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The use of laser in garment manufacturing: an overview

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Abstract
Laser is being used in apparel industry from nineteenth century for various garment manufacturing applications. There are several advantages of using laser over the conventional processes in cutting, engraving, embossing, denim fading and other applications. In addition, product damage potential is reduced, no/less consumables are needed and no problem of toxic by-product disposal as found in some processes. Today's laser equipment is a result of continuous research and development of earlier products, which has undergone several changes. The initial laser systems were cumbersome, hard to run and difficult to maintain. However, the modern laser systems are simpler in operation and maintenance. Furthermore, the earlier systems were involved with more safety issues and needed the gasses to be constantly replenished. The garment manufactures around the globe should take the advantage of laser application in the post multi-fibre agreement regime to make their products more competitive. This review focuses on the technology of laser including various classifications. In addition it includes the applications of laser in garment manufacturing, their potential hazards and health related concerns.

Keywords: Laser, Fabric cutting, Denim fading, Mass customization, Engraving

Introduction

Laser is being used in apparel industry from ninenteenth century. Recently the use of laser in apparel industry is increasing in cutting garment patterns, patterning designer neckties, 3D body scanning, denim fading and engraving leather (Nayak and Khandual 2010; Istook and Hwang 2001; Simmons and Istook 2003; Ortiz-Morales et al. 2003; Ozguney 2007; Bahtiyari 2011). The major reasons for wide application of laser in garment industries may be due to reduced cost, flexibility and anti-counterfeiting (Kovacs et al. 2006; Tarhan and Sarıışık, 2009; Yuan et al. 2012). For example the artwork of high-end necktie producers are digitally stored rather than physical patterns to lower the theft risk. When needed, the digital patterns are converted into physical samples using lasers (Lucas et al. 2015; Kan 2015). Recently, the application of laser in denim engraving is increasing rapidly for value addition by replacing the traditional denim-distressing technics, which will take the denim segment to a height of sophistication that can never be realised by non-laser methods (Kan 2014a). The unique nature of the garment manufacturing industry needs laser applications, which combines performance with reduced cost by eliminating the handling systems used in non-laser workstations.

Laser is an energy source, whose intensity and power can be precisely controlled. The laser beam can be focused to a desired object at specific angle depending on the application. Laser can help to cut a variety of objects ranging from flexible fabric to rigid and strong metal (Belli et al. 2005; Ondogan et al. 2005). 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 (Kan et al. 2010; Lu et al. 2010; Sutcliffe et al. 2000). For example the conventional cutting tools such as band blades, discs and reciprocating knives suffer from the limitations especially on delicate materials as the cutting force can displace the material, which can lead to inaccurate cutting (Nayak and Padhye 2015b). The traditional cutting methods often require an operator with full attention (Vilumsone-Nemes 2012). Hence, there is a trade-off between the maximum speed of cutting and the accuracy. In addition, other limitations include intricacy of the cut components, tool longevity and machine downtime during tool servicing. These limitations are not present in laser devices, which helps to achieve improved efficiency and reduced cost.

Laser cutting with processing speed, high precision, simple operation and other advantages, so in most industries can be used to, but it is in the clothing industry, leather processing plays a different role, can quickly cut leather graphics and draw precise clothing model (Potluri and Atkinson 2003; Ready et al. 2001). The benefit of laser cutting operations involve highly collimated beam that can be focused to a very fine dot of extremely high energy density for precise cutting. Garment industry pay attention to the size of the garment when processing precision, the purpose is to achieve high efficiency, exquisite tailoring, it is better than the traditional manual cutting by spectrum.

Although there are several applications of laser in apparel manufacturing, there are limited publications on this. Hence, an attempt was made in the current article to perform a thorough review that covers various applications and recent developments in laser that can provide guidelines for future directions. In addition, a systematic description has been done on the technology of laser including various types of laser. In addition, this review includes the applications of laser in garment manufacturing, their potential hazards and health related concerns.

Laser technology

LASER is *light amplification by stimulated emission of radiation*. Laser is an electromagnetic radiation, produced by the atoms due to energy states are changed in some materials (Dowden 2009). 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 used to express the wavelength of a laser is in nanometre (nm).

Laser light (Fig. 1) 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

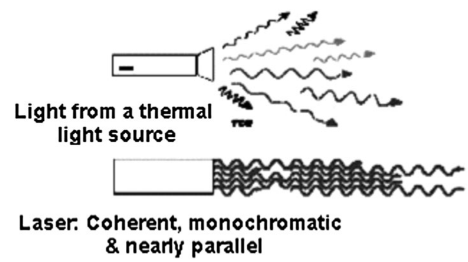

Fig. 1 An ordinary light and a Laser beam

of some milliwatts (mW). All the lasers are not powerful in spite of the light with high intensity as intensity is estimated from the power output/area.

From Fig. 1 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.

For the production of the laser beam a lasing material is stimulated with electric discharge in an enclosed container. A number of partial mirrors help in multiple internal reflections that lead to obtain the desired coherency and power output. Mirrors or other optical devices help in focusing the laser to a lens, which then reflects the laser to the working zone. In order to enable the cutting action by a laser away from the edge, it should be pierced before the laser cut using a high-power pulsed laser beam.

Classes of lasing media

A substance, which can be excited by input energy, is called a lasing media. The lasing media have the ability to stay in a metastable state. It is generally transparent to light. The substance used as lasing media can be a solid, gas, liquid dye or semiconductor. Solid lasing media is used for producing solid-state laser. Due to the high density of lasing atoms, solid-state lasers can generate higher power output per unit volume compared to the gaseous-state lasers. A single gas or gaseous mixture can be used to produce gaseous-state lasers. Gaseous-state lasers are produced by passing the electric discharge in the gaseous lasing medium. The most common type of gaseous laser is produced from helium–neon (He–Ne). This laser is mainly used in teaching laboratories, at construction sites and supermarkets.

Liquid dyes can also produce laser by using ultraviolet (UV) light. These liquid dyes can be prepared by dissolving the solid dye particles in suitable solvent. The dyes and solvents with similar energy levels are selected, that help to form a continuum for achieving high energy output with wavelengths of visible light. Better tunability is the unique feature of a dye laser, which distinguishes it from the solid laser. A single dye produces a single wavelength whereas dyes can be mixed to obtain a range of wavelengths. Semiconductors can also be used to produce laser with the help of electric discharge. These lasers are characterised by their efficiency, miniature size and durability.

Laser classification based on hazards

Since the early 1970s, lasers were 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. A Class 1 laser is absolutely not dangerous when used, whereas the Class 4 laser is the most dangerous. The existing system was the revised system since 2002, prior to that the old system was used. In the new system amendments have been done to certain types of lasers having a lower hazard than mentioned in the old system. Based on the output power in a specific wavelength, lasers are classified. It is essential the correct information on the laser class, potential hazards and safety instructions are specified by the equipment manufacturers. In the classes 1–4 laser, there are the sub-classes 1M, 2M, 3A and 3B. The new system currently in use (shown in Table 1) uses Arabic numerals (1–4), whereas it was classified with Roman numerals (I–IV) in the old system.

Classification based on generating media

Based on the generating media, lasers can be classified into three groups: (1) carbon dioxide (CO_2) lasers, (2) neodymium (Nd) lasers and (3) neodymium yttrium-aluminium-garnet (Nd-YAG) lasers (Thawari et al. 2005; Mathew et al. 1999; Schuocker 1989). The CO_2 lasers can be used for boring, cutting and engraving (Chow et al. 2012; Kan 2014b). CO_2 lasers can be of the four types: (a) fast axial flow, (b) slow axial flow, (c) transverse flow and (d) slab lasers (Powell 1993). In fast axial flow, a mixture of CO_2, nitrogen (N_2) and helium (He) is used at high speed by a turbine. A simple blower is

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 s. 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 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

used for slow axial flow and transverse flow lasers. Slab lasers need no pressurization as they work in static condition.

The Nd lasers and Nd-YAG lasers, although similar in style, they are applied in different areas (Schuocker 1989). The former is used for boring, whereas the later is used for engraving. All the laser classes can be used for welding.

Generally, CO_2 lasers are produced by passing the electric discharge through a gaseous mixture excited by direct current (DC) with radio frequency (RF) energy. This method is widely used as the DC-excited designs need electrodes inside the cavity, due to risk of erosion. Industrial cutting of steel, aluminium, paper, plastics, wood, and fabrics can be performed by CO_2 lasers. For cutting metals and ceramics; and scribing Nd-YAG lasers are used.

The laser generator and external optics need cooling while in use (Choudhury and Shirley 2010). This can be achieved by a coolant such as water by circulating through a chiller in the laser equipment. The use of water cools the material and removes the debris. In addition, it helps to achieve parallel kerf and multi-directional cutting at high dicing speeds.

Another type of solid-state laser known as "fibre laser" is now becoming popular in metal cutting industry. This laser is produced from a solid gain medium without the use of any liquid or gas. The major advantage of fibre laser is the extremely small spot size. Fibre lasers, with a wavelength of 1.064 μm, can produce an extremely small spot size, which makes it ideal for cutting reflective metals.

Application of laser in apparel industry

As an all-new process, there are several applications of laser in apparel industry. Laser engraving and cutting technologies now being widely applied in many garment industries, fabric production units, other textile and leather industries (Choudhury and Shirley 2010; Nayak and Khandual 2010). Various applications of laser are discussed in the following section.

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 (Mallik-Goswami and Datta 2000; Ribolzi et al. 1993; Mursalin et al. 2005). 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

After they were introduced in the 19th century, the fashion designers are widely adopting laser cutting in garment manufacturing (Petrak and Rogale 2001). In synthetic fabrics, laser cutting produces well-finished edges as the laser melts and fuses the edge, which avoids the problem of fraying produced by conventional knife cutters. Furthermore, use of laser cutting is increasingly used for leather due to the precision of cut components. In fashion accessories such as jewellery, laser cutting can be used to produce new and unusual designs to produce a fusion of apparel design and jewellery style.

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 (Fig. 2) 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 (N_2, 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. Automatic single ply laser cutters are faster (30–40 m/min) than automatic multiple ply knife cutters (5–12 m/min). However, while cutting multiple plies, knife cutters are faster per garment cut and also cheaper.

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. In some cases the sealing of the edges of cut patterns and sewn garment parts is essential to prevent fraying, where the laser plays the role. As in garment production facilities emphasis is given in multiple lay cutting, the laser cutting seems unlikely to become widespread. However, it is successfully used in cutting of sails where single ply cutting is the norm and a slight fusing of the edge of synthetics and woven materials is desirable. In addition, laser cutting is used in some areas of home furnishing.

Laser cutting is cheaper compared with the traditional cutting methods (Mahrle and Beyer 2009). Furthermore, as the laser cutting doesn't have mechanical action, high

Fig. 2 A laser-cutting machine

precision of the cut components at high cutting speed are feasible (Mathew et al. 1999). The laser cutters are safer and include simple maintenance features, which can be operated for 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.

Laser cutting machines are suitable for cutting textile fabrics, composites and lather materials (Caprino and Tagliaferri 1988; Steen et al. 2010; Cenna and Mathew 2002). They can operate for a wide range of fabric, which is not possible with die cutters. Hence, laser cutting machines are gradually been accepted in garment manufacturing. 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

Objective evaluation of seam pucker

Garment appearance greatly influences garment quality. Seam pucker negatively affects the garment appearance (Nayak and Padhye 2014b, 2015a; Nayak et al. 2010, 2013; Fan and Liu 2000). There are several methods to measure seam pucker, but the conventional rating system developed by American Association of Textile Chemists and Colourists (AATCC) is mainly used. 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. Physical parameters such as log σ^2 (σ is variance) can be obtained from the pucker profile, which can then be linearly related to grade for seam pucker. From the objectively measured log σ^2, the pucker grade can be objectively evaluated.

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 (Nayak and Padhye et al. 2015a). 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 (D'Apuzzo 2007; Tong et al. 2012; Ashdown et al. 2004). In order to confirm the harmlessness of the beam, only eye-safe lasers can be used. Additional optical devices such as mirrors can be used to assist a single laser beam. The laser scanning unit (Fig. 3) consisting of light sensors and optical systems focuses on the human body for digitisation. The number of light sensors and optical systems can vary as per the positions of the body. For example, Vitronic1 body scanner consists of three scanning units that can synchronously move vertically along three pillars.

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 (Ortiz-Morales et al. 2003; Tarhan and Sarıışık 2009). 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 et al. 2010). A laser-faded denim sample is shown in the Fig. 4.

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 (Kan et al. 2010; Juciene et al. 2013). 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. One machine can be used to cut through thin materials as well as

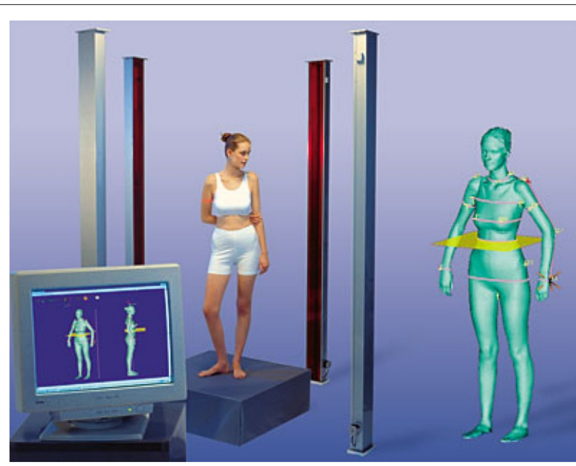

Fig. 3 3D body scanning by Laser scanner

Fig. 4 Denim faded by laser

make engravings on them. Laser engraving is used to engrave the printing screens, for hollowing, for creating pattern buttons, to engrave leather, denim etc. (Fig. 5). 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

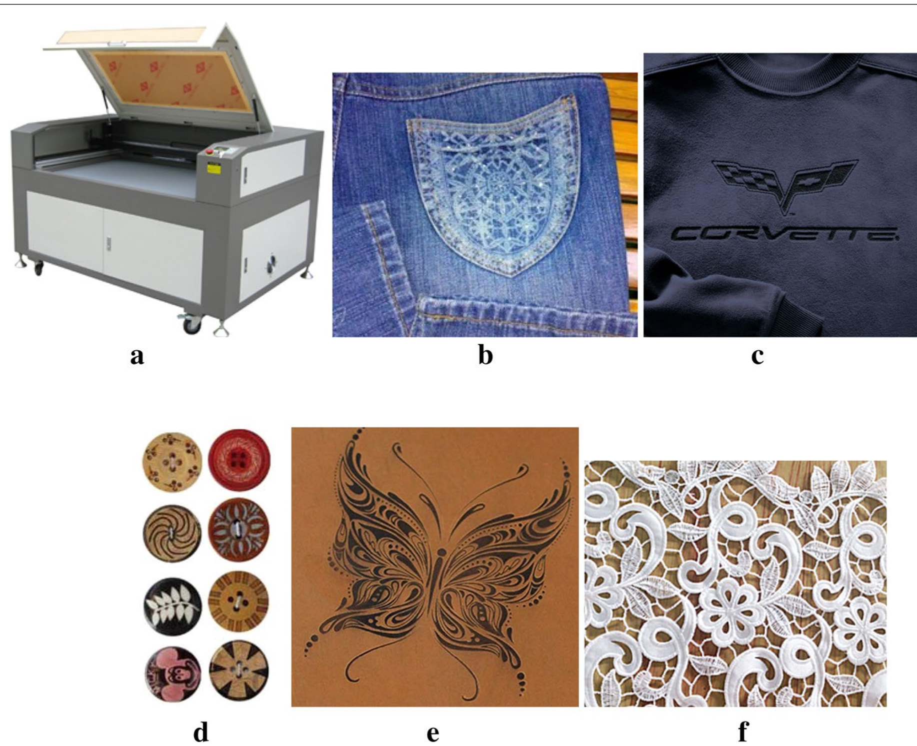

Fig. 5 Laser engraving items: **a** engraving machine, **b** denim, **c** garment, **d** buttons, **e** leather and **f** embroidery

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 (Juciene et al. 2013; Kan 2014a). The laser is used to create minute designs and patterns on denim fabric as well as finished denims. This technic can be used in place of the traditional techniques such as sandblasting and acid washing. The accuracy and design flexibility is very wide, which can't be achieved by the traditional methods. Lasers can produce 3D effects by techniques such as embroidering, embossing, or even apparent cuts, tears and mends. Any image that is created in a computer aided design (CAD), can be transferred to denim by suitable laser process. While using lasers, features such as good mode quality, high power stability, real-time control of laser power and fast pulse rise-time are the important parameters that can lead to colour change without charring or other damage to the fabric. Such damage could reduce the product life and cosmetically unacceptable. The advantages of laser engraving over traditional methods include:

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

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 (Petrie 2015). 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. However, some of the recent manufacturers are using Radio Frequency Identification (RFID) based tags instead of barcodes due to certain advantages (Nayak and Padhye 2014c). The RFID tag can be processed quickly and it avoids the physical handling of the product as in barcode systems (Nayak et al. 2007, Nayak et al. 2015b; Nayak and Padhye 2015b). The mechanism of a bar code scanner is shown in Fig. 6.

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

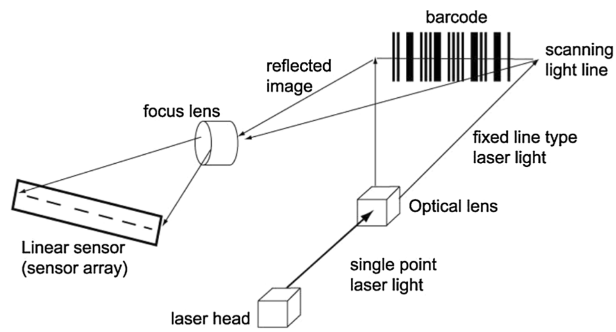

Fig. 6 A laser bar code scanner

in clothing, leather and metals. Laser marking is considered to be the best choice for branded clothing and marking fashion accessories during processing.

Miscellaneous uses

There are many other applications of laser in apparel industry as discussed below:

- In some stitching machines (e.g., automatic welt pocket attaching machine) laser beam is engaged for automatic and accurate positioning of the welt and to make a slit across the fabric.
- In some metal detection machines laser beam is employed to find if any needle part is there in the final finished garment.
- Laser-engraving machine can engrave any decoration on the surface layer of any material, making the products looking high grade and exquisite.
- Laser technology is gaining impetus in garment finishing which can produce various surface ornamentations without any wet processing. This technique is very accurate and can work fast with good repeatability and reproducibility (Hung et al. 2011; Kan et al. 2010).
- The application of antimicrobial finishes into textiles has significantly improved compared to the past (Nayak and Padhye 2014a; Nayak et al. 2008). Laser treatment was used for durable antibacterial properties on cotton fabric using silver nanoparticles by Nourbakhsh et al. (Nourbakhsh and Ashjaran 2012).

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 (Sliney 1995). 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 from its electrical outlet.

Eye injury potential

Eye is the most vulnerable body part to a laser beam (Henderson et al. 2003; Buckley 2010; Barkana and Belkin 2000). With certain lasers severe damage can be caused due to the high concentration of laser energy on retina (Wyrsch et al. 2010). 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. Tables 2 and 3 describe various types of laser hazards and precautions to be taken as specified by American National Standards Institute (ANSI) and Occupational Safety and Health Administration (OSHA).

Various standards are devised around the world for the laser related hazards. The standards devised by ANSI are shown in Table 4.

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 (Yashima et al. 1991; Sliney 1995). 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

Table 2 Nature of hazards and precautions for various classes of lasers

Laser class	Nature of hazard (ANSI and OSHA)	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 scattered radiation

Table 3 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

Table 4 Various ANSI 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

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 (Bernstein et al. 1997). 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.

The objective of hazard control methods is primarily stop the laser contacting the skin or entering into the eye (Protection 1996). These control methods can be grouped into three sections such as: (a) administrative controls [labels, signs, standard operating procedures (SOPs), etc.], (b) engineering controls (barriers, blocks, etc.) and (c) protective controls (eyewear, uniform, etc.).

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.

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.

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 (Nayak et al. 2015c). The skin covering and the eyewear protect the skin and eye, respectively from direct exposure.

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.

Authors' contributions
RN designed the paper, performed the literature survey and completed the paper. RP guided during the paper design and helped in feedback and comments in final format of the paper.

Competing interests
The authors declare that they have no competing interests.

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