

# Chapter 2

## Precision Fabric Production in Industry

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**Abstract** This chapter describes different types of textile structures suited for smart textiles and gives a short overview of production methods for weaved, knitted, and nonwoven fabrics.

### 2.1 Introduction

Textiles are the basic material for all kinds of smart garments or textile electronics. Therefore, the variety of materials usable for smart or electronic purposes is almost as wide as the variety of textiles commonly available in the textile industry. Many of these textiles show very different properties resulting in a wide choice according to varying operational demands. The right combination of raw material, production process, machine parameters, and finishing conditions is crucial for the suitability of any product for special purposes.

The main methods to produce a textile plain out of one or more yarns or fibers are weaving, knitting (warp and weft), as well as using one of several nonwoven processes.

For smart textiles, applications, especially weaving and knitting, have received widespread interest since they can generate large-area precision textile surfaces.

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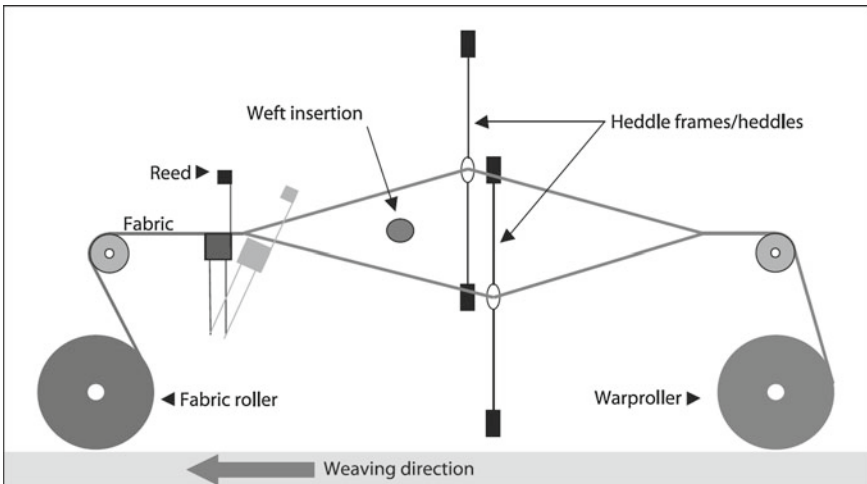
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## 2.2 Precision Weaving Technology

Precision fabrics represent an attractive medium for electronic integration as they are very precise and can be automatically produced creating large-area surfaces with specific conductive properties at very high speeds. For example, typical industrial weaving machines are capable of fabricating more than 106 square meters of fabric per year in micrometers precision. Subsequent development in this field has seen a drive to integrate the desired functionalities inside the fabric architecture. This implies creating smart textiles in which electronic sensors and output devices can be introduced at the fabric level.

Precision fabrics are produced by a weaving process. Weaving is the oldest method of making yarn into fabric. While modern methods are more complex and much faster, the basic principle of interlacing yarns remains unchanged. Weaving is a process that interlaces two perpendicular sets of yarns, called the weft and warp. Weaving is done on a machine called loom. Before the weaving process is started, the loom needs to be set up with warp yarn. During the weaving process, some of the warp yarns are moved up and the rest are moved down using a “harness,” and the opening created between the up- and down-warp yarns is called the shed. The raising/lowering sequence of warp yarns gives rise to many possible weave structures. In comparison, the weft yarns are rolled around several spools (known as bobbins) and inserted into the textile architecture perpendicularly to the warp yarns by a device called shuttle.

Figure 2.1 shows a close-up of the central weaving region in a weaving machine. Warp yarns are spanned parallel to each other on a loom and “pulled” through the weaving machine at a constant rate.



**Fig. 2.1** Scheme of a weaving machine (Image courtesy of Sefar)

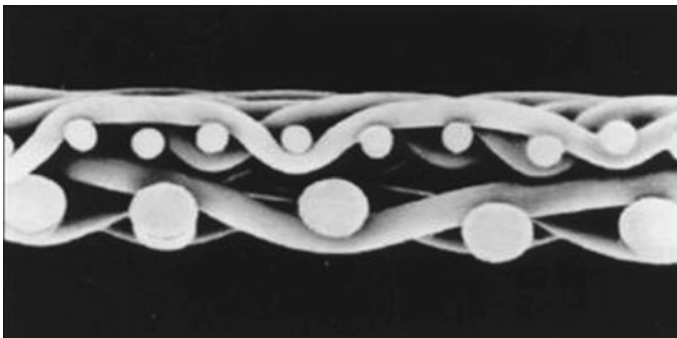
Some of these machines carry the weft yarns across the loom at rates in excess of 2,000 m/min. The resulting fabric is particularly strong. There are three basic weaves with numerous variations. The plain weave, in which the filling is alternately passed over one warp yarn and under the next one, the twill weave, in which the yarns are interlaced to form diagonal ridges across the fabric, and the satin weave, the least common of the three, produce a smooth fabric with high sheen.

Most fabrics are finished to make them look and feel more attractive. Finishing processes may consist of washing, thermosetting, winding, and optical control of the resulting fabric. This is the final step in the manufacturing process.

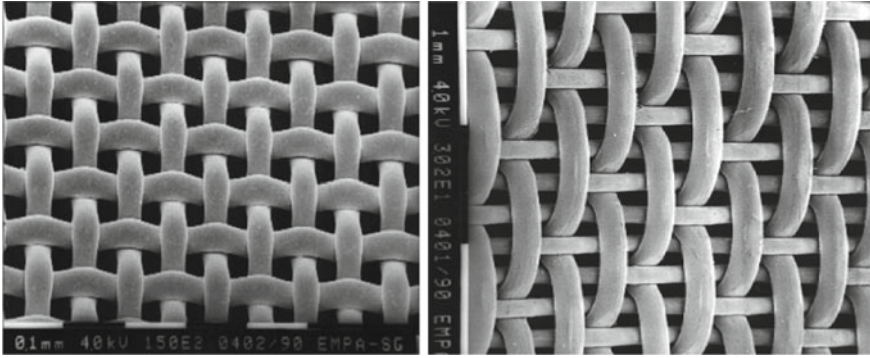
Although such “precision fabrics” are not different from standard fabrics in principal, they must have certain physical, chemical, and functional properties that are connected with their intended application. They have to be dimensionally stable, with precisely defined mesh size, with very narrow tolerances to temperature or UV radiation changes, solvent resistant, etc.

Precision fabrics for electronic applications are designed in such a way that the conductive capabilities are embedded during manufacturing, e.g., weaving of metal wires. A non-conductive fabric usually consists of polymer yarns such as polyester or polyamide, whereas conductive components ideally utilize good conductors such as silver and copper wire either in extremely thin strands or as metallic coating of polymer fibers. Polymer threads form a carrier frame, called substrate, for the conductive threads. In this kind of fabric, conductive layer and substrate are embedded into each other.

The weaving technique can also be differentiated according to the number and arrangement of the thread systems. A single-surface fabric is called a single-chain/single-weft sheet. But also multiple warp or weft systems can be provided which are fixed together and will be arranged one above the other (Fig. 2.2). Such fabrics are called two chain/one-weft or one chain/two-weft. These are reinforced fabrics such as double weave, hollow fabric.



**Fig. 2.2** Double layer fabric (Image courtesy of Sefar)



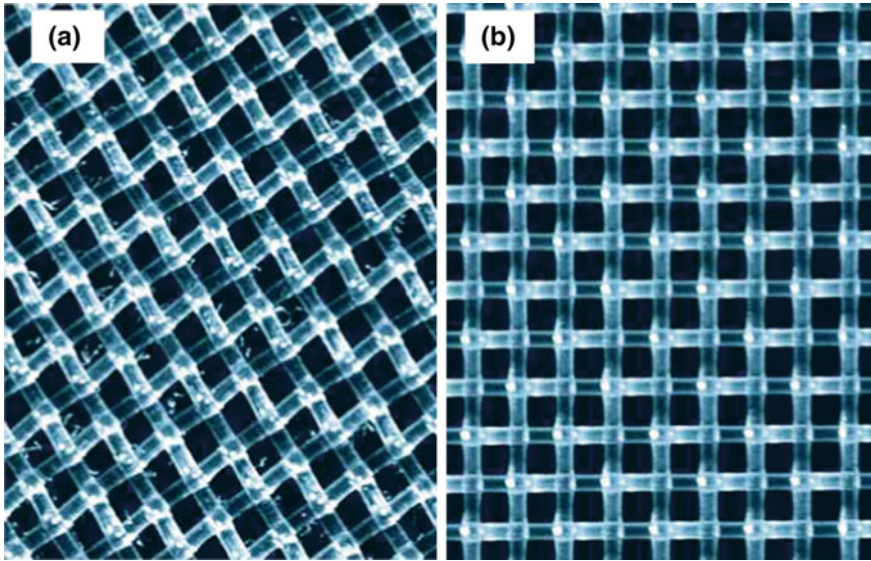
**Fig. 2.3** Pictures of fabrics with different bonding types (Image courtesy of Sefar)

There can be several bonding types in a fabric. It is referred to as equilateral bonding when the number of warp and weft cross-link points is the same on both sides of the fabric, and a fabric with more cross-link points on one side is called one-sided fabric (Fig. 2.3).

### ***2.2.1 Quality Criteria for Precision Fabrics***

The crucial difference between standard fabric and precision fabric is the demands that are made regarding the quality of the fabric: Precision fabrics are characterized by exactly defined, reproducible, and systematically controlled fabric properties. These requirements mainly concern the geometry of the fabrics but are also defined by application-oriented properties, for example:

- Fiber count per cm (weave density),
- Size, regularity, and squareness of the meshes,
- Air permeability,
- Shrinking and stretching behavior,
- Regularity of the visual aspects, including color regularity,
- Cleanliness and biocompatibility (especially in personal use or in medical application, etc.),
- Placement and thickness of the conductive wires (especially in the electronic industry, sensors, e-meshes, etc.),
- Regularity of the distances between many parallel woven conductive stripes (stripe pattern), and
- Long-term stability, washability, etc.

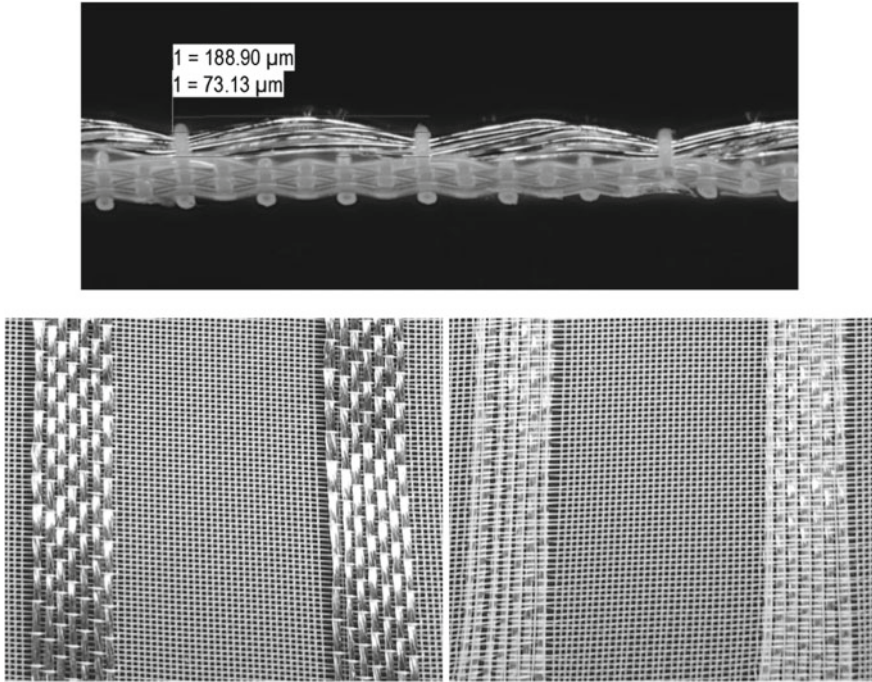


**Fig. 2.4** The contrast clearly shown between a standard fabric **a** and a precision fabric **b** having a precise, reproducible mesh size and weave geometry (Image courtesy of Sefar)

These requirements affect all phases of the production process from the choice of the raw material to the production of the fabric in the weaving mill and also the finishing and making-up processes. For this reason, only yarns that display a high regularity are possible for use in the production of precision fabric. This means the diameter of a fiber may differ from the stated value only by one percent along its entire length. Narrow tolerances also apply to pore sizes, the fabric thickness, and the regularity of the surface.

If special physical or chemical properties are demanded in the application, these have to comply exactly with the specification. To guarantee the required precision and reproducibility of fabric properties, rigorous quality controls are indispensable during the entire production process (Fig. 2.4).

Several examples for precision fabrics have been used in the EU-funded Simple Skin Project. The designs show varying stripe patterns of conductive and non-conductive components in Sect. 2.3. Together with other textile materials, each type of fabric can be combined to resistive pressure sensors (here with Sefar Carbotex fabric, of Sefar and ITV) (Figs. 2.5 and 2.6), can be used as capacitive sensors on the human skin (capacitive wristband of DFKI and ITV), or can be used as base for contact pads (pocket connector of ETH Zurich and ITV).



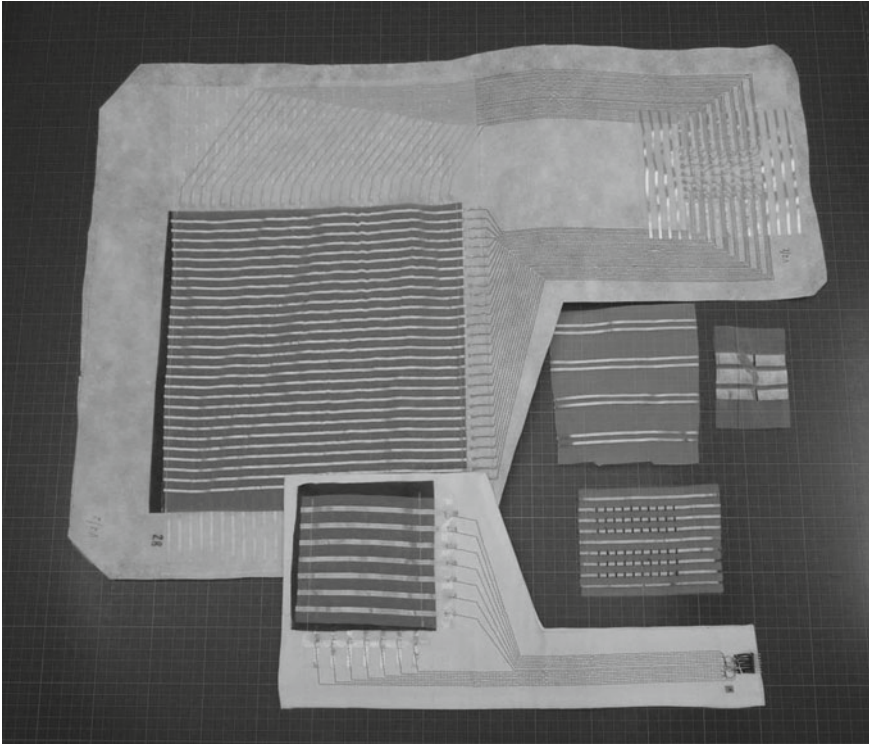
**Fig. 2.5** Sefar precision fabric from side, from *top*, and from *bottom* (Images courtesy of Sefar)

### 2.3 Knitting Technology

General properties of both knitted and woven textiles are low weight, portable, and skin comfort (e.g., breathability) compared to standard electrical and optical systems. Woven fabrics are usually durable and provide a more stable shape than knitted fabrics. This allows for more accurate placement of individual yarns and more dense integration of electronic and optical functionalities. Furthermore, woven textiles are relatively strong and deformation resistant, whereas knitted fabrics are characterized by high elasticity and elongation, good conformability in mechanically active environments (e.g., textiles used in clothing), as well as good air permeability, thermal retention, and humidity transport properties.

Knitting is a technique for producing a mostly two-dimensional fabric made from a one-dimensional yarn or thread. Knitted fabric consists of a number of consecutive rows of loops, called stitches. Knitted fabrics can be produced of all kinds of yarns: natural materials such as wool or cotton, synthetic materials such as PES or PAC, or even spun metal or carbon fibers. According to the thickness of the processed yarns and the gauge of the knitting machine, the knitted stitches may show a wide variety of shapes and sizes. Compared to woven structures, knitted fabrics can be easily deformed and therefore adapt to different shapes according to their use. This makes





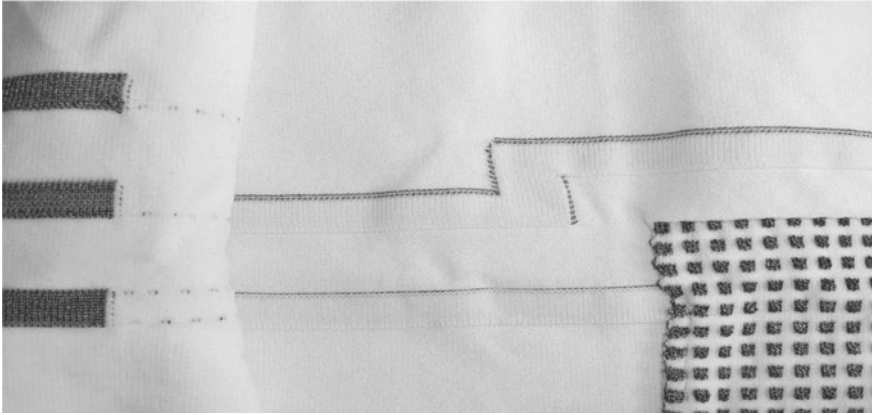
**Fig. 2.6** Several types of conductive universal sensing fabrics from Sefar, on the *left* side two textile pressure sensors (Image courtesy of ITV Denkendorf)

them favorable for the clothing industry to fit the varying shapes of the human body as well as for the automotive industry to fit smoothly on 3D surfaces. Knitted fabrics can be produced on circular knitting machines or on flat knitting machines.

Circular knitting machines offer usually high production capacities of relatively simple structures, mostly plain fabrics. After textile finishing processes, these fabrics can be cut and sewn according to the requirements of their intended use. Recent generations of body wear circular knitting machines are capable of producing highly sophisticated shaped jacquard garments.

Flat knitting machines are less productive than the circulars. But they offer a high versatility in terms of theoretically unlimited pattern, shape, and structure possibilities. Different shapes and structures can be produced in knitted fabrics, with individually shaped areas of different materials including conductive and non-conductive properties (intarsia knitting), connecting threads between these areas, and other useful features.

The production quantities of the flat machines are much less than those of the circulars due to the limited number of threads that can be processed simultaneously. But as the flat knitted products can be designed and constructed very closely to the



**Fig. 2.7** Flat knitted intarsia structure with conductive and non-conductive yarns (Image courtesy of Stoll)



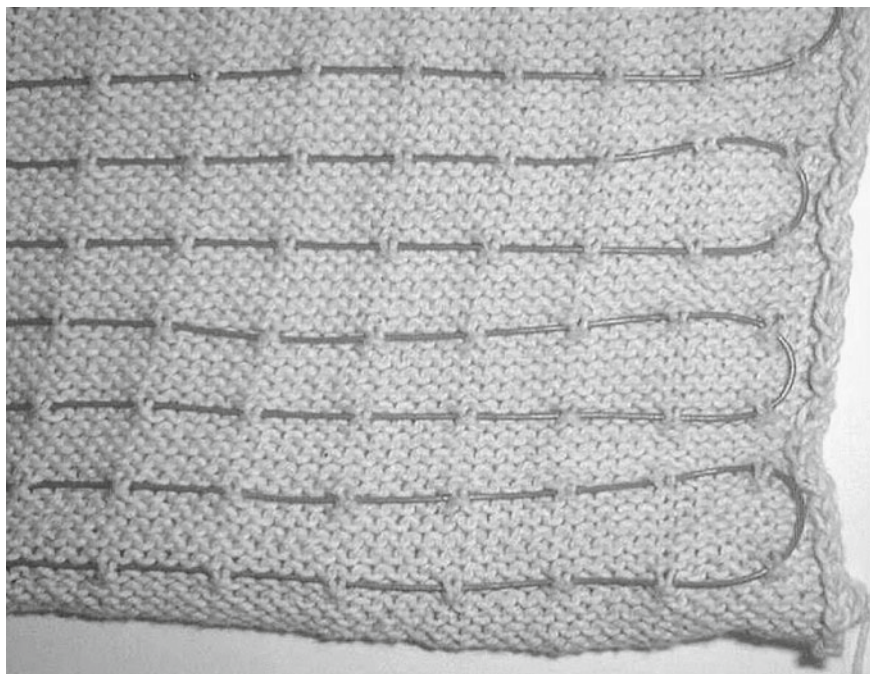
**Fig. 2.8** Detail of intarsia structure (Image courtesy of Stoll)

later purpose and shape of the textile product and therefore save expensive materials as well as manufacturing costs in the following production stages, the production of complicated products on flat knitting machines can be highly competitive (Figs. 2.7, 2.8, 2.9, 2.10 and 2.11).

### **2.3.1 Warp Knitting Technology**

Warp-knitted fabrics consist of interconnected loops, but the yarn does not follow the rows of stitches, and in warp-knitted fabrics, the yarn forms the wales. The production of warp-knitted fabrics starts with the preparation of a warp like in weaving. Warp knitting is highly productive. Modern techniques allow to feed different types of yarn

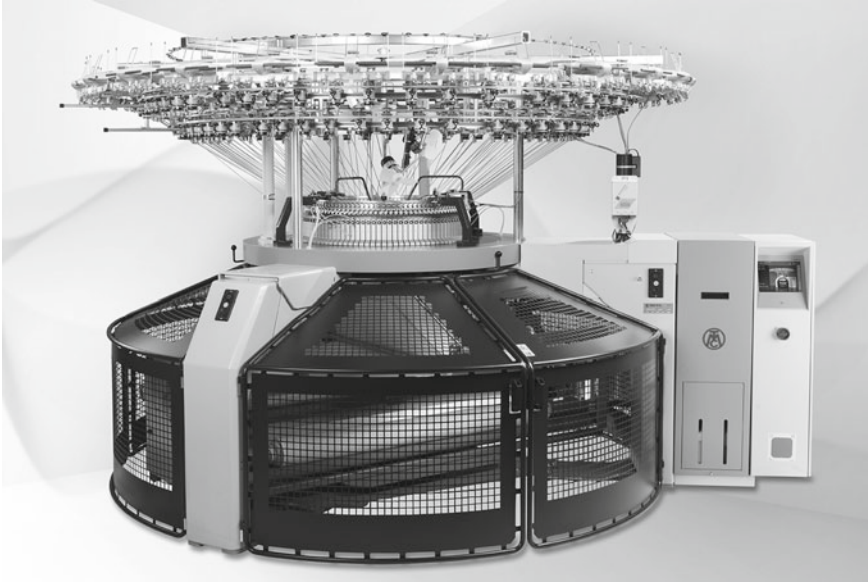




**Fig. 2.9** Flat knitted fabric with laid-in wire threads (Image courtesy of Stoll)



**Fig. 2.10** Flat knitting machine CMS 530 HP (Image courtesy of Stoll)



**Fig. 2.11** Circular knitting machine (Image courtesy of Mayer and Cie)

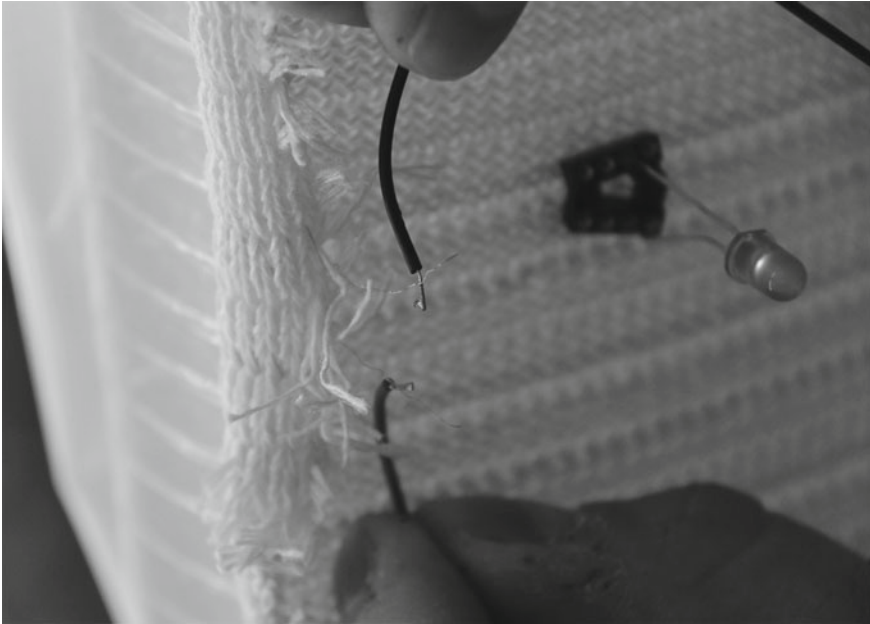
into the fabric, even in weft direction. This can be used to produce partially conductive fabrics. Because the production machinery for such fabrics is very expensive and the efforts to run new patterns are very high, the method of warp knitting is appropriate for production purposes, but not for generating first prototype samples (Figs. 2.12 and 2.13).

### ***2.3.2 Weft Knitting Technology***

Weft knitting produces fabrics which are closely comparable to the knitted fabrics. The difference is made by the production process, but not by the product. Particularly, in intarsia knitting, weft knitting offers possibilities comparable to flat knitting.

### ***2.3.3 Fleece***

Fleece is a knitted fabric which was mechanically treated to produce a hairy surface. Compared to the basic fabric, a fleece has better thermal insulating properties due to the higher amount of air held within the fibers of the fleece.



**Fig. 2.12** Spacer fabric with conductive yarn, demonstrated with an activated LED (Image courtesy of Karl Mayer)

## 2.4 Nonwovens

Nonwovens consist of fibers which have not been spun to yarns. These fibers (filament or staple) are spread on a surface as evenly as possible and usually aiming at homogenous properties. There are many different techniques to produce nonwoven structures with the main differentiation between staple nonwovens and spunlaid nonwovens. There are several mechanical processes in cards or using aerodynamic or hydrodynamic principles. The properties of nonwoven fabrics depend on materials such as natural fibers, PP, PET, or glass. The bonding of these fibers can be achieved by applying physical influences like heat, mechanical influences such as needles or water jets, or chemical processes.

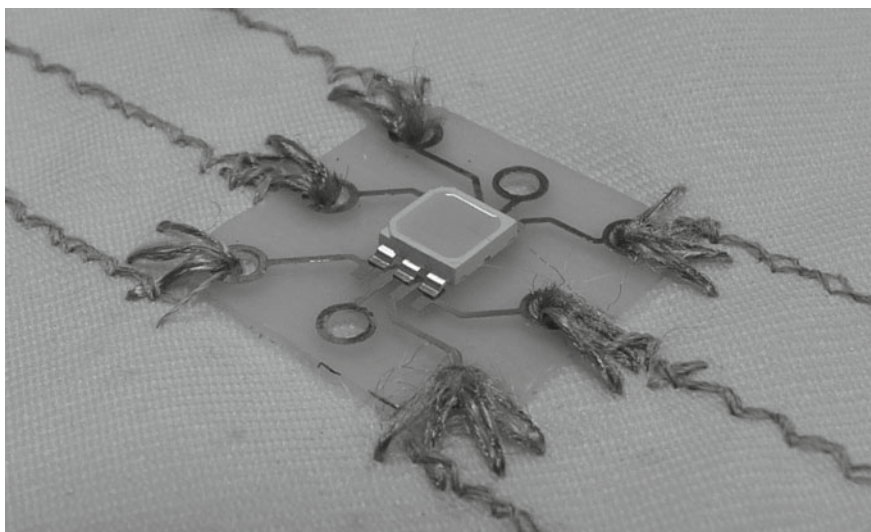
They can be produced as flat two-dimensional structures as well as in complicated shapes in three dimensions. Due to the irregular position of the fibers, it is hardly possible to produce fabrics with geometrically exactly defined property changes during production.

The nonwoven fabrics can be used as base layer for the integration of conductive yarns and of electronic components (Fig. 2.14).

A further possibility to bring electrical conductivity into a fabric that may be a nonwoven is the technique of laser direct structuring (LDS). Using fibers spun out of a special material, the textile fabric has to be exposed to a laser treatment where elec-

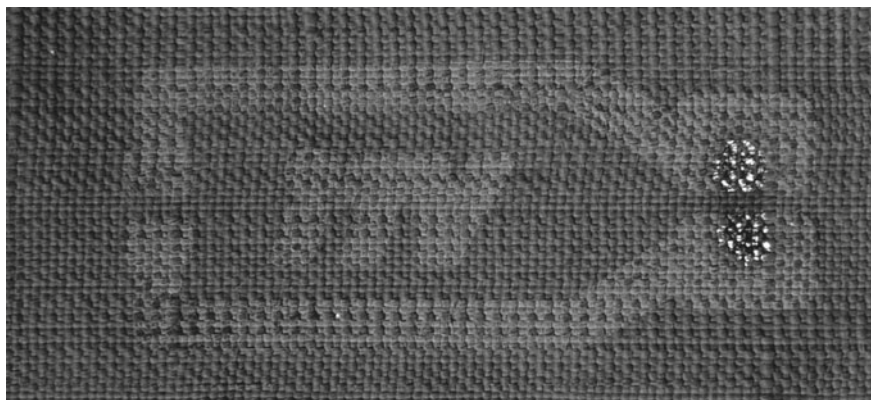


**Fig. 2.13** Warp knitting machine HDR 6 (Image courtesy of Karl Mayer)

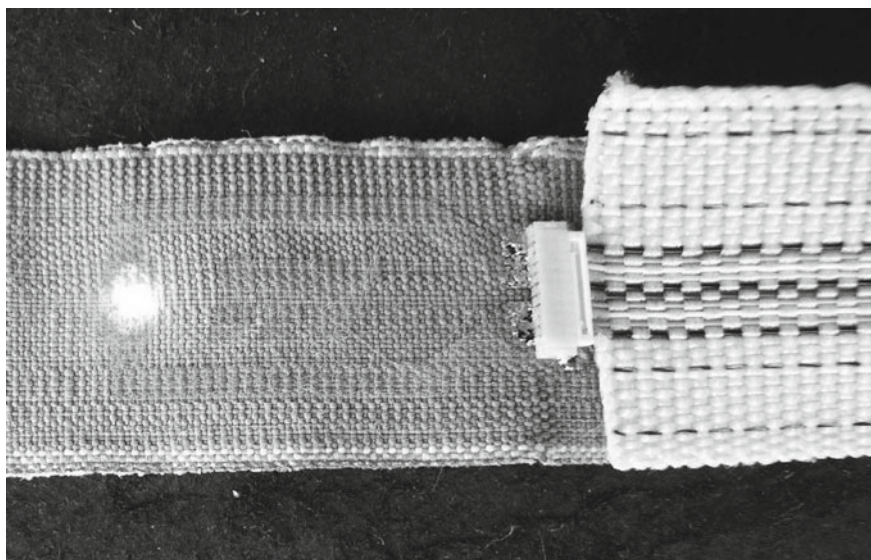


**Fig. 2.14** SMD electrically and mechanically connected with conductive thread (Image courtesy of ITV Denckendorf)





**Fig. 2.15** Fabric with conductive areas after the LDS process (Image courtesy of ITV Denkendorf)



**Fig. 2.16** Electrically connected fabric with activated LED (Image courtesy of ITV Denkendorf)

trically conductive areas are required. After a sophisticated chemical process, these areas are metallized with a thin copper coating and therefore conductive (Figs. 2.15 and 2.16).

This new technology offers the chance for new application areas especially on three-dimensional nonwoven construction elements.



## 2.5 Conclusion

The textile base and its properties cover a wide area of applications in smart textiles. They are of crucial importance for the performance of the smart textile product. The combination of textile behavior such as tactile grip, dimensional stability, breathability, washability, and many other parameters with other functional requirements—especially conductivity and further electrical properties—makes textiles suitable for many different application areas. Some of these properties are difficult to bring together in one fabric, especially the elasticity of many textiles is hard to combine with the good electrical properties of all metals. The low elasticity and poor flexural properties of metals carry the risk of early failure under everyday conditions. Different techniques such as weaving, knitting, and some nonwoven processes allow the production of textiles with a wide variety of properties and production costs.

During the last few years, big steps of progress have been made concerning the use of textiles for smart applications, but the big commercial success lies still ahead.

### Summary Box

In this chapter, we provide an overview of current industrial production techniques for textiles. In particular, we focus on the following types of fabrics:

- Weaved fabrics,
- Knitted fabrics, and
- Nonwoven fabrics

**Acknowledgements** Acknowledgments are made to

- ITV Denkendorf: Carsten Linti and Stefan Loy, for their contributions concerning the LDS technology, for photographs of sensors and fabrics
- SEFAR AG: for photographs and picture
- H. Stoll AG and Co. KG: for photographs of flat knitted fabrics and flat knitting machine
- Mayer and Cie. GmbH and Co. KG: for photograph of circular machine
- Karl Mayer: for photographs of weft-knitted fabric and weft knitting machine

Acknowledgements are also made to

- the European Commission for funding the FP7-project SimpleSkin, during which this chapter was written,
- the Bundesministerium für Bildung und Forschung for funding the project, “Laserstrukturierte textile Schaltungsträger - LaTeSt”, Förderkennzeichen 16SV5064

## Further Reading

- Von der Faser zum Stoff: Textile Werkstoff- und Warenkunde Taschenbuch—2006, by Ursula Völker (author), Katrin Brückner (author) ISBN-13: 978-3582051127
- Textiles (11th Edition) by Sara J. Kadelph (author) ISBN-13: 978-0135007594

Smart Textiles

Fundamentals, Design, and Interaction

Schneegass, S.; Amft, O. (Eds.)

2017, IX, 396 p. 199 illus., 135 illus. in color., Hardcover

ISBN: 978-3-319-50123-9