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(54) ELECTROCONDUCTIVE FIBER, CLOTHING INCLUDING ELECTROCONDUCTIVE FIBER, AND ELECTRICAL/ELECTRONIC INSTRUMENT INCLUDING ELECTROCONDUCTIVE FIBER

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(57) ABSTRACT

A conductive fiber includes a metal layer on a fiber surface, having an average number of crimps of 2 crimps/cm or more, a volume resistivity of 2×10−6 Ω·cm to 1×10−2 Ω·cm, and a total fineness of 10 dtex to 1000 dtex, and having an average single-fiber diameter of 5 μm to 20 μm.

ELECTROCONDUCTIVE FIBER, CLOTHING INCLUDING ELECTROCONDUCTIVE FIBER, AND ELECTRICAL/ELECTRONIC INSTRUMENT INCLUDING ELECTROCONDUCTIVE FIBER

TECHNICAL FIELD

[0001] This disclosure relates to a conductive fiber particularly suitable for incorporation into a fabric such as a smart textile, and a garment or an electric or electronic device using the same.

BACKGROUND

[0002] In recent years, there has been an increasing demand for smart textiles in which electronic components such as various devices, sensors and IC chips are incorporated in a textile such as a knitted fabric and a woven fabric. Such smart textiles are expected to be worn in various scenes since the smart textiles can be designed according to a purpose from sports to medical applications.

[0003] In the smart textiles in which these electronic components are incorporated, electric wiring having a low resistance value is required for transmission of electricity serving as a drive source of a device and electric signal transmission from a sensor. When a normal copper wire is used for the electric wiring, although the copper wire exhibits sufficient conductivity for the power transmission and the signal transmission, there is a problem that the copper wire cannot follow deformation such as bending and stretch of the textile, and a sense of discomfort is caused when the copper wire is incorporated into a garment.

[0004] In view of such a background, various techniques of imparting stability of electrical characteristics against the deformation and flexibility to a conductive fiber have been studied. For example, an elastic conductive fiber in which a conductive layer made of copper iodide is formed in the vicinity of an inside of a front surface side of an elastic fiber using elastomers (see JP 2010-209481 A), and a technique of forming a conductive fiber into a spring shape and imparting high elasticity to obtain conductive wiring having high elasticity and excellent durability (see National Institute of Advanced Industrial Science and Technology) have been proposed.

[0005] Furthermore, as a method of imparting conductivity to a crimped synthetic fiber, a composite fiber in which a conductive layer containing carbon black and a non-conductive layer having fiber formability form a side-by-side or eccentric core-sheath composite, and the conductive layer forms at least a part of a fiber surface (see JP 2009-46785 A) has been proposed.

[0006] As another technique of imparting functionality by forming a metal layer on a fiber, there has been proposed an electromagnetic wave shielding sheet which includes a metal layer adhered to a constituent fiber of a nonwoven fabric and in which the nonwoven fabric includes a crimped fiber and an adhesive fiber solidified portion (see JP 2020-17615 A).

[0007] According to the technique in JP '481, the conductive fiber having elasticity and stability of electrical characteristics can be obtained by imparting conductivity to a sheath portion of a core-sheath composite fiber using two different types of elastomers. However, in the technique of JP '481, in addition to a problem that a fiber diameter of a fiber obtained by using the elastomers is substantially increased, since a repulsive force is generated in a bent portion and an elongated portion due to an elastic behavior specific to the elastomer, a sense of discomfort is generated when the conductive fiber is incorporated into a garment.

[0008] According to the technique of National Institute of Advanced Industrial Sciences and Technology, the conductive fiber having excellent elasticity and durability can be obtained by forming the conductive fiber into the spring shape. However, an outer diameter of a spring-shaped fiber bundle is large, and the repulsive force is generated in a bent portion and an elongated portion due to an elastic behavior of a spring-shaped structure, and thus when the conductive fiber is incorporated into the garment, a sense of discomfort is caused.

[0009] According to the technique of JP '785, a conductive fiber having excellent elasticity can be obtained by forming a crimped fiber having the conductive layer containing carbon black. However, the obtained fiber has a high volume resistance value of 1×10^{-1} Ω·cm or more, and has insufficient conductivity for use in transmission of electricity and signal transmission from a sensor, and since the conductivity is caused by dispersibility of carbon black, unevenness of the resistance value tends to be large, and stability of electrical characteristics cannot be sufficiently ensured.

[0010] In a technique of JP '615, the electromagnetic wave shielding sheet in which the metal layer is adhered to the nonwoven fabric is proposed. However, when the nonwoven fabric is cut out and used for electric wiring to obtain sufficient conductive performance, a larger area of a conductive layer than that of a conductive fiber is required, and it is difficult to weave or knit the nonwoven fabric into a fabric because of a shape of the nonwoven fabric, and thus the nonwoven fabric is inappropriate as the electric wiring of a smart textile.

[0011] Therefore, it could be helpful to provide a conductive fiber having excellent flexibility in addition to high conductivity and stability of electrical characteristics against deformation, and particularly suitable for incorporation into a fabric such as a smart textile, and to provide a garment or an electric or electronic device using the same.

SUMMARY

[0012] We found that it is important that a conductive fiber used for transmission of electricity and signal transmission from a sensor in a smart textile in which an electronic component is incorporated have excellent flexibility to follow movement of the textile without a sense of discomfort, in addition to high conductivity and stability of electrical characteristics against deformation.

[0013] We also found that when a metal layer is disposed on a surface of a fiber having a specific number of crimps and volume resistivity and total fineness are set within specific ranges, the excellent flexibility that does not cause the sense of discomfort even when the conductive fiber is incorporated in the textile, is exhibited in addition to deformation followability and the stability of electrical characteristics, and this disclosure has been completed.

[0014] Thus, our conductive fiber includes a metal layer on a fiber surface, and has an average number of crimps of 2 crimps/cm or more, a volume resistivity of 2×10^{-6} Ω·cm to 1×10^{-2} Ω·cm, and a total fineness of 10 dtex to 1000 dtex.

[0015] Preferably, the conductive fiber has an average single-fiber diameter of 5 m to 20 m.

[0016] Preferably, the conductive fiber includes a filament fiber.

[0017] Preferably, the conductive fiber has a volume resistivity of 2×10^{-6} Ω·cm to 1×10^{-2} Ω·cm when the conductive fiber is elongated by 10% in a fiber axis direction.

[0018] Preferably, the conductive fiber has a crimped shape being a three-dimensional coil shape.

[0019] Additionally, in a garment or our electric or electronic device, at least a part thereof includes the above-mentioned conductive fiber.

[0020] It is thus possible to obtain a conductive fiber having excellent flexibility in addition to high conductivity and stability of electrical characteristics against deformation, and particularly suitable for incorporation into a fabric such as a smart textile, and a garment or an electric or electronic device using the same.

DETAILED DESCRIPTION

[0021] Our conductive fiber has an average number of crimps of 2 crimps/cm or more, includes a metal layer on a fiber surface, has a volume resistivity of 2×10^{-6} Ω·cm to 1×10^{-2} Ω·cm, and further has a total fineness of 10 dtex to 1000 dtex. Hereinafter, the constituent elements will be described in detail, but this disclosure is not limited to the scope to be described below in any way.

Conductive Fiber

[0022] In the conductive fiber, a portion other than the metal layer is preferably made of a thermoplastic polymer. When the portion other than the metal layer is made of the thermoplastic polymer, a fiber shape is easily obtained by molding using a melt spinning method, and the conductive fiber having a uniform shape in a fiber axis direction can be obtained.

[0023] Examples of the thermoplastic polymer used in the conductive fiber include polyester-based polymers such as polyethylene terephthalate, polytrimethylene terephthalate, polybutylene terephthalate, and polyhexamethylene terephthalate and copolymers thereof, aliphatic polyester-based polymers such as polylactic acid, polyethylene succinate, polybutylene succinate, polybutylene succinate adipate, polyhydroxybutyrate-polyhydroxyvalerate copolymer, and polycaprolactone and copolymers thereof, aliphatic polyamide-based polymers such as polyamide 6, polyamide 66, polyamide 610, polyamide 10, polyamide 12, and polyamide 6-12 and copolymers thereof, polyolefin-based polymers such as polypropylene, polyethylene, polybutene, and polymethylpentene and copolymers thereof, water-insoluble ethylene-vinyl alcohol copolymer-based polymers containing 25 mol % to 70 mol % of an ethylene unit, and polystyrene-based, polydiene-based, chlorine-based, polyolefin-based, polyester-based, polyurethane-based, polyamide-based, fluorine-based, and other elastomeric polymers, which can be selected and used. Among these polymers, the polyester-based polymers and the copolymers thereof are preferably used since the metal layer is relatively easily formed by plating or the like and peeling or the like of the metal layer is less likely to occur.

[0024] The conductive fiber may contain, in the thermoplastic polymer, inorganic substances such as titanium oxide, silica, and barium oxide, coloring agents such as carbon black, dyes, and pigments, various additives such as flame retardants, fluorescent brighteners, antioxidants, and ultraviolet absorbers, as long as the desired effects are not impaired.

[0025] The conductive fiber may be not only a monocomponent fiber, but also a composite fiber obtained by combining two or more kinds of polymers. When the conductive fiber is the composite fiber, examples thereof include a core-sheath type composite fiber, a sea-island type composite fiber, a side-by-side type composite fiber, and an eccentric core-sheath type composite fiber, and the side-by-side type or the eccentric core-sheath type, which is a composite form in which a three-dimensional coil-shaped (spiral) crimp is developed in a fiber by a combination of polymers, is preferable. When the side-by-side type is used as the composite form, as examples of the combination of the polymers, a combination of the same type of polyester-based polymers having different viscosities, a combination of the same type of polyamide-based polymers having different viscosities, a combination of different types of polyester-based polymers such as polyethylene terephthalate and polybutylene terephthalate and the like are preferably used. In addition, when the eccentric core-sheath type is used as the composite form, as an example of the combination of the polymers, a combination of a polyester-based polymer and a polyurethane-based polymer, a combination of a polyamide-based polymer and a polyurethane-based polymer or the like is preferably used in addition to the above-described examples of the combination of the side-by-side type.

[0026] It is important that the conductive fiber has an average number of crimps of 2 crimps/cm or more. When the average number of crimps is 2 crimps/cm or more, preferably 3 crimps/cm or more, and more preferably 4 crimps/cm or more, a 10% modulus of the conductive fiber tends to decrease, and thus flexibility is improved. An upper limit of the average number of crimps is not particularly limited, and is substantially about 60 crimps/cm.

[0027] The average number of crimps is determined as follows:

[0028] (1) A single-fiber taken out from a multifilament is placed on a sample stage in an unloaded state, and an image of the single-fiber of 1 cm is captured with a microscope.

[0029] (2) After the number of peaks and troughs of the fiber is counted from the captured image, a total thereof is divided by 2 to obtain the number of crimps.

[0030] (3) The above measurement is performed five times with different single-fibers per level, and an arithmetic mean value thereof is taken as the average number of crimps.

[0031] A crimped shape of the conductive fiber can be a crimped shape such as a saw-tooth shape, a three-dimensional coil shape, and a combination thereof, and the three-dimensional coil shape is preferable among the shapes. When the crimped shape of the conductive fiber is the three-dimensional coil shape, followability to stretch in a fiber axis direction and complicated movement is increased, and thus the conductive fiber can be suitably used for a textile such as a garment.

[0032] It is important that the conductive fiber includes the metal layer on the fiber surface. By providing the metal layer on the fiber surface, the volume resistivity of the conductive fiber can be reduced, and conductivity sufficient for power transmission and signal transmission can be obtained.

[0033] The metal layer on the fiber surface in the conductive fiber is not particularly limited as long as the metal layer satisfies our conductive performance, and is preferably formed by copper plating and/or silver plating. When the metal layer on the fiber surface is formed by the copper plating and/or the silver plating, the volume resistivity of the conductive fiber can be reduced, and the metal layer can be easily uniformly formed on the fiber surface, and thus the conductivity and uniformity in the fiber axis direction thereof are improved. When the metal layer on the fiber surface is formed only by the copper plating, the conductivity decreases (the volume resistivity increases) compared to when the metal layer is formed only by the silver plating, but a cost can be reduced.

[0034] It is important that the conductive fiber has a volume resistivity of 2×10^{-6} Ω·cm to 1×10^{-2} Ω·cm. When the volume resistivity is 2×10^{-6} Ω·cm or more, preferably 1×10^{-5} Ω·cm or more, a proportion of the metal layer in a fiber cross section is substantially reduced, and thus mechanical properties such as strength are improved. When the volume resistivity is 1×10^{-2} Ω·cm or less, preferably 1×10^{-3} Ω·cm or less, sufficient conductivity for the power transmission and the signal transmission can be obtained.

[0035] The volume resistivity is determined as follows:

[0036] (1) The conductive fiber having a length of 10 cm is held at a temperature of 25° C. and humidity of 65% RH for 1 hour or more.

[0037] (2) The conductive fiber is set without tension in a manner of being in contact with a probe including two rod terminals connected to an insulation resistance meter and having a distance between the terminals of 5 cm.

[0038] (3) After measuring a resistance value (Ω) at an applied voltage of 100 V and dividing an obtained resistance value by the probe distance of 5 cm, a value is obtained by multiplying an obtained resistance value by a cross-sectional area A (cm^2) of the conductive fiber subjected to the measurement by the method to be described later.

[0039] (4) The above measurement is performed five times at different measurement locations for each level, and an arithmetic mean value thereof is taken as the volume resistivity (Ω·cm).

[0040] When the conductive fiber is a monofilament, the volume resistivity is volume resistivity of the monofilament alone, and when the conductive fiber is the multifilament, the volume resistivity is volume resistivity of the entire multifilament. That is, in the multifilament, a total of the cross-sectional areas A (cm^2) of all the single-fibers constituting the multifilament corresponds to the cross-sectional area A (cm^2) of the above (3).

[0041] The conductive fiber preferably has volume resistivity of 2×10^{-6} Ω·cm to 1×10^{-2} Ω·cm when elongated by 10% in the fiber axis direction. When the volume resistivity when the conductive fiber is elongated by 10% in the fiber axis direction is preferably 2×10^{-6} Ω·cm or more, and more preferably 1×10^{-5} Ω·cm or more, an excessive change in volume resistivity is eliminated even at the time of elongating deformation, and thus a conductive fiber having stable volume resistivity against the deformation is obtained. When the volume resistivity when the conductive fiber is elongated by 10% in the fiber axis direction is preferably 1×10^{-2} Ω·cm or less, and more preferably 1×10^{-3} Ω·cm or less, there is no excessive increase in volume resistivity due to the elongating deformation, and even when the conductive fiber is incorporated to the textile and subjected to complex movement, the conductivity sufficient for the power transmission and the signal transmission can always be obtained, and thus the conductive fiber having excellent stability of electrical characteristics against the deformation is obtained.

[0042] The volume resistivity when the conductive fiber is elongated by 10% in the fiber axis direction is obtained by setting the conductive fiber in a manner of being in contact with the probe after the conductive fiber is elongated by 10% from an unloaded state when the above-mentioned volume resistivity is measured.

[0043] It is important that the conductive fiber has the total fineness of 10 dtex to 1000 dtex. When the total fineness is 10 dtex or more, preferably 20 dtex or more, and more preferably 30 dtex or more, a low resistance value sufficient for the power transmission and the signal transmission can be achieved, and breaking strength of the fiber is increased, and thus the conductive fiber excellent in post-processability and durability is obtained. When the total fineness is 1000 dtex or less, preferably 800 dtex or less, and more preferably 500 dtex or less, even if the conductive fiber is incorporated into the textile such as a garment, the conductive fiber does not give a sense of discomfort and is excellent in wearing comfort.

[0044] The total fineness is determined by reeling the conductive fiber by 100 m, multiplying a mass of the skein by 100 to calculate total fineness (dtex), measuring the total fineness 5 times per level, and calculating an arithmetic mean value thereof. When the conductive fiber is shorter than 100 m or cannot be reeled, a length (m) and a mass (g) of the conductive fiber may be measured, and the total fineness (dtex) may be calculated by dividing the mass (g) by the length (m)×10,000.

[0045] The conductive fiber preferably has an average single-fiber diameter of 5 m to 20 m. When the average single-fiber diameter is preferably 5 m or more, more preferably 6 m or more, and still more preferably 7 μm or more, since strength of the single-fiber is increased, yarn breakage due to rubbing such as friction is reduced, and the conductive fiber having high durability is obtained. When the average single-fiber diameter is preferably 20 μm or less, more preferably 18 μm or less, and still more preferably 16 μm or less, since the fiber easily follows deformation such as bending and is a flexible fiber, the conductive fiber does not give a sense of discomfort and is excellent in wearing comfort even if the conductive fiber is incorporated into the textile such as a garment.

[0046] The average single-fiber diameter is determined as follows:

[0047] (1) The single-fiber taken out from the multifilament is cut in a direction perpendicular to a fiber axis, and an image is captured using a scanning electron microscope at magnification at which an entire cross section of the single-fiber can be observed.

[0048] (2) With respect to the captured image, a cross-sectional area A formed by a cross-sectional outline of the single-fiber is measured using image analysis software, and a diameter (μm) of a perfect circle having the same area as the cross-sectional area A is calculated.

- **[0049]** (3) All the single-fibers constituting the multifilament are calculated, and an arithmetic mean value thereof is taken as the average single-fiber diameter (m).

[0050] When the eccentric core-sheath type is used as the composite form of the conductive fiber, a degree of eccentricity in the cross section of the single-fiber is preferably 0.05 to 0.80. When the degree of eccentricity is preferably 0.05 or more, more preferably 0.10 or more, and still more preferably 0.15 or more, since the average number of crimps is increased, the flexibility is improved, and the conductive fiber having the stability of electrical characteristics against the deformation is obtained. When the degree of eccentricity is preferably 0.80 or less, more preferably 0.65 or less, and still more preferably 0.50 or less, since cross-section formability in a spinning process is improved, the conductive fiber excellent in process stability and having few defects such as yarn breakage is obtained.

[0051] The degree of eccentricity is determined as follows:

- **[0052]** (1) The single-fiber taken out from the multifilament is cut in the direction perpendicular to the fiber axis, and the image is captured using the scanning electron microscope at the magnification at which the entire cross section of the single-fiber can be observed.
- **[0053]** (2) With respect to the captured image, a center of gravity a obtained from a cross section of the entire composite fiber and a center of gravity b obtained from a cross section of only a core component are calculated using the image analysis software, and the degree of eccentricity is calculated by the following formula:

$$\text{Degree of eccentricity}=(\text{distance between center of gravity } a \text{ and center of gravity } b)/(\tfrac{1}{2}\times\text{average single-fiber diameter}).$$

[0054] The conductive fiber can take any shape such as a spun yarn including a filament fiber or a staple fiber, and among these fibers, the conductive fiber preferably includes the filament fiber. When the conductive fiber includes the filament fiber, since unevenness in conductivity is reduced, the conductive fiber exhibits stable volume resistivity in the fiber axis direction, and has high productivity and excellent mechanical properties.

[0055] The conductive fiber preferably has breaking strength of 1.5 cN/dtex or more. When the breaking strength is preferably 1.5 cN/dtex or more, and more preferably 2.0 cN/dtex or more, since yarn breakage in a post-processing process such as weaving and knitting is prevented, the conductive fiber having process stability is obtained. On the other hand, an upper limit of the breaking strength is not particularly limited, and is substantially about 10.0 cN/dtex.

[0056] The breaking strength is determined by setting the conductive fiber without applying tension based on tensile strength and elongation described in JIS L 1013:2010 8.5, measuring strength (cN) at break under a condition of a sample length of 200 mm and a tensile speed of 200 mm/min, calculating strength (cN/dtex) by dividing the strength (cN) at break by the total fineness (dtex), measuring the strength five times per level, and calculating an arithmetic mean value thereof.

[0057] The conductive fiber preferably has breaking elongation of 15% to 200%. When the breaking elongation is preferably 15% or more, more preferably 20% or more, and still more preferably 30% or more, since the yarn breakage in the post-processing process is reduced, the conductive fiber having the process stability is obtained. When the breaking elongation is preferably 200% or less, more preferably 180% or less, and still more preferably 160% or less, since plastic deformation is less likely to occur when the fiber is elongated, the conductive fiber having the excellent durability is obtained.

[0058] The breaking elongation is determined by setting the conductive fiber without applying the tension based on the tensile strength and the elongation described in JIS L 1013:2010 8.5, measuring elongation (%) at break under the condition of the sample length of 200 mm and the tensile speed of 200 mm/min, measuring the elongation five times per level, and calculating an arithmetic mean value thereof.

[0059] The conductive fiber preferably has a 10% modulus of 1.50 cN/dtex or less. When the 10% modulus is preferably 1.50 cN/dtex or less, more preferably 1.00 cN/dtex or less, and still more preferably 0.50 cN/dtex or less, since stress caused by the deformation is reduced, the conductive fiber having the excellent flexibility is obtained. On the other hand, a lower limit of the 10% modulus is not particularly limited, and is substantially about 0.00 cN/dtex.

[0060] The 10% modulus is determined by setting the conductive fiber without applying the tension based on the tensile strength and the elongation described in JIS L 1013:2010 8.5, measuring the stress (cN/dtex) when the conductive fiber is elongated by 10% under a condition of the sample length of 200 mm and the tensile speed of 200 mm/min, measuring the stress five times per level, and calculating an arithmetic mean value thereof.

[0061] Since the conductive fiber has excellent flexibility in addition to high conductivity and the stability of electrical characteristics against the deformation, the conductive fiber can be used, for example, as an antistatic material in various applications such as clothing such as stockings, tights and dustproof clothing, textiles such as curtains, and carpets or mats and floor materials to be laid indoors and outdoors, and in vehicles, taking advantage of these characteristics, and can be particularly suitably used for a smart textile such as for transmission of electricity serving as a drive source of a device incorporated in fabrics and electric signal transmission from a sensor. By incorporating the conductive fiber into a portion requiring an operation such as stretch or bending in an electric or electronic device, the conductive fiber can be suitably used for the transmission of the electricity, the electric signal transmission from a sensor and the like.

Garment

[0062] At least a part of our garment includes our conductive fiber. When the conductive fiber is included in at least a part thereof, a garment that does not give a sense of discomfort when worn and is excellent in wearing comfort is obtained.

[0063] The garment is an article to be worn for partially or entirely covering a body, and includes not only clothes such as upper and lower garments, kimonos and coveralls, but also hats, gloves, socks and the like. Among these, by applying the conductive fiber to the smart textile which is a garment in which electronic components such as various devices, sensors, and IC chips are incorporated, it is possible to fully exhibit the characteristics of the conductive fiber such as high conductivity, stability of electrical characteristics against deformation, and flexibility, which is more preferable.

[0064] For example, when the conductive fiber is applied to the smart textile, a smart textile is obtained that does not hinder movement of a human body due to the high flexibility caused by crimping, and that does not give a sense of discomfort when worn since total fineness is within a specific range, and that is excellent in wearing comfort. Further, since the conductive fiber has lower volume resistivity than a fiber containing carbon black, it is possible to transmit the electricity serving as the drive source of the device and to transmit an electric signal from the sensor, and it is excellent in the stability of electrical characteristics against the deformation. Accordingly, the conductive fiber can be applied to the smart textile for various applications.

[0065] In the garment, when the conductive fiber is used for the transmission of the electricity, a portion where the conductive fiber is disposed may be covered with an insulating material. By covering the portion where the conductive fiber is disposed with the insulating material, it is possible to prevent electric shock and the like, which is preferable.

Electric or Electronic Device

[0066] At least a part of the electric or electronic device includes the conductive fiber. When the conductive fiber is included in at least a part thereof, it is possible to smoothly perform operations such as stretch and bending, and it is possible to provide an electric device or an electronic device having the excellent stability of electrical characteristics against the deformation.

[0067] The conductive fiber is capable of transmitting the electricity and transmitting the electric signal from the sensor, and is also excellent in the stability of electrical characteristics against the deformation. Accordingly, the conductive fiber can be applied to the electric or electronic device for various applications requiring the operations such as stretch and bending.

[0068] In the electric or electronic device, when the conductive fiber is used for the transmission of the electricity, a portion where the conductive fiber is disposed may be covered with an insulating material. By covering the portion where the conductive fiber is disposed with the insulating material, it is possible to prevent electric shock and the like, which is preferable.

Methods of Producing Conductive Fiber, Garment, and Electric or Electronic Device

[0069] Next, a preferred example of producing the conductive fiber will be specifically described.

[0070] The method of producing the conductive fiber can be selected from a solution spinning method, the melt spinning method and the like, and it is preferable to apply the melt spinning method from the viewpoint of low environmental load and easy production.

[0071] The thermoplastic polymer used in the method is preferably dried before being subjected to spinning for the purpose of preventing moisture mixing and removing oligomers from the viewpoint of improving yarn formation properties. As a drying condition, vacuum drying at 80° C. to 200° C. for 1 hour to 24 hours is usually used.

[0072] In melt spinning, a melt spinning method using an extruder such as a pressure melter extruder or a single-screw or double-screw extruder can be applied. The extruded thermoplastic polymer passes through a pipe, is measured by a measuring device such as a gear pump, passes through a filter removing a foreign matter, and is then guided to a spinneret to be discharged. When the fiber is the composite fiber, respective thermoplastic polymers are guided from separate pipes to the spinneret, are merged in the spinneret by being subjected to shape regulation into the side-by-side type, the eccentric core-sheath type or the like, and are discharged as the composite fiber. The composite fiber obtained in this manner is subjected to a stretching process to be described later to form the fiber having the three-dimensional coil shape.

[0073] When polyester or polyamide is used as the thermoplastic polymer, a temperature (spinning temperature) from a polymer pipe to the spinneret is preferably equal to or higher than a melting point of the thermoplastic polymer+20° C. to increase fluidity, and is preferably equal to or lower than 320° C. to prevent thermal decomposition of the thermoplastic polymer.

[0074] In the spinneret used for the discharge, it is preferable that a diameter D of a spinneret hole is 0.1 mm or more and 0.6 mm or less, and it is preferable that L/D defined by a quotient obtained by dividing a land length L (length of a straight pipe portion that is the same as a hole diameter of the spinneret hole) of the spinneret hole by the hole diameter is 1 or more and 10 or less.

[0075] The fiber discharged from the spinneret hole is cooled and solidified by blowing cooling air (air). A temperature of the cooling air can be determined by balance with a cooling air speed from the viewpoint of cooling efficiency, and is preferably 30° C. or less. When the temperature of the cooling air is preferably 30° C. or less, a solidification behavior by the cooling is stabilized, and the conductive fiber having high uniformity of a fiber diameter is obtained.

[0076] The cooling air is preferably blown in a direction substantially perpendicular to an unstretched fiber discharged from the spinneret. In this example, a speed of the cooling air is preferably 10 m/min or more from the viewpoint of the cooling efficiency and the uniformity of the fiber diameter, and is preferably 100 m/min or less from the viewpoint of yarn forming stability. By setting a blowing direction of the cooling air to one direction and cooling the fiber using the thermoplastic polymer having large specific heat capacity, a hollowed fiber, or the like, it is possible to obtain an unstretched fiber having a difference in molecular orientation ratio in a fiber cross-sectional direction, and it is also possible to obtain a crimped fiber by subjecting the unstretched fiber to the stretching process to be described later.

[0077] The cooled and solidified unstretched fiber is taken up by a roller (godet roller) rotating at a constant speed. The take-up speed is preferably 300 m/min or more to improve the uniformity of the fiber diameter and the productivity, and is preferably 4000 m/min or less to not cause the yarn breakage.

[0078] The unstretched fiber obtained in this manner is continuously subjected to the stretching process after being wound up or taken out once. The stretching is performed by causing the unstretched fiber to run on a heated first roller or a heating device provided between the first roller and the second roller, for example, in a heating bath or on a heating plate. A stretching condition is determined by mechanical properties of the obtained unstretched fiber, a stretching temperature is determined by a temperature of the heated first roller or the heating device provided between the first roller and the second roller, and a stretching ratio is determined by a ratio of a circumferential speed of the first roller to a circumferential speed of the second roller.

[0079] Furthermore, after passing through the second roller, it is also possible to heat a stretched fiber by a heated third roller or a heating device provided between the second roller and the third roller, and perform heat setting. By performing the heat setting, crystallization proceeds, and a conductive fiber having excellent shape stability is obtained.

[0080] The stretched fiber obtained by the above producing method can express the three-dimensional coil shape in a state after being stretched by performing the above composite fiber production, cooling condition adjustment, or the like. It is also possible to apply mechanical crimping to the obtained stretched fiber with a crimper, a gear or the like.

[0081] The obtained crimped fiber is subjected to a plating treatment to form the metal layer on the fiber surface. A metal to be plated is not particularly limited as long as the metal satisfies our conductive performance, and copper and/or silver is preferable from the viewpoint of the conductive performance and the cost. The plating treatment may be a method of forming the metal layer on the crimped fiber, and examples thereof include an electroless plating method, an electrolytic plating method, a molten metal plating method, a vacuum deposition method, a chemical vapor deposition method, and a physical vapor deposition method. Before the plating treatment, a surface modification treatment or the like may be performed to facilitate the formation of the metal layer.

[0082] The conductive fiber obtained by forming the metal layer on a surface of the crimped fiber obtained by the above producing method is incorporated into the textile such as a woven fabric or a knitted fabric. When the conductive fiber is incorporated into the woven fabric or the knitted fabric, a method of using the conductive fiber for a part or all of fibers to be subjected to a producing process, a method of sewing the conductive fiber onto a gray fabric or a knitted fabric formed by another fiber or the like may be used. The garment is sewn using the textile (woven fabric or knitted fabric) obtained in this manner. A method of directly sewing the conductive fiber to the garment may also be used. Further, when the conductive fiber is incorporated into the electric or electronic device, a method similar to that of an ordinary electric wiring such as a copper wire can be adopted.

EXAMPLES

[0083] Next, our fibers, clothing, instruments and methods will be described in detail based on Examples. However, this disclose is not limited only to the Examples. In the measurement of each physical property, unless otherwise specified, the measurement was performed based on the method described above.

(1) Total Fineness

[0084] Measurement was performed as described above using an electric measuring device "YC-1" manufactured by Intec Co., Ltd.

(2) Average Single-Fiber Diameter

[0085] An image of a single-fiber taken out from the multifilament was captured using a scanning electron microscope "5-5500" manufactured by Hitachi High-technologies Corporation at the magnification at which the entire cross section of the single-fiber could be observed. Thereafter, "WinROOF 2015" manufactured by Mitani Corporation was used as the image analysis software, and the measurement was performed as described above.

(3) Average Number of Crimps

[0086] The single-fiber taken out from the multifilament was measured as described above using a digital microscope "VHX-2000" equipped with a wide-range zoom lens "VH-Z100R" manufactured by Keyence Corporation.

(4) Breaking Strength, Breaking Elongation, and 10% Modulus

[0087] Measurement was performed as described above using a tensile tester "Tensilon UCT100" manufactured by Orientec Corporation.

(5) Volume Resistivity, Volume Resistivity at 10% Elongation

[0088] Measurement was performed as described above using an insulation resistance meter "SM-8220" manufactured by DKK-Toa Corporation.

(6) Stability of Electrical Characteristics Against Deformation

[0089] Two conductive fibers obtained in Example and Comparative Example were sewn 15 cm in parallel at intervals of 3 cm (in-and-out stitch and intervals of 0.5 cm) in a high elongation direction of a polyester stretch knitted fabric (moss knitting and weight per unit area of 170 g/m^2) having breaking elongation of 15% or more in at least one of vertical and horizontal directions and not including a conductive layer. Next, after the stretch fabric was elongated by 10% in the high elongation direction, the stretch fabric was returned to the unloaded state, and then two sewing threads were knotted to prevent loosening, whereby the two sewing threads were fixed. Terminals of an axial DC fan "D02X (rated voltage 5V)" manufactured by Nidec Corporation, were connected to end portions of the two sewing threads, and a DC power supply device having an output voltage of 5V was connected to other ends of the sewing threads. Thereafter, 10% stretch (reciprocation) was repeated 10 times at a speed of 3 seconds/time while rotating the fan by passing a current, and when "the fan sufficiently rotated and the number of revolutions of the fan did not change during a stretch operation," it was evaluated as "A (good)," "when the number of revolutions of the fan changed during the stretch operation," it was evaluated as "B (slightly poor)," and when "rotation of the fan was significantly slow or the rotation of the fan was stopped," it was evaluated as "C (poor)," whereby the stability of electrical characteristics against the deformation was evaluated.

Example 1

[0090] High-viscosity polyethylene terephthalate (PET) having intrinsic viscosity of 0.9 dL/g as a polymer A and low-viscosity PET having intrinsic viscosity of 0.6 dL/g as a polymer B were vacuum-dried at 150° C. for 12 hours and then melt-spun at a spinning temperature of 290° C. In melt spinning, the high-viscosity PET and the low-viscosity PET were melt-extruded by separate double screw extruders, respectively, and were guided to a spinneret while being weighed by a gear pump. Thereafter, in the spinneret, the polymers are merged in the spinneret by being subjected to shape regulation into a side-by-side type having a volume ratio of high-viscosity PET:low-viscosity PET=50:50, and yarns were spun out at a discharge amount per hole of 0.82 g/min from the spinneret having 36 round holes each having a hole diameter of 0.3 mmφ.

[0091] The yarn spun out from the spinneret was passed through a heat retention region of 50 mm, and then was air-cooled over a length of 1.0 m under conditions of a temperature of 25° C. and a wind speed of 30 m/min by using a uniflow-type cooling device. Thereafter, an oil agent was applied 2.0 m below a spinneret surface, and 36 filaments were wound by a winder via a first godet roller and a second godet roller of 1000 m/min to obtain an unstretched fiber.

[0092] The unstretched fiber was taken out by a feed roller attached with a nip roller, tension was applied to the unstretched fiber between itself and the first roller, and then the fiber was made to make six laps around the first roller and the second roller heated to 90° C. to perform heat stretching. Further, the fiber was made to make six laps around a third roller heated to 140° C. to perform heat setting. A total stretching ratio was 3.50 times, and the fiber which had passed through the third roller was wound in the winder via a non-heating roller having a circumferential speed of 400 m/min to obtain a stretched fiber.

[0093] A surface of the stretched fiber was washed, degreased, and subjected to an etching treatment, and then a palladium catalyst was supported on the fiber surface, and a copper plating treatment was performed in an aqueous copper sulfate solution.

[0094] For an obtained conductive fiber, total fineness, an average single-fiber diameter, an average number of crimps, breaking strength, breaking elongation, volume resistivity, volume resistivity at 10% elongation, and stability of electrical characteristics against deformation were evaluated. Evaluation results are shown in Table 1.

Examples 2 and 3

[0095] Conductive fibers were obtained in the same manner as in Example 1 except that the discharge amount per hole in the spinning process was changed to 1.40 g/min in Example 2 and 0.56 g/min in Example 3. Evaluation results of the obtained conductive fibers are shown in Table 1.

Example 4

[0096] A conductive fiber was obtained in the same manner as in Example 1 except that the volume ratio in the spinning process was high-viscosity PET:low-viscosity PET=20:80. An evaluation result of the obtained conductive fiber is shown in Table 1.

Example 5

[0097] A conductive fiber was obtained in the same manner as in Example 1 except that polybutylene terephthalate (PBT) "'TORAYCON' 1200M" manufactured by Toray Industries, Inc. was used as the polymer A. An evaluation result of the obtained conductive fiber is shown in Table 2.

Example 6

[0098] A conductive fiber was obtained in the same manner as in Example 1, except that in the spinning process, an eccentric core-sheath type composite fiber having a degree of eccentricity of 0.30, in which the polymer A was disposed in a sheath and the polymer B was disposed in a core, was used. An evaluation result of the obtained conductive fiber is shown in Table 2.

Comparative Example 1

[0099] A conductive fiber was obtained in the same manner as in Example 6 except that a stretched fiber including polypropylene terephthalate (PPT-CB) obtained by melt-kneading a furnace black (type L, average particle diameter: 23 m) manufactured by Degussa Corporation as the polymer A, and PET (copolymerized PET) obtained by copolymerizing 7 mol % of isophthalic acid (IPA) and 4 mol % of a bisphenol A-ethylene oxide adduct (BPA-EO) as the polymer B was used, and plating treatment was not performed. An evaluation result of the obtained conductive fiber is shown in Table 2.

Example 7

[0100] A conductive fiber was obtained in the same manner as in Example 1 except that, in the spinning process, only the polymer A was spun out using a hollow spinneret (slit width: 0.08 mm, slit diameter: 0.8 mm, 3 slits) and then air-cooled using a uniflow-type cooling device under a condition of a wind speed of 50 m/min to use an unstretched fiber having a difference in molecular orientation ratio in a fiber cross-sectional direction. An evaluation result of the obtained conductive fiber is shown in Table 3.

Comparative Example 2

[0101] A conductive fiber was obtained by performing a copper plating treatment in the same manner as in Example 1 using a polyurethane elastic fiber "LYCRA T-127" manufactured by Toray Opelontex Co., Ltd. as a stretched fiber. An evaluation result of the obtained conductive fiber is shown in Table 3.

TABLE 1

Item	Example 1	Example 2	Example 3	Example 4
Composite form	Side-by-side	Side-by-side	Side-by-side	Side-by-side
Polymer A	High-viscosity PET	High-viscosity PET	High-viscosity PET	High-viscosity PET
Ratio (%)	50	50	50	20
Polymer B	Low-viscosity PET	Low-viscosity PET	Low-viscosity PET	Low-viscosity PET
Ratio (%)	50	50	50	80
Total fineness (dtex)	101	173	67	101
Average single-fiber diameter (μm)	14.8	19.4	12.3	14.8
Average number of crimps (crimps/cm)	11	6	13	3

TABLE 1-continued

Item	Example 1	Example 2	Example 3	Example 4
Crimped shape	Three-dimensional coil	Three-dimensional coil	Three-dimensional coil	Three-dimensional coil
Breaking strength (cN/dtex)	2.7	2.1	3.1	2.5
Breaking elongation (%)	55	63	42	45
10% modulus (cN/dtex)	0.08	0.21	0.05	0.93
Metal layer	Copper plating	Copper plating	Copper plating	Copper plating
Volume resistivity (Ω · cm)	9.3×10^{-5}	1.3×10^{-4}	4.9×10^{-5}	8.6×10^{-5}
Volume resistivity at 10% elongation (Ω · cm)	7.4×10^{-5}	1.4×10^{-4}	4.1×10^{-5}	8.5×10^{-4}
Stability of electrical characteristics against deformation	A	A	A	A

TABLE 2

Item	Example 5	Example 6	Comparative Example 1
Composite form	Side-by-side	Eccentric core-sheath	Eccentric core-sheath
Polymer A	PBT	High-viscosity PET	PPT-CB
Ratio (%)	50	50	50
Polymer B	Low-viscosity PET	Low-viscosity PET	Copolymerized PET
Ratio (%)	50	50	50
Total fineness (dtex)	107	102	105
Average single-fiber diameter (μm)	15.1	14.8	15.0
Average number of crimps (crimps/cm)	11	7	10
Crimped shape	Three-dimensional coil	Three-dimensional coil	Three-dimensional coil
Breaking strength (cN/dtex)	2.6	2.9	2.1
Breaking elongation (%)	52	48	68
10% modulus (cN/dtex)	0.06	0.18	0.08
Metal layer	Copper plating	Copper plating	—
Volume resistivity (Ω · cm)	8.1×10^{-5}	9.3×10^{-5}	5.8×10^{1}
Volume resistivity at 10% elongation (Ω · cm)	6.9×10^{-5}	8.1×10^{-5}	3.2×10^{1}
Stability of electrical characteristics against deformation	A	A	C

TABLE 3

Item	Example 7	Comparative Example 2
Cross-sectional shape	Hollow	Round
Polymer	High-viscosity PET	Polyurethane
Total fineness (dtex)	110	106
Average single-fiber diameter (μm)	17.2	34.1
Average number of crimps (crimps/cm)	5	0
Crimped shape	Three-dimensional coil	—
Breaking strength (cN/dtex)	2.3	2.1
Breaking elongation (%)	48	581
10% modulus (cN/dtex)	0.32	0.03
Metal layer	Copper plating	Copper plating
Volume resistivity (Ω · cm)	1.2×10^{-4}	1.8×10^{-4}
Volume resistivity at 10% elongation (Ω · cm)	1.0×10^{-4}	Unmeasurable (reached measurable upper limit)
Stability of electrical characteristics against deformation	A	C

[0102] In Examples 1 to 7, we found that, in addition to the total fineness being within a specific range, since the average number of crimps was large and the 10% modulus was low, the flexibility was excellent, and since the metal layer was disposed, the volume resistivity was low, and further, the stability of electrical characteristics against the deformation was excellent.

[0103] On the other hand, we found that in Comparative Example 1, since the volume resistivity was high, electricity was difficult to flow and the fan was not driven, and in Comparative Example 2, the metal layer on the surface was broken at the time of 10% elongation, the conductivity was remarkably lowered, and the rotation of the fan was stopped, and thus the stability of electrical characteristics against the deformation was poor.

[0104] Although our fibers, clothing, instruments and methods have been described in detail using specific examples, it will be apparent to those skilled in the art that various modifications and variations are possible without departing from the spirit and scope of this disclosure. This application is based on JP No. 2020-127087 filed on Jul. 28, 2020, the entire contents of which are incorporated herein by reference.

1-7. (canceled)

8. A conductive fiber comprising a metal layer on a fiber surface, and having an average number of crimps of 2 crimps/cm or more, a volume resistivity of 2×10^{-6} Ω·cm to 1×10^{-2} Ω·cm, and a total fineness of 10 dtex to 1000 dtex.

9. The conductive fiber according to claim **8**, having an average single-fiber diameter of 5 m to 20 m.

10. The conductive fiber according to claim **8**, comprising a filament fiber.

11. The conductive fiber according to claim **8**, having a volume resistivity of 2×10^{-6} Ω·cm to 1×10^{-2} Ω·cm when the conductive fiber is elongated by 10% in a fiber axis direction.

12. The conductive fiber according to claim **8**, having a crimped shape being a three-dimensional coil shape.

13. A garment, at least a part of which comprises the conductive fiber according to claim **8**.

14. An electric or electronic device, at least a part of which comprises the conductive fiber according to claim **8**.

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