as the blink reflex if not viewed through optical instruments. Similar to Class 1M, this class laser lights are with a large divergence, the light passing through the pupil should not exceed the specifications for Class 2
Class 3	This laser class is safe only if handled with precautions and proper protective clothing.
Class 3A	This laser class is safe if handled carefully. The maximum permissible exposure (MPE) can be exceeded, which is associated with a low injury risk
Class 3B	This class is hazardous if exposed directly to the eye. Protective eyewear must be used where direct viewing is needed or may occur. The equipment with Class 3B lasers must be fitted with a safety interlock and a key switch
Class 4	This class is the most dangerous among all lasers. This laser can cause permanent eye damage or burn the skin as a result of direct, diffuse or indirect beam viewing or contact. These lasers may cause a fire risk as they can ignite combustible materials. Several laser used in scientific, industrial, military and medical applications fall in this category. The equipment with Class 4 lasers must be fitted with a safety interlock and a key switch

Applications of Laser

Laser engraving and cutting technologies now being widely applied in many garment industries, fabric production units, other textile and leather industries. The features of laser applications include:

- Laser marking, laser engraving and laser cutting combined in one step
- No mechanical wear, hence good quality
- No fixation of material is required due to force-free processing
- No fabric fraying in synthetic fibres due to formation of fused edges
- It is clean and lint-free
- Simple process due to integrated computer design
- High quality raw materials and significant cost saving
- Extremely high precision in cutting contours
- High working speed
- Contactless, wear-free technique
- No chips, less waste

- **Fabric fault detection:** When fabric is received at the stores of a garment production unit, the faults in the fabric can be detected with morphological image processing based on laser. Laser-based optical Fourier transform analysis can be used for fault detection in the fabric as the pattern is repeated at regular intervals. The fabric is focused with a laser and the diffraction gratings obtained from the periodicity of longitudinal and transverse threads in the fabric are superimposed. A Fourier lens is used to produce the diffraction pattern of the fabric. A second Fourier lens with same focal length magnifies and inverts the test sample image. A charge-coupled device (CCD) camera is used to capture the image. The data is transferred and stored in a computer. The computer programming helps in comparing the acquired images with the stored images by converting the image into binary mode. A fault is reported when the measured parameter is deviating from the standard. The severity of the fault depends upon the amount of deviation from the standard.
- **Laser cutting:** In laser cutting a laser is used to cut the fabric into the desired pattern shapes. A very fine laser is focused on to the fabric surface, which increases the temperature substantially and cutting takes place due to vaporization. Normally gas lasers (CO_2) are used for cutting of fabric. The cutting machine includes a source of laser, a cutting head fitted with mirrors to reflect the laser beam to the cutting line, a computer to control the entire system and a suitable mean for removing the cut parts. The application of inert gases (N2, He) during cutting prevents the charring and removes debris and smoke from the cutting area. Like the mechanical cutting devices, a laser beam does not become blunt and need sharpening.

Advantages of Laser Cutting

- Laser cutting is cheaper compared with the traditional cutting methods. Furthermore, as the laser cutting doesn't have mechanical action, high precision of the cut components at high cutting speed are feasible (Nayak and Khandual 2010) [5].
- The laser cutters are safer and include simple maintenance features, which can be operated or longer duration. The laser cutters can be integrated to the computer technology.
- It can produce the products at the same time when designing in the computer. Laser cutting machines have faster speed and simpler operation.

Limitation of Laser Cutting: The limitation of laser cutting is the number of lays of the fabric that can be cut by the beam. Best result is obtained while cutting single or a few lays, but the accuracy and precision is not obtained with several plies. In addition there is a chance of the cut edges to be fused together especially in case of synthetics.

- **Objective evaluation of seam pucker:** Garment appearance greatly influences garment quality. Seam pucker negatively affects the garment appearance. The laser beam can measure the degree of puckering in garments by geometrical models. In this method a seam in the garment is scanned by a 3D laser scanner by putting the garment on a dummy. The laser head can be moved to any 3D space within a confined place by an operator. It is possible to scan the target object from different angles. A pucker profile of the scanned seam can be obtained by processing the image with a 2D digital filter.
- **Mass customization:** The term mass customization is used when custom-fit garments are obtained depending on the body dimensions and individual's choice. The very first thing to mass customize garments is the accurate measurements of individual's body. Laser scanning technology is one of the many techniques used for measurement. Laser scanning technology uses one or multiple thin and sharp stripe lasers to measure body size. Cameras are also used to acquire the scene and assist the laser scanner. The body measurements are derived by applying simple geometrical rules. In order to confirm the harmlessness of the beam, only eye-safe lasers can be used.

  Lu *et al.* (2010) [4] studied the development of an intelligent system for customized clothing making. The system involves body dimension collection, clothing pattern generation and fabric cutting. First, body dimensions can be collected by analyzing the 3D scanning images or 2D photographs. Further, the clothing patterns can be generated by using computer-aided design (CAD) techniques based on the collected dimensions. By presenting the generated clothing patterns in DXF (Drawing Exchange Format), the CNC laser-cutting machine can then cut the fabric into pattern pieces automatically. Finally, by integrating the system with the processes of garment sewing, fitting test and final adjustment, the concept of customized clothing making can be realized. It can not only assure good fitness of the customized clothing but also reduce human efforts, costs, and production time.

- **Laser-based denim fading:** Now the age of fading of denim by sandblasting is becoming older as the new technology of laser fading is replacing it. In laser fading, a computer drives the laser beam to the material where marking or fading is required. The laser beam decomposes the dye and the resulting vapors are vented away. The material fades only where the beam impacts on the fabric. Commercially two types of lasers are being used: solid based (wavelength of 1 µm) and gas based (wavelength of 10 µm). The desired degree of fading depends upon the wavelength, power density, and pulse width of the laser beam. The method of marking or fading by laser is more environmental friendly as compared to acid washing or sandblasting.

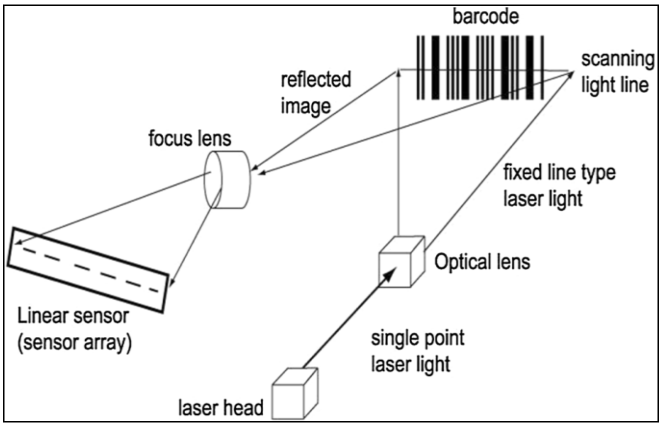
  Kan (2014) [3] used a carbon dioxide (CO_2) laser for the colour-fading treatment of denim fabrics. Two types of denim fabrics were laser-treated: one was manufactured with low-twist yarn spun by torque-free ring-spinning technology, and the other was manufactured by conventional ring-spun yarn. The denim fabric samples were treated with a CO_2 laser under the same conditions, and two laser processing parameters, namely, (i) resolution and (ii) pixel time, were used to adjust the laser power. After laser treatment, the colour properties and dimensional stability of the denim samples were compared, and the results were analysed thoroughly. In addition, the colour-fading effect induced by CO_2 laser treatment was compared with that induced by conventional cellulase treatment. Experimental results revealed that CO_2 laser treatment is an effective alternative means of producing the colour-fading effect in denim fabrics if the processing parameters can be carefully controlled.
- **Laser engraving:** In laser engraving laser is used to mark or engrave an object. The process is very complex, and often computerised systems are used to drive the laser head In spite of the complexity, very precise and clean engravings can be obtained with high rate of production. The technique does not involve physical contact with the engraving surface, hence, no wear and tear. The marks produced by laser engraving are clean, crisp and permanent. In addition, lasers are faster than other conventional methods used for product imprinting, which provides greater versatility in material selection. Laser engraving is used to engrave the printing screens, for hollowing, for creating pattern buttons, to engrave leather, denim etc. Pictures, flower patterns and even personalized signatures can be engraved on leather shoes, leather bag, wallet, leather belt, leather sofa and leather clothes, greatly increasing the added value of products. In addition laser engraving is used to create embroidered pattern in the fabric by colour fading and burning the fabrics. The low cost sealed CO_2 lasers are preferred for laser engraving. Denim engraving is another fast-growing application of laser using sealed CO_2 lasers. The laser is used to create minute designs and patterns on denim fabric as well as finished denims.

Advantages of laser engraving over traditional methods

- High working speed without mechanical contact
- No wear and tear of components
- Reduced waste
- Complete exhaust and filtering
- Exact contours possible

Yuan *et al.* (2012) were of the view that in today's fashion world, technology has taken on an important role for the creation of novel design effects. As a type of digital technology, laser engraving is applied for decorative purposes with unique fashion design looks. With this technology, simple and complex patterns can be engraved onto the surface of garments by using laser beam scanning. This study explores the application of laser technology on assembled garments for diverse engraved patterns. To improve the visual appearance, different design methods, such as the graphic and resist methods, are applied for carbon dioxide (CO_2) laser engraving onto garments made from rayon/polyester blended fabric with optimal laser engraving parameters, including resolution and pixel time. This study also revealed many potential of fashion designs through the use of laser engraving technology. Based on computer-aided design, laser engraving could open up new possibilities for green fashion design with distinct patterns and textures that would cater to the demands of industries and consumers.

- **Welded garment production:** Welding is an alternative process of joining fabrics for garment production where the thermoplastic materials are joined together by the application of heat. The heat can be supplied by ultrasonic or by high powerful laser. The welded garment though weaker than the sewn counterpart, gives better appearance as it does not contain bulky seam and is more flexible.
- **Bar code scanning:** The scanners used to scan the barcodes for product identification typically uses helium-neon (He–Ne) lasers. The laser beam bounces out of a rotating mirror while scanning the code. This sends a modulated beam to a computer, which contains the product information. Semiconductor based-lasers can also be used for this purpose.



- **Laser marking:** Laser can also be used in marking on various surfaces. The advantages of laser marking include fast, high precision and clear marking on products of varying contour and hardness. It can also be used for a wide range of organic polymers where precession can be obtained even with complex designs. Laser marking is durable and can be applied in clothing, leather and metals. Laser marking is considered to be the best choice for branded clothing and marking fashion accessories during processing.

- **Laser dyeing:** Laser technology can offer digital design capabilities combined with the ability for short run production. This is a dry technology, which if used as an alternative to traditional textile wet processing, has the potential to offer increased environmental sustainability through significant reduction in energy and wastewater effluent.

Akiwowo (2015) [1] studied 'Digital Laser Dye' (DLD) patterning process as an alternative textile coloration method within a textile design context, relevant to industrial textile procedures and employed Carbon Dioxide (CO_2) laser technology to modify polyester (PET) surface fibres. Standardized polyester (PET) knitted jersey and plain woven fabrics were modified with CO_2 lasers in order to graphically engineer dye onto the fabric surface as well as sportswear garments and intimate apparel. Laser technology was investigated as a method to modify surface fibres for dyeing in order to generate tonally varied high-resolution patterns on to the textiles, defined as 'laser-dye patterning'. The results suggested that CO_2 laser technology can be relied upon for patterning process in textile colouration and dyeing.

- **Laser surface modification:** Laser irradiation of polymers can be used to generate a modification of the surface morphology at the irradiated regions. The normally smooth surface of synthetic fibers can be modified by this non contacting technique to a regular role like structure, which has a great effect on the general properties of the fibre.
  Bahtiyari (2011) [2] investigated a new method for the modification of the properties of polyamide fabric, based on exposure to the output from a CO_2 laser. It was found that, after laser modification of polyamide fabric, the dyeability of fabric was increased significantly, while the bursting strength was decreased. The reasons for this drastic increase in dyeability of polyamide fabrics have been analyzed with the help of FTIR and iodine sorption methods, revealing a relationship with a decrease in the crystallinity of the polyamide. It was observed that, as the laser modification of the fabric was carried out with low intensity, the concentration of free amino groups, which are necessary during dyeing with acid and reactive dyes, increased.

Hazards by laser and their control

- **Electrical shock**: More people are being killed by electrocution from the laser electronics than blinded from exposure to a laser beam. Lethal voltages are present in the power supplies of lasers. If one is not experienced working with high voltages in general and laser power supplies in particular, then the person should not be allowed to carry out any work with the laser. During maintenance, the power supply should be unplugged its electrical outlet.
- **Eye injury potential**: Eye is the most vulnerable body part to a laser beam. With certain lasers severe damage can be caused due to the high concentration of laser energy on retina (Nayak and Padhye 2016) [6]. Class 4 lasers can damage the tissues in the eye interior. The class and duration of laser exposure are the deciding factors in the eye injury. For example, no injury is be expected while working with the laser with wavelength in the visible spectrum (400–700 nm). Lasers of Class 3B or Class 4 can lead to an eye injury before the aversion response can protect the eye.

Laser class	Nature of hazard	Precautions
Class 1	Low power, safe to view	No potential hazard
Class 1M	Low power, hazardous when viewed directly for longer than 1000 s	Do not view directly with optical instruments
Class 2	Low power, hazardous when viewed directly for longer than 0.25 s	Do not stare into the beam
Class 2M	Medium power, nonhazardous when viewed directly for less than 0.25 s	Do not stare into the beam, do not view directly with optical instruments
Class 3A	Medium power (0.5 W), are hazardous when viewed directly	Avoid direct eye exposure
Class 3B	Medium power (0.5 W), are hazardous when viewed directly	Avoid direct eye exposure
Class 4	High power (>0.5 W), produce ocular, skin and fire hazards	Avoid eye or skin exposure to direct or scatteredradiation

- **Skin injury potential:** The injury to the skin due to laser radiation is less severe compared to the eye. However, the chances of exposure of skin is higher than that of the eye due to its greater surface area. The eye injury is more significant than the skin as the loss in the vision is irreparable. In normal laser working condition there is very less chance that a large area of the skin is exposed. The injury to the skin due to laser exposure can be divided into two categories:

a) **thermal injury and**
b) **Photochemical induced injury.**

- The former is caused by the high power laser beams, whereas the latter is caused by exposure to scattered ultraviolet (UV) laser radiation.
- Direct contact or exposure to the laser beam can lead to thermal injuries. Although these injuries are painful, usually they are not serious and proper beam management and hazard awareness can prevent these. In addition, specular or even diffused reflections can lead to photochemical injury over time.

Harmful effect of laser radiation on eye and skin

Laser type	Wavelengths (nm)	Impacts on eye	Impacts on skin
Excimer laser	100–315	Cornea ignition	Sunburn, accelerated aging
He–Ne laser	315–380	Lens opacity	Increased pigmentation
Nd-YAG laser	380–780	Violation of the retina	Darkening of pigment, burns
High performance diode laser	780–1400	Lens opacity, violation of the retina	Burns
CO_2 laser	1400–3000	Lens opacity, burning of the cornea	Burns
CO_2 laser	3000–10,000	Burning of the cornea	Burns

The objective of hazard control methods is primarily stop the laser contacting the skin or entering into the eye. These control methods can be grouped into three sections such as:

a) **Administrative controls:** The management should only allow the trained persons to work on laser equipment. The operator should follow the instructions as in SOPs. The laser equipment should be switched off while not being used. All laser equipment of Class 3B or Class 4 lasers need to be labelled with "Danger" symbol, specifying the laser class. A Class 3B laser device should mention "Laser Radiation-Avoid Direct Exposure to the Beam", Which Must Be Written Above The Tail Of The Sunburst. A Class 4 Laser Device Should Mention "Laser

Radiation-Avoid Eye or Skin Exposure to Direct or Scattered Radiation" above the tail of the sunburst.

b) **Engineering controls:** The possibility of accidental exposures to laser hazards can be best controlled by engineering controls. All the Class 3B and Class 4 laser equipment should prevent the access of unauthorized personnel in the working area while laser is operational. All the Class 3B and Class 4 lasers should have a non-flammable cover sufficient to hold the excitation device and the beam. The laser systems can be fitted with key switches or password protected for better safety. In the laser chamber, the setting should guarantee no direct eye contact. The most hazardous aspect of laser use is the beam alignment, where most eye injuries occur. Hence to avoid this, the instructions described in the SOP must be understood. The lowest visible beam power should be used for beam alignment.

c) **Protective equipment controls:** The user of laser equipment should wear appropriate personal protective clothing/ device for eye and skin protection during initial setting as well as the normal working. The skin covering and the eyewear protect the skin and eye, respectively from direct exposure.

Various ANSI (American National Standads Institute) standards dealing with laser hazards

Laser standards	Description
ANSI Z136.1 (safe use of lasers)	This standard is the foundation of laser safety programs for industry, military, research and development and higher education (universities)
ANSI Z136.2 (safe use of optical fibre communication systems utilizing laser diode and LED sources)	This standard provides guidelines for the safe use, maintenance, service and installation of optical systems utilizing laser diodes or light emitting diodes operating at wavelengths between 0.6 µm and 1 mm
ANSI Z136.3 (safe use of lasers in health care)	This standard provides guidelines for individuals working with Class 3B and Class 4 lasers and laser systems in health care
ANSI Z136.4 (recommended practice for laser safety measurements for hazard evaluation)	This standard provides guidelines for measurement procedures necessary for the classification and evaluation of optical radiation hazards
ANSI Z136.5 (Safe use of lasers in educational institutions)	This standard provides guideline for organisations and implementation of laser safety and training programs. In addition, it privides graphics for entryway controls, laser installations and laser laboratory layouts
ANSI Z136.6 (safe use of lasers outdoors)	This standard provides guidelines for the safe use of lasers in an outdoor environment such as construction, light shows, scientific, research and military
ANSI Z136.7 (testing and labelling of laser protective equipment)	This standard provides guidelines on the test methods and protocols used to provide eye protection from lasers and laser systems
ANSI Z136.8 (safe use of lasers in research, development, or testing)	This standard provides guidelines on the safe use of lasers and laser systems found in research, development or testing environments, where safety controls common for commercial lasers may either be missing or disabled
ANSI Z136.9 (safe use of lasers in manufacturing environments)	This standard provides guidelines for laser exposures when lasers are used in manufacturing environments. This also includes policies and procedures for safety in both public and private industries as well as product development along with testing

Conclusions and future directions: Laser technology can be used for various applications on materials ranging from metals to textiles with noncontact patterns. In garment production, it can be applied onto different products ranging from home textiles to fashion accessories. In garment manufacturing, CO_2 gas lasers have wide and successful applications. Laser technique, is entirely different from traditional textile processes, as it has the flexibility in design and operation without any pollution or waste material. There are several other advantages of using laser over the conventional methods in cutting, engraving, embossing, denim fading etc. In addition, laser involves lower risk of product damage, use of low consumables and free from disposing of toxic by-products, as there may be with some methods. The laser equipment of today has gradually evolved from those used in early days. The old laser equipment were difficult to run, cumbersome and hard to maintain. However, the modern equipment are easy to operate, simple to learn and easy to maintain. Furthermore, the earlier equipment had several safety issues and they needed replenishment of gasses at regular intervals. The garment production units should take the advantage of applying laser in the post multi-fibre agreement regime to produce more competitive products.

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