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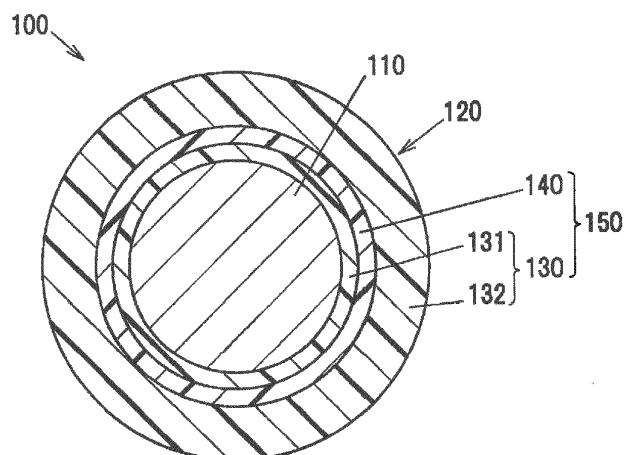
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(54) **INSULATED WIRE**

(57) An insulated wire comprises a conductor and a cover layer arranged around the conductor. The cover layer comprises a laminated structure formed by laminating an inner flame-retardant layer, a high-electrical insulating layer and an outer flame-retardant layer. The inner flame-retardant layer is arranged around the conductor and comprises a polymer composition (A) comprising a flame retardant. The high-electrical insulating layer is arranged around the inner flame-retardant layer and comprises a polymer composition (B) having a vol-

ume resistivity of not less than $1 \times 10^{16} \Omega \text{cm}$. The outer flame-retardant layer is arranged around the high-electrical insulating layer and comprises a polymer composition (C) comprising a flame retardant. The high-electrical insulating layer receives not less than **80%** of voltage applied in a thickness direction of the laminated structure. The thickness of the high-electrical insulating layer is smaller than at least one of the thickness of the inner flame-retardant layer and the thickness of the outer flame-retardant layer.

FIG.1



Description

BACKGROUND OF THE INVENTION

5 1. FIELD OF THE INVENTION

[0001] The invention relates to an insulated wire.

10 2. DESCRIPTION OF THE RELATED ART

[0002] Insulated wires used for wiring in rolling stocks or vehicles, etc., are required to have not only insulating properties but also flame retardancy so as not to be burnt easily in the event of fire. Thus, a flame retardant is mixed to cover layers of the insulated wires. For example, JP-A-2010-97881 discloses an insulated wire in which a cover layer is formed by laminating a flame-retardant layer containing a flame retardant on the outer surface of an insulation layer having insulating properties.

SUMMARY OF THE INVENTION

[0003] In recent years, insulated wires are required to have a smaller diameter in view of, e.g., weight reduction. However, it is not easy to reduce a diameter while achieving high insulating properties and high flame retardancy.

[0004] It is an object of the invention to provide an insulated wire that has a reduced diameter while satisfying high insulating properties and high flame retardancy.

[1] According to an embodiment of the invention, an insulated wire comprises:

a conductor; and
 a cover layer arranged around the conductor,
 wherein the cover layer comprises a laminated structure formed by laminating an inner flame-retardant layer,
 a high-electrical insulating layer and an outer flame-retardant layer,
 wherein the inner flame-retardant layer is arranged around the conductor and comprises a polymer composition
 (A) comprising a flame retardant,
 wherein the high-electrical insulating layer is arranged around the inner flame-retardant layer and comprises a
 polymer composition (B) having a volume resistivity of not less than $1 \times 10^{16} \Omega \text{cm}$,
 wherein the outer flame-retardant layer is arranged around the high-electrical insulating layer and comprises a
 polymer composition (C) comprising a flame retardant,
 wherein the high-electrical insulating layer receives not less than 80% of voltage applied in a thickness direction
 of the laminated structure, and
 wherein the thickness of the high-electrical insulating layer is smaller than at least one of the thickness of the
 inner flame-retardant layer and the thickness of the outer flame-retardant layer.

[2] According to another embodiment of the invention, an insulated wire comprises:

a conductor; and
 a cover layer arranged around the conductor,
 wherein the cover layer comprises a semiconducting layer, a high-electrical insulating layer and a flame-retardant
 layer,
 wherein the semiconducting layer is arranged around the conductor and comprises a polymer composition (A)
 comprising a conductive agent and having a volume resistivity of not more than $1 \times 10^9 \Omega \text{cm}$,
 wherein the high-electrical insulating layer is arranged around the semiconducting layer and comprises a polymer
 composition (B) having a volume resistivity of not less than $1 \times 10^{16} \Omega \text{cm}$,
 wherein the flame-retardant layer is arranged at least around the high-electrical insulating layer and comprises
 a polymer composition (C) comprising a flame retardant, and
 wherein the thickness of the high-electrical insulating layer and the thickness of the semiconducting layer are
 each smaller than the thickness of the flame-retardant layer.

Effects of the invention

[0005] According to an embodiment of the invention, an insulated wire can be provided that has a reduced diameter

while satisfying high insulating properties and high flame retardancy.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Next, the present invention will be explained in more detail in conjunction with appended drawings, wherein:

FIG.1 is a cross sectional view showing an insulated wire in the first embodiment of the present invention taken perpendicular to the longitudinal direction thereof;

FIG.2 is a cross sectional view showing a conventional insulated wire taken perpendicular to the longitudinal direction thereof;

FIG.3 is a cross sectional view showing an insulated wire in the second embodiment of the invention taken perpendicular to the longitudinal direction thereof;

FIG.4 is a cross sectional view showing an insulated wire in another embodiment taken perpendicular to the longitudinal direction thereof; and

FIG.5 is a cross sectional view showing a conventional insulated wire taken perpendicular to the longitudinal direction thereof.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

First embodiment

[0007] The inventors studied the insulated wire structure which allows a diameter to be reduced while achieving high insulating properties and high flame retardancy.

[0008] A conventional wire structure will be firstly described, and the concept of the wire structure in the first embodiment of the present invention will be then described. **FIG.2** is a cross sectional view showing a conventional insulated wire taken perpendicular to the longitudinal direction thereof.

[0009] An insulated wire **200** having a conventional structure has a conductor **210**, an insulation layer **220** arranged around the conductor **210**, and a flame-retardant layer **230** arranged around the insulation layer **220** and containing a flame retardant.

[0010] In case of the insulated wire **200** which has a conventional structure, an additive having (some) flame retardancy (e.g., an inorganic filler such as calcium carbonate or clay) is mixed in a polymer composition constituting the insulation layer **220** so that the insulation layer **220** per se can have some flame retardancy.

[0011] Since a flame-retardant additive, etc. is mixed, the insulating properties of the polymer composition constituting the insulation layer **220** is lower than the insulating properties of a base polymer used to form the polymer composition. When the base polymer of the polymer composition constituting the insulation layer **220** is, e.g., polyethylene, a volume resistivity of the base polymer is, e.g., of the order of about $1 \times 10^{16} \Omega \text{cm}$. A flame-retardant additive, etc., is then mixed to the polymer composition, and this reduces a volume resistivity of the polymer composition constituting the insulation layer **220** down to the order of about $1 \times 10^{14} \Omega \text{cm}$.

[0012] The inventors examined if the thinner flame-retardant layer **230** can be provided to reduce a diameter of the insulated wire **200**. However, only by reducing the thickness of the flame-retardant layer **230** (without changing the thickness of the insulation layer **220**), the insulated wire **200** cannot have high flame retardancy.

[0013] Then, it was examined if the thinner insulation layer **220** can be provided. However, when simply reducing the thickness of the insulation layer **220**, the insulated wire **200** cannot have high insulating properties. Therefore, it was examined if the amount of a flame-retardant additive, etc., mixed to the insulation layer **220** can be reduced so that the insulating properties of the polymer composition constituting the insulation layer **220** are increased closer to high insulating properties of the base polymer. However, when simply reducing the amount of the flame-retardant additive, etc., mixed to the insulation layer **220**, the insulation layer **220** cannot have sufficient flame retardancy.

[0014] Based on the above, the inventors conceived a new structure in which the insulation layer **220** is divided into a flame-retardant layer containing a flame-retardant additive and arranged on the inner side (on the conductor side) and an insulation layer containing a reduced amount of flame-retardant additive, etc., and arranged on the outer side (on the opposite side to the conductor). Hereinafter, the insulation layer containing a reduced amount of flame-retardant additive, etc., is referred to as "high-electrical insulating layer". Then, the flame-retardant layer arranged on the inner side of the high-electrical insulating layer is referred to as "inner flame-retardant layer" and a flame-retardant layer arranged on the outer side of high-electrical insulating layer is referred to as "outer flame-retardant layer".

[0015] In such a structure, when the high-electrical insulating layer is formed of a polymer composition of which insulating properties is enhanced (a decrease in insulating properties is suppressed) by reducing the mixed amount of flame-retardant additive, etc., the thickness of the high-electrical insulating layer required to obtain desired insulating properties can be reduced. In addition, it is also possible to obtain desired flame retardancy by the inner flame-retardant

layer and the outer flame-retardant layer. Furthermore, since the thickness of the easily combustible high-electrical insulating layer can be reduced, it is possible to reduce the thicknesses of the inner flame-retardant layer and the outer flame-retardant layer, i.e., to reduce the thickness of the combined flame-retardant layer.

[0016] By reducing the mixed amount of flame-retardant additive, etc., the volume resistivity of the polymer composition constituting the high-electrical insulating layer can be significantly increased to, e.g., about **100** times higher than the volume resistivity of the polymer composition originally used to form the insulation layer **220**. Thus, reducing the thickness of the insulation layer by increasing the volume resistivity while achieving desired insulating properties is easier way than reducing the thickness of the flame-retardant layer.

[0017] In general, conductors have a twisted wire structure formed by twisting strands and thus have bumps and recesses on a surface thereof. If the high-electrical insulating layer is arranged directly on the conductor, the high-electrical insulating layer is likely to be broken due to electric field concentration caused by the bumps and recesses on the surface of the conductor and the thickness of the high-electrical insulating layer thus should not be reduced. Since the inner flame-retardant layer, which is arranged directly on the conductor and covers the bumps and recesses, serves as a bump-and-recess smoothing layer, the high-electrical insulating layer which is arranged on the inner flame-retardant layer can have a reduced thickness.

[0018] The wire structure, which allows for diameter reduction while achieving high insulating properties and high flame retardancy, is thus obtained.

[0019] Such wire structure is preferably applied to, e.g., a thin insulated wire which has an outer diameter (a cross-sectional diameter) of not more than **3** mm. The insulating properties of insulated wire are evaluated by, e.g., a DC stability test which is described later. Flame retardancy of insulated wire is evaluated by, e.g., VFT or VTFT which are also described later. The intended use of the insulated wire is not specifically limited and is, e.g., for rolling stocks, vehicles or medical application.

[0020] Next, an insulated wire **100** in the first embodiment of the invention will be described in reference to **FIG.1**. **FIG.1** is a cross sectional view showing an example of the structure of the insulated wire **100** taken perpendicular to the longitudinal direction thereof.

Configuration of insulated wire

[0021] The insulated wire **100** has a conductor **110** and a cover layer **120** arranged around the conductor **110**.

Conductor

[0022] The conductor **110** used here can be, e.g., a twisted wire formed by twisting plural strands (metal wires). The strand can be, e.g., a copper wire, a copper alloy wire, an aluminum wire, a gold wire or a silver wire, etc., or may be a wire of which outer surface is plated with a metal such as tin or nickel. The outer diameter (the cross-sectional diameter) of the conductor **110** is, e.g., not less than **0.70** mm and not more than **1.70** mm. The outer diameter (the cross-sectional diameter) of the strand is, e.g., not less than **0.10** mm and not more than **0.30** mm. The material, structure and size, etc., of the conductor **110** can be appropriately selected according to the characteristics required for the conductor **110** of the insulated wire **100**.

Cover layer

[0023] The cover layer **120** has a laminated structure **150** composed of an inner flame-retardant layer **131** arranged around the conductor **110**, a high-electrical insulating layer **140** arranged around the inner flame-retardant layer **131**, and an outer flame-retardant layer **132** arranged around the high-electrical insulating layer **140**. The combined flame-retardant layer **130** is composed of the inner flame-retardant layer **131** and the outer flame-retardant layer **132**.

Inner flame-retardant layer

[0024] The inner flame-retardant layer **131**, i.e., a flame-retardant layer **131** arranged on the inner side (on the conductor **110** side) of the high-electrical insulating layer **140**, is formed of a polymer composition (A) containing a flame retardant. The inner flame-retardant layer **131** is formed by, e.g., extruding the polymer composition (A) on the outer surface of the conductor **110**.

[0025] A base polymer of the polymer composition (A) is e.g. a polyolefin resin. The polyolefin resin used here can be, e.g., a polyethylene-based resin, etc. Examples of the polyethylene-based resin used here include polyethylene such as low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE) and high-density polyethylene (HDPE), ethylene-vinyl acetate copolymer (EVA), ethylene-ethyl acrylate copolymer, ethylene-methyl acrylate copolymer and ethylene-glycidyl methacrylate copolymer, etc. These polyolefin resins may be used alone or in combination of two

or more.

[0026] The base polymer of the polymer composition (A) preferably contains, e.g., EVA. EVA is preferable since its relatively high filler acceptability allows a flame retardant to be added easily and the resin per se has some flame retardancy.

[0027] The flame retardant added to the polymer composition (A) is preferably a halogen-free flame retardant since it does not produce toxic gas, and for example, a metal hydroxide can be preferably used. As the metal hydroxide, it is possible to use, e.g., magnesium hydroxide, aluminum hydroxide, calcium hydroxide and these metal hydroxides with dissolved nickel. These flame retardants may be used alone or in a combination of two or more.

[0028] The flame retardant is preferably surface-treated with, e.g., a silane coupling agent, a titanate-based coupling agent, fatty acid such as stearic acid, fatty acid salt such as stearate, or fatty acid metal such as calcium stearate to control mechanical characteristics (a balance between tensile strength and elongation) of the inner flame-retardant layer 131. The amount of the flame retardant to be mixed is preferably, e.g., not less than 100 parts by mass and not more than 250 parts by mass with respect to 100 parts by mass of the base polymer. When the mixed amount is less than 100 parts by mass, desired high flame retardancy may not be obtained. When the mixed amount is more than 250 parts by mass, mechanical characteristics of the inner flame-retardant layer 131 may decrease, resulting in a decrease in elongation percentage.

[0029] The inner flame-retardant layer 131 is preferably formed of the cross-linked polymer composition (A) to improve flame retardancy and heat resistance. The crosslinking method can be, e.g., radiation crosslinking, chemical crosslinking or silane crosslinking, etc. The polymer composition (A) may contain a crosslinking aid or a cross-linking agent so as to be well cross-linked. Since radiation crosslinking is preferable to cross-link the high-electrical insulating layer 140 as described later, it is efficient to cross-link the inner flame-retardant layer 131 by radiation crosslinking at the same time as radiation crosslinking of the high-electrical insulating layer 140, i.e., in the same process as radiation crosslinking of the high-electrical insulating layer 140.

[0030] The inner flame-retardant layer 131 is, e.g., an electrical insulating layer formed of the polymer composition (A) with a volume resistivity of about $1 \times 10^{14} \Omega \text{cm}$ (or more). In this regard, where the inner flame-retardant layer 131 is formed of the cross-linked polymer composition (A), the volume resistivity of the polymer composition (A) is defined as the volume resistivity of the cross-linked polymer composition (A).

[0031] The polymer composition (A) may contain, if required, other additives, e.g., carbon fiber, talc and clay, etc., as long as the characteristics of the inner flame-retardant layer 131 are not impaired.

High-electrical insulating layer

[0032] The high-electrical insulating layer 140 is formed of a polymer composition (B) having a volume resistivity of not less than $1 \times 10^{16} \Omega \text{cm}$. The high-electrical insulating layer 140 is formed by, e.g., extruding the polymer composition (B) on the outer surface of the inner flame-retardant layer 131.

[0033] A base polymer of the polymer composition (B) is a polymer having a volume resistivity of not less than $1 \times 10^{16} \Omega \text{cm}$, e.g., polyolefin resin, etc. The polyolefin resin used here can be, e.g., polyethylene such as LDPE, LLDPE or HDPE. These polyolefin resins may be used alone or in combination of two or more.

[0034] The base polymer of the polymer composition (B) preferably contains, e.g., polyethylene. Polyethylene is preferable since its volume resistivity can be improved by cross-linking. The polyethylene used here may be any of LDPE, LLDPE and HDPE. LDPE may be used since it is easily cross-linked.

[0035] The high-electrical insulating layer 140 is preferably formed of the cross-linked polymer composition (B) to improve the volume resistivity. The crosslinking method can be, e.g., radiation crosslinking, chemical crosslinking or silane crosslinking, etc. The polymer composition (B) may contain a crosslinking aid or a cross-linking agent so as to be well cross-linked. Particularly, radiation crosslinking not requiring addition of additives is preferable to prevent a decrease in electrical insulating properties.

[0036] When the high-electrical insulating layer 140 is formed of the cross-linked polymer composition (B), the volume resistivity of the polymer composition (B) means the volume resistivity of the cross-linked polymer composition (B).

[0037] It is preferable that the polymer composition (B) contain as little additives as possible to suppress as decrease in the volume resistivity, but if required, various additives may be contained as long as the volume resistivity of not less than $1 \times 10^{16} \Omega \text{cm}$ can be maintained. Examples of the additives include antioxidant and copper inhibitor, etc.

[0038] It is preferable that the polymer composition (B) do not contain, e.g., inorganic filler such as calcium carbonate, clay, talc, silica, wollastonite, zeolite, diatomaceous earth, silica sand, pumice powder, slate powder, alumina, aluminum sulfate, barium sulfate, lithopone, calcium sulfate and molybdenum disulfide, or flame retardant such as metal hydroxide to prevent a decrease in volume resistivity of the polymer composition (B).

Outer flame-retardant layer

[0039] The outer flame-retardant layer **132**, i.e., a flame-retardant layer **132** arranged on the outer side (on the opposite side to the conductor **110**) of the high-electrical insulating layer **140**, is formed of a polymer composition (C) containing a flame retardant. The outer flame-retardant layer **132** is formed by, e.g., extruding the polymer composition (C) on the outer surface of the high-electrical insulating layer **140**.

[0040] A base polymer of the polymer composition (C) is, e.g., the same as the base polymer of the polymer composition (A) constituting the inner flame-retardant layer **131**, and is preferably, e.g., a polymer containing EVA. The base polymer of the polymer composition (C) constituting the outer flame-retardant layer **132** may be the same as or different from the base polymer of the polymer composition (A) constituting the inner flame-retardant layer **131**.

[0041] The flame retardant added to the polymer composition (C) is, e.g., the same as that added to the polymer composition (A) constituting the inner flame-retardant layer **131**, and is preferably, e.g., a metal hydroxide. The amount of the flame retardant to be mixed can be, e.g., the same as the amount of the flame retardant to be mixed to the polymer composition (A) constituting the inner flame-retardant layer **131**. The flame retardant added to the polymer composition (C) constituting the outer flame-retardant layer **132** may be the same as or different from the flame retardant added to the polymer composition (A) constituting the inner flame-retardant layer **131**. Likewise, the amount of the flame retardant mixed in the polymer composition (C) may be the same as or different from that in the polymer composition (A).

[0042] The outer flame-retardant layer **132** is preferably formed of the cross-linked polymer composition (C) to improve flame retardancy and heat resistance. The crosslinking method can be, e.g., radiation crosslinking, chemical crosslinking or silane crosslinking, etc. The polymer composition (C) may contain a crosslinking aid or a cross-linking agent so as to be well cross-linked. Since radiation crosslinking is preferable to cross-link the high-electrical insulating layer **140**, it is efficient to cross-link the outer flame-retardant layer **132** by radiation crosslinking at the same time as radiation crosslinking of the high-electrical insulating layer **140**, i.e., in the same process as radiation crosslinking of the high-electrical insulating layer **140**.

[0043] The outer flame-retardant layer **132** is, e.g., an electrical insulating layer formed of the polymer composition (C) with a volume resistivity of about $1 \times 10^{14} \Omega \text{cm}$ (or more). In this regard, when the outer flame-retardant layer **132** is formed of the cross-linked polymer composition (C), the volume resistivity of the polymer composition (C) means the volume resistivity of the cross-linked polymer composition (C).

[0044] The polymer composition (C) may contain, if required, other additives, e.g., carbon fiber, talc and clay, etc., as long as the characteristics of the outer flame-retardant layer **132** are not impaired.

Laminated structure of cover layer

[0045] Next, the laminated structure **150** of the cover layer **120** composed of the inner flame-retardant layer **131**, the high-electrical insulating layer **140** and the outer flame-retardant layer **132** will be further described.

[0046] The high-electrical insulating layer **140** is configured to receive preferably not less than **80%**, more preferably not less than **90%**, further preferably not less than **95%**, of voltage applied in the thickness direction of the laminated structure **150**.

[0047] Thus, voltage applied to each of the inner flame-retardant layer **131** and the outer flame-retardant layer **132** can be reduced accordingly. In the inner flame-retardant layer **131** and the outer flame-retardant layer **132** which contain many additives such as flame retardant, insulation breakdown is more likely to occur than in the high-electrical insulating layer **140**. High insulating properties of the insulated wire **100** can be achieved by reducing voltage applied to the inner flame-retardant layer **131** and the outer flame-retardant layer **132**.

[0048] Meanwhile, the high-electrical insulating layer **140** is formed thinner than at least one of the inner flame-retardant layer **131** and the outer flame-retardant layer **132**.

[0049] This reduces the thickness of the laminated structure **150** and thus reduces the diameter of the insulated wire **100**, and at the same time, high flame retardancy is achieved since flammability of the laminated structure **150** due to having the high-electrical insulating layer **140** is reduced by the inner flame-retardant layer **131** and the outer flame-retardant layer **132**. Along with the thickness reduction of the easily combustible high-electrical insulating layer **140**, the thickness of the combined flame-retardant layer **130** (the inner flame-retardant layer **131** and the outer flame-retardant layer **132**) can be also reduced.

[0050] In order to form the high-electrical insulating layer **140** so as to receive not less than **80%** of voltage applied to the laminated structure **150** and also to be thinner than at least one of the inner flame-retardant layer **131** and the outer flame-retardant layer **132**, the volume resistivity of the polymer composition (B) constituting the high-electrical insulating layer **140** is preferably at least not less than $1 \times 10^{16} \Omega \text{cm}$, more preferably not less than $1 \times 10^{17} \Omega \text{cm}$. The upper limit of the volume resistivity of the polymer composition (B) is not specifically limited.

[0051] In order to form the high-electrical insulating layer **140** so as to receive not less than **80%** of voltage applied to the laminated structure **150** and also to be thinner than at least one of the inner flame-retardant layer **131** and the outer

flame-retardant layer **132**. the volume resistivity of the polymer composition (B) constituting the high-electrical insulating layer **140** is preferably not less than **10** times, more preferably not less than **50** times, further preferably not less than **100** times the volume resistivity of the polymer composition (A) constituting the inner flame-retardant layer **131** and that of the polymer composition (C) constituting the outer flame-retardant layer **132**.

[0052] To reduce the diameter while achieving high flame retardancy, the thickness of the high-electrical insulating layer **140** is more preferably not more than half the thickness of the combined flame-retardant layer **130** (the sum of the thickness of the inner flame-retardant layer **131** and the thickness of the outer flame-retardant layer **132**), further preferably not more than half of at least one of the thickness of the inner flame-retardant layer **131** and the thickness of the outer flame-retardant layer **132**.

[0053] To be a thin insulated wire, the outer diameter (the cross-sectional diameter) of the insulated wire **100** is preferably not more than **3** mm, more preferably not more than **2.5** mm. The rated (AC) voltage of the insulated wire **100** is, e.g., not more than **660V** (**600V**, as an example). Having a small diameter is also advantageous in that it is easy to simultaneously cross-link the inner flame-retardant layer **131**, the high-electrical insulating layer **140** and the outer flame-retardant layer **132** by radiation crosslinking.

[0054] In view of diameter reduction, the upper limit of the thickness of the high-electrical insulating layer **140** is, e.g., preferably not more than **0.2** mm, more preferably not more than **0.15** mm. Meanwhile, the lower limit of the thickness of the high-electrical insulating layer **140** is not specifically limited as long as desired insulating properties are obtained, but not less than **0.05** mm is preferable so that, for example, the high-electrical insulating layer **140** can have a highly uniform thickness and resulting stable insulating properties can be obtained.

[0055] To obtain flame retardancy of the insulated wire **100**, the combined flame-retardant layer **130** is formed to have a well-balanced, sufficiently large thickness which can prevent the high-electrical insulating layer **140** from burning. To obtain such thickness, the respective thicknesses of the inner flame-retardant layer **131** and the outer flame-retardant layer **132** can be appropriately changed, if required, in a well-balanced manner so that the combined flame-retardant layer **130** can have a sufficient thickness. For example, the outer flame-retardant layer **132** can be thicker than the inner flame-retardant layer **131**, the inner flame-retardant layer **131** can be thicker than the outer flame-retardant layer **132**, or, the inner flame-retardant layer **131** and the outer flame-retardant layer **132** can have the same thickness. However, to increase flame retardancy, the outer flame-retardant layer **132** is preferably thicker than the inner flame-retardant layer **131**. The thickness of the combined flame-retardant layer **130** is preferably, e.g., not less than double the high-electrical insulating layer **140**.

[0056] In view of diameter reduction, the upper limit of the thickness of the combined flame-retardant layer **130** is, e.g., preferably not more than **0.4** mm. Meanwhile, the lower limit of the thickness of the combined flame-retardant layer **130** is not specifically limited as long as it is determined according to the thickness of the high-electrical insulating layer **140** and the flame retardancy can be obtained, but not less than **0.2** mm is preferable to obtain, e.g., stable flame retardancy.

[0057] The inner flame-retardant layer **131** is arranged directly on the conductor **110** (in contact with the conductor **110**) and covers the bumps and recesses on the surface of the conductor **110**, thereby serving as a bump-and-recess smoothing layer to prevent electric field concentration. Thus, the high-electrical insulating layer **140** which is arranged on the inner flame-retardant layer **131** can have a reduced thickness. The thickness of the inner flame-retardant layer **131** here is expressed as a thickness on the bumps of the twist on the surface of the conductor **110** (a thickness of the thinnest portion), i.e., a thickness from the outer diameter of the conductor **110**.

[0058] The upper limit of the thickness of the inner flame-retardant layer **131** can be appropriately selected within the thickness range of the combined flame-retardant layer **130**, and is not specifically limited. Meanwhile, the lower limit of the thickness of the inner flame-retardant layer **131** is not specifically limited, but is preferably not less than **0.05** mm so that, for example, the bumps and recesses on the surface of the conductor **110** are sufficiently covered, and also, the inner flame-retardant layer **131** can have a highly uniform thickness and resulting stable flame retardancy can be obtained.

[0059] The upper limit of the thickness of the outer flame-retardant layer **132** can be appropriately selected within the thickness range of the combined flame-retardant layer **130**, and is not specifically limited. Meanwhile, the lower limit of the thickness of the outer flame-retardant layer **132** is not specifically limited, but is preferably not less than **0.05** mm so that, for example, the outer flame-retardant layer **132** can have a highly uniform thickness and resulting stable flame retardancy can be obtained.

[0060] In view of diameter reduction, preferably, another layer is not arranged between the inner flame-retardant layer **131** and the high-electrical insulating layer **140**. In other words, the high-electrical insulating layer **140** is preferably arranged directly on the inner flame-retardant layer **131** (in contact with the inner flame-retardant layer **131**). Likewise, preferably, another layer is not arranged between the high-electrical insulating layer **140** and the outer flame-retardant layer **132**. In other words, the outer flame-retardant layer **132** is preferably arranged directly on the high-electrical insulating layer **140** (in contact with the high-electrical insulating layer **140**). Furthermore, preferably, another layer is not arranged around the outer flame-retardant layer **132**. In other words, it is preferable that the outer flame-retardant layer **132** be the outermost layer of the cover layer **120**, i.e., the outermost layer of the insulated wire **100**.

[0061] The inner flame-retardant layer **131**, the high-electrical insulating layer **140** and the outer flame-retardant layer **132** are preferably simultaneously extruded on the conductor **110**. In this case, air dust to be a cause of electric field concentration can be prevented from attaching to a boundary surface between the inner flame-retardant layer **131** and the high-electrical insulating layer **140** and to a boundary surface between the high-electrical insulating layer **140** and the outer flame-retardant layer **132**.

[0062] Alternatively, the inner flame-retardant layer **131** may have, if required, a laminated structure composed of plural flame-retardant layers (sub-flame-retardant layers). Likewise, the high-electrical insulating layer **140** may have, if required, a laminated structure composed of plural insulating layers (sub-insulating layers). Also, the outer flame-retardant layer **132** may have, if required, a laminated structure composed of plural flame-retardant layers (sub-flame-retardant layers).

[0063] As described above, in the first embodiment, it is possible to reduce a diameter of the insulated wire while achieving high insulating properties and high flame retardancy.

[0064] The insulated wire in the first embodiment can be used alone, and also can be used, if required, in combination with another member, e.g., used as a core of a cable.

[0065] The invention will be described in more detail below in reference to Examples. However, the invention is not limited thereto.

Manufacturing of insulated wire

[0066] Insulated wires in Examples **1**, **2** and Comparative Examples **1** to **4** were made as follows.

[0067] The polymer composition (A) for forming an inner flame-retardant layer, the polymer composition (B) for forming a high-electrical insulating layer and the polymer composition (C) for forming an outer flame-retardant layer were prepared. The same polymer composition was prepared as the polymer composition (A) for forming an inner flame-retardant layer and the polymer composition (C) for forming an outer flame-retardant layer. As the polymer composition (B) for forming a high-electrical insulating layer, three types of polymer compositions (compositions **1** to **3**) with various volume resistivities were prepared according to the different volume resistivities of the high-electrical insulating layers of the respective samples. The mixing proportions for the polymer compositions (A) and (C) are shown in Table **1**, and the mixing proportions for the polymer compositions (B) are shown in Table **2**.

Table 1

Polymer compositions (A) and (C) for forming Inner and Outer flame-retardant layers		
Base polymer	EVA	85
	Acid-modified polyolefin resin	15
Flame retardant	Magnesium hydroxide	200
Colorant	FT carbon	2
Lubricant	Zinc stearate	1

Parts by mass

Table 2

Polymer composition (B) for forming High-electrical insulating layer		Composition 1 (Example 1)	Composition 2 (Example 2)	Composition 3 (Comparative Example 1 to 4)
Base polymer	High-density polyethylene	100	-	-
	Linear low-density polyethylene	-	100	100
Inorganic filler	Clay	-	-	100
Volume resistivity (Ωcm)		1.34E+17	9.48E+16	1.60E+15

Parts by mass

[0068] Conductors having an outer diameter of 1.23 mm (each formed by twisting thirty-seven 0.18 mm-diameter tin-plated copper strands) were prepared. The polymer compositions (A), (B) and (C) were simultaneously extruded on each of the conductors and were cross-linked by electron beam irradiation, thereby forming the inner flame-retardant layer, the high-electrical insulating layer and the outer flame-retardant layer.

[0069] The high-electrical insulating layers of the insulated wires in Examples 1, 2 and Comparative Examples 1 to 4 had different volume resistivities, i.e., were formed of the polymer compositions (B) with different mixing proportions. Also, the outer flame-retardant layer and the high-electrical insulating layer were formed in various thicknesses. The volume resistivity was the same between the inner flame-retardant layer and the outer flame-retardant layer, and was fixed for all of Examples 1, 2 and Comparative Examples 1 to 4. The thickness of the inner flame-retardant layer was also fixed.

[0070] Table 3 shows the configuration of the insulated wires of Examples 1, 2 and Comparative Examples 1 to 4; volume resistivity of the polymer composition used to form the flame-retardant layer (volume resistivity of the flame-retardant layer), volume resistivity of the polymer composition used to form the high-electrical insulating layer (volume resistivity of the high-electrical insulating layer), thickness of the high-electrical insulating layer, thickness of the inner flame-retardant layer and thickness of the outer flame-retardant layer.

[0071] Table 3 also shows a voltage sharing rate in the laminated structure composed of the inner flame-retardant layer, the high-electrical insulating layer and the outer flame-retardant layer, i.e., a ratio of resistance of the high-electrical insulating layer to the sum of resistance of the inner flame-retardant layer, resistance of the high-electrical insulating layer and resistance of the outer flame-retardant layer, in the thickness direction of the laminated structure.

Table 3

		Example 1	Example 2	Comparative Example 1	Comparative Example 2	Comparative Example 3	Comparative Example 4
Volume resistivity of flame-retardant layer (Ωcm)		4.00E+14	4.00E+14	4.00E+14	4.00E+14	4.00E+14	4.00E+14
Volume resistivity of high-electrical insulating layer (Ωcm)		1.34E+17	9.48E+16	1.60E+15	1.60E+14	1.60E+14	1.60E+14
Thickness of high-electrical insulating layer (mm)		0.11	0.18	0.11	0.2	0.11	0.18
Thickness of inner flame-retardant layer (mm)		0.1	0.1	0.1	0.1	0.1	0.1
Thickness of outer flame-retardant layer (mm)		0.3	0.3	0.3	0.3	0.1	0.15
Voltage sharing rate (%)		98.9	99.1	52.4	66.7	68.8	74.2
DC stability test (hour)		Not less than 240	Not less than 240	108	67	112	119
Flame retardancy	VFT	◎	◎	◎	◎	×	×
	VTFT	◎	○	◎	○	×	×
Overall evaluation		○	○	×	×	×	×

Evaluation of insulated wire

[0072] Insulating properties (electrical characteristics) and flame retardancy of the insulated wires in Examples 1, 2 and Comparative Examples 1 to 4 were evaluated as follows. Table 3 shows the evaluation results.

Electrical characteristics

[0073] To evaluate electrical characteristics, i.e., insulation reliability, of the insulated wires, a DC stability test was conducted by applying **300V** DC voltage to the insulated wires in **3% NaCl** solution at **85°C** in accordance with EN **50305.6.7**. The wires with no short-circuit for **10** days, i.e., time to short-circuit of not less than **240** hours, were regarded as "Pass", and those short-circuited within **10** days, i.e., time to short-circuit of less than **240** hours, were regarded as "Fail".

Flame-retardancy

[0074] Flame-retardancy of the insulated wires was evaluated by the following flame tests (vertical flame test: VFT and vertical tray flame test: VTFT).

[0075] VFT was conducted in accordance with the Test for vertical flame propagation for a single insulated wire or cable specified by EN **60332-1-2**. In detail, **600** mm-long insulated wires were held vertical and a flame was applied thereto for **60** seconds. The wires passed the test (⊙: excellent) when the fire was extinguished within **30** seconds after removing the flame, the wires passed the test (○: acceptable) when the fire was extinguished within **60** seconds, and the wires failed the test (×) when the fire was not extinguished within **60** seconds.

[0076] VTFT was conducted in accordance with the Test for vertical flame spread of vertically mounted bunched wires (Flame propagation in bunched cables) specified by EN **50266-2-4**. In detail, seven **3.5**-meter insulated wires were twisted into one bundle, and eleven bundles were vertically arranged at equal intervals and were burnt for **20** minutes. Then, a char length from the lower end after self-extinction was measured. The wires with a char length of not more than **1.5** m were regarded as "Pass (⊙: excellent)", those with a char length of not more than **2.5** m were regarded as "Pass (○: acceptable)", and those with a char length of more than **2.5** m were regarded as "Fail (×)".

Overall evaluation

[0077] The overall evaluation was rated as "Pass (○)" for the insulated wires which passed both the electrical characteristic and flame retardant tests, and the others were rated as "Fail (×)".

Examples 1 and 2

[0078] The volume resistivity of the flame-retardant layer was $4 \times 10^{14} \Omega\text{cm}$ in both Examples 1 and 2, the volume resistivity of the high-electrical insulating layer was $1.34 \times 10^{17} \Omega\text{cm}$ in Example 1 and $9.48 \times 10^{16} \Omega\text{cm}$ in Example 2, and the voltage sharing rate of the high-electrical insulating layer **140** was **98.9%** in Example 1 and **99.1%** in Example 2. The thickness of the inner flame-retardant layer was **0.1** mm in both Examples 1 and 2, and the thickness of the outer flame-retardant layer was **0.3** mm in both Examples 1 and 2. The thickness of the high-electrical insulating layer was **0.11** mm in Example 1 and **0.18** mm in Example 2.

[0079] The insulated wires in Examples 1 and 2 passed both the electrical characteristic and flame retardant tests since the volume resistivity of the high-electrical insulating layer was not less than $1 \times 10^{16} \Omega\text{cm}$, the voltage sharing rate of the high-electrical insulating layer was not less than **80%**, and furthermore, the high-electrical insulating layer was thinner than at least one of the inner flame-retardant layer and the outer flame-retardant layer. In both Examples 1 and 2, the voltage sharing rate of the high-electrical insulating layer not only just satisfied the condition of not less than **80%**, but also achieved the conditions of not less than **90%** and not less than **95%**.

[0080] The thickness of the combined flame-retardant layer (the inner flame-retardant layer and the outer flame-retardant layer) was **0.4** mm in both Examples 1 and 2, and the thickness of the high-electrical insulating layer was not more than half the thickness of the combined flame-retardant layer (specifically, not more than **0.2** mm) in both Examples 1 and 2. In Example 1, since the thickness of the high-electrical insulating layer was not more than half of at least one of the thickness of the inner flame-retardant layer and the thickness of the outer flame-retardant layer (more specifically, not more than **0.15** mm), higher flame retardancy and smaller diameter than Example 2 were obtained. In Example 1, since the volume resistivity of the high-electrical insulating layer was not less than $1 \times 10^{17} \Omega\text{cm}$, it was possible to obtain the thinner high-electrical insulating layer than Example 2.

[0081] Meanwhile, a ratio of the volume resistivity of the high-electrical insulating layer to the volume resistivity of the flame-retardant layer was **335** times in Example 1 and **237** times in Example 2, and the conditions of **10** times, not less than **50** times, and not less than **100** times were satisfied in both Examples 1 and 2.

Comparative Examples 1 and 2

[0082] The volume resistivity of the flame-retardant layer was $4 \times 10^{14} \Omega\text{cm}$ in both Comparative Examples 1 and 2, the volume resistivity of the high-electrical insulating layer was $1.60 \times 10^{15} \Omega\text{cm}$ in both Comparative Examples 1 and 2.

The voltage sharing rate of the high-electrical insulating layer **140** was **52.4%** in Comparative Example **1** and **66.7%** in Comparative Example **2**. The thickness of the inner flame-retardant layer was **0.1** mm in both Comparative Examples **1** and **2**, and the thickness of the outer flame-retardant layer was **0.3** mm in both Comparative Examples **1** and **2**. The thickness of the high-electrical insulating layer was **0.11** mm in Comparative Example **1** and **0.2** mm in Comparative Example **2**.

[0083] The insulated wires in Comparative Examples **1** and **2** failed the electrical characteristic test since the volume resistivity of the high-electrical insulating layer was less than $1 \times 10^{16} \Omega\text{cm}$ and the voltage sharing rate of the high-electrical insulating layer was less than **80%**. However, the samples passed the flame retardant test since the high-electrical insulating layer was thinner than at least one of the inner flame-retardant layer and the outer flame-retardant layer. Meanwhile, the ratio of the volume resistivity of the high-electrical insulating layer to the volume resistivity of the flame-retardant layer was **4** times in both Comparative Examples **1** and **2**, which is less than **10** times.

Comparative Examples 3 and 4

[0084] The volume resistivity of the flame-retardant layer was $4 \times 10^{14} \Omega\text{cm}$ in both Comparative Examples **3** and **4**, the volume resistivity of the high-electrical insulating layer was $1.60 \times 10^{15} \Omega\text{cm}$ in both Comparative Examples **3** and **4**. The voltage sharing rate of the high-electrical insulating layer **140** was **68.8%** in Comparative Example **3** and **74.2%** in Comparative Example **4**. The thickness of the inner flame-retardant layer was **0.1** mm in both Comparative Examples **3** and **4**, and the thickness of the outer flame-retardant layer was **0.1** mm in Comparative Example **3** and **0.15** mm in Comparative Example **4**. The thickness of the high-electrical insulating layer was **0.11** mm in Comparative Example **3** and **0.18** mm in Comparative Example **4**.

[0085] The insulated wires in Comparative Examples **3** and **4** failed electrical characteristic test since the volume resistivity of the high-electrical insulating layer was less than $1 \times 10^{16} \Omega\text{cm}$ and the voltage sharing rate of the high-electrical insulating layer was less than **80%**. Furthermore, the samples also failed the flame retardant test since the high-electrical insulating layer was thicker than both the inner flame-retardant layer and the outer flame-retardant layer. Meanwhile, the ratio of the volume resistivity of the high-electrical insulating layer to the volume resistivity of the flame-retardant layer was **4** times in both Comparative Examples **3** and **4**, which is less than **10** times.

[0086] Although the invention has been described in reference to the first embodiment, the invention is not limited thereto. It will be obvious for those skilled in the art that various changes, modifications and combinations, etc., can be implemented.

Preferred embodiments of the invention

[0087] Preferred embodiments of the invention will be described below.

[1] An insulated wire, comprising:

a conductor; and

a cover layer arranged around the conductor,

wherein the cover layer comprises a laminated structure formed by laminating an inner flame-retardant layer, a high-electrical insulating layer and an outer flame-retardant layer, the inner flame-retardant layer being arranged around the conductor and comprising a polymer composition (A) containing a flame retardant, the high-electrical insulating layer being arranged around the inner flame-retardant layer and comprising a polymer composition (B) having a volume resistivity of not less than $1 \times 10^{16} \Omega\text{cm}$, and the outer flame-retardant layer being arranged around the high-electrical insulating layer and comprising a polymer composition (C) containing a flame retardant, the high-electrical insulating layer receives not less than **80%** of voltage applied in a thickness direction of the laminated structure, and the thickness of the high-electrical insulating layer is smaller than at least one of the thickness of the inner flame-retardant layer and the thickness of the outer flame-retardant layer.

[2] The insulated wire defined by [1], wherein the high-electrical insulating layer receives more preferably not less than **90%**, further preferably not less than **95%** of the voltage applied in the thickness direction of the laminated structure.

[3] The insulated wire defined by [1] or [2], wherein the polymer composition (B) has a volume resistivity of not less than $1 \times 10^{17} \Omega\text{cm}$.

[4] The insulated wire defined by any one of [1] to [3], wherein the volume resistivity of the polymer composition (B) constituting the high-electrical insulating layer is preferably not less than **10** times, more preferably not less than **50** times, further preferably not less than **100** times the volume resistivity of the polymer composition (A) constituting the inner flame-retardant layer.

[5] The insulated wire defined by any one of [1] to [4], wherein the volume resistivity of the polymer composition (B) constituting the high-electrical insulating layer is preferably not less than 10 times, more preferably not less than 50 times, further preferably not less than 100 times the volume resistivity of the polymer composition (C) constituting the outer flame-retardant layer.

[6] The insulated wire defined by any one of [1] to [5], wherein the thickness of the high-electrical insulating layer is not more than half the sum of the thickness of the inner flame-retardant layer and the thickness of the outer flame-retardant layer.

[7] The insulated wire defined by any one of [1] to [6], wherein the thickness of the high-electrical insulating layer is not more than half of at least one of the thickness of the inner flame-retardant layer and the thickness of the outer flame-retardant layer.

[8] The insulated wire defined by any one of [1] to [7], wherein the outer diameter of the insulated wire is preferably not more than 3 mm, more preferably not more than 2.5 mm.

[9] The insulated wire defined by any one of [1] to [8], wherein the thickness of the high-electrical insulating layer is preferably not more than 0.2 mm, more preferably not more than 0.15 mm.

[10] The insulated wire defined by any one of [1] to [9], wherein the sum of the thickness of the inner flame-retardant layer and the thickness of the outer flame-retardant layer is not more than 0.4 mm.

[11] The insulated wire defined by any one of [1] to [10], wherein the inner flame-retardant layer is arranged directly on the conductor (in contact with the conductor).

[12] The insulated wire defined by any one of [1] to [11], wherein the high-electrical insulating layer is arranged directly on the inner flame-retardant layer (in contact with the inner flame-retardant layer).

[13] The insulated wire defined by any one of [1] to [12], wherein the outer flame-retardant layer is arranged directly on the high-electrical insulating layer (in contact with the high-electrical insulating layer).

[14] The insulated wire defined by any one of [1] to [13], wherein the outer flame-retardant layer is the outermost layer of the insulated wire.

[15] The insulated wire defined by any one of [1] to [14], wherein the conductor is a twisted wire formed by twisting plural strands.

[16] The insulated wire defined by any one of [1] to [15], wherein the inner flame-retardant layer is an electrical insulating layer formed of the polymer composition (A) having a volume resistivity of not less than $1 \times 10^{14} \Omega \text{cm}$.

[17] The insulated wire defined by any one of [1] to [16], wherein the outer flame-retardant layer is an electrical insulating layer formed of the polymer composition (C) having a volume resistivity of not less than $1 \times 10^{14} \Omega \text{cm}$.

Second embodiment

[0088] The inventors studied the insulated wire structure which allows a diameter to be reduced while achieving high insulating properties and high flame retardancy.

[0089] A conventional wire structure will be firstly described, and the concept of the wire structure in the second embodiment of the present invention will be then described. FIG.5 is a cross sectional view showing a conventional insulated wire taken perpendicular to the longitudinal direction thereof.

[0090] A insulated wire 2200 having a conventional structure has a conductor 2210, an insulation layer 2220 arranged around the conductor 2210, and a flame-retardant layer 2230 arranged around the insulation layer 2220 and containing a flame retardant.

[0091] In case of the insulated wire 2200 which has a conventional structure, an additive having (some) flame retardancy (e.g., an inorganic filler such as calcium carbonate or clay) is mixed in a polymer composition constituting the insulation layer 2220 so that the insulation layer 2220 per se has some flame retardancy.

[0092] Since a flame-retardant additive, etc. is mixed, the insulating properties of the polymer composition constituting the insulation layer 2220 is lower than the insulating properties of a base polymer used to form the polymer composition. When the base polymer of the polymer composition constituting the insulation layer 2220 is, e.g., polyethylene, a volume resistivity of the base polymer is, e.g., of the order of about $1 \times 10^{16} \Omega \text{cm}$. A flame-retardant additive, etc., is then mixed to the polymer composition, and this reduces a volume resistivity of the polymer composition constituting the insulation layer 2220 down to the order of about $1 \times 10^{14} \Omega \text{cm}$.

[0093] The inventors examined if the thinner flame-retardant layer 2230 can be provided to reduce a diameter of the insulated wire 2200. However, only by reducing the thickness of the flame-retardant layer 2230 (without changing the thickness of the insulation layer 2220), the insulated wire 2200 cannot have high flame retardancy.

[0094] Then, it was examined if the thinner insulation layer 2220 can be provided. However, when simply reducing the thickness of the insulation layer 2220, the insulated wire 2200 cannot have high insulating properties. Therefore, it was examined if the amount of a flame-retardant additive, etc., mixed to the insulation layer 2220 can be reduced so that the insulating properties of the polymer composition constituting the insulation layer 2220 can be increased closer to high insulating properties of the base polymer to allow the thickness of the insulation layer 2220 required to obtain

desired insulating properties to be reduced.

[0095] In this regard, however, the conductor **2210** has a twisted wire structure formed by twisting strands and thus has bumps and recesses on a surface thereof. Therefore, insulation breakdown is likely to occur in the insulation layer **2220** due to electric field concentration caused by the bumps and recesses on the surface of the conductor **2210**, and the insulation layer **2220** needs to be thick to some extent to improve voltage-resistant characteristics. Thus, the thickness of the insulation layer **2220** should not be simply reduced.

[0096] Based on the above, the inventors conceived a new structure using an insulation layer containing a reduced amount of flame-retardant additive, etc., and a semiconducting layer containing a conductive agent and arranged directly on the conductor at the same time on the inner side (on the conductor side) of such insulation layer. Hereinafter, the insulation layer containing a reduced amount of flame-retardant additive, etc., is referred to as "high-electrical insulating layer".

[0097] In such a structure, when using the high-electrical insulating layer of which insulating properties are enhanced (a decrease in insulating properties is suppressed) by reducing the mixed amount of flame-retardant additive, etc., the thickness of the high-electrical insulating layer required to obtain desired insulating properties can be reduced. In addition, since the semiconducting layer which covers the bumps and recesses on the conductor surface serves as a bump-and-recess smoothing layer, the high-electrical insulating layer which is arranged on the semiconducting layer can have a reduced thickness. Furthermore, since the thickness of the easily combustible high-electrical insulating layer can be reduced, the thicknesses of the flame-retardant layer required to obtain desired flame retardancy can be also reduced.

[0098] By reducing the mixed amount of flame-retardant additive, etc., the volume resistivity of the polymer composition constituting the high-electrical insulating layer can be significantly increased to, e.g., about **100** times higher than the volume resistivity of the polymer composition originally used to form the insulation layer **2220**. Thus, reducing the thickness of the insulation layer by increasing the volume resistivity while achieving desired insulating properties is easier way than reducing the thickness of the flame-retardant layer.

[0099] The wire structure, which allows for diameter reduction while achieving high insulating properties and high flame retardancy, is thus obtained.

[0100] Such wire structure is preferably applied to, e.g., a thin insulated wire which has an outer diameter (a cross-sectional diameter) of not more than 7 mm. The insulating properties of insulated wire are evaluated by, e.g., a DC stability test which is described later. Flame retardancy of insulated wire is evaluated by, e.g., VFT or VTFT which are also described later. The intended use of the insulated wire is not specifically limited and is, e.g., for rolling stocks, vehicles or medical application.

[0101] Next, an insulated wire **2100** in the second embodiment of the invention will be described in reference to **FIG.3**. **FIG.3** is a cross sectional view showing an example of the structure of the insulated wire **2100** taken perpendicular to the longitudinal direction thereof.

Configuration of insulated wire

[0102] The insulated wire **2100** has a conductor **2110** and a cover layer **2120** arranged around the conductor **2110**.

Conductor

[0103] The conductor **2110** used here can be, e.g., a twisted wire formed by twisting plural strands (metal wires). The strand can be, e.g., a copper wire, a copper alloy wire, an aluminum wire, a gold wire or a silver wire, etc., or may be a wire of which outer surface is plated with a metal such as tin or nickel. The outer diameter (the cross-sectional diameter) of the conductor **2110** is, e.g., not less than 1 mm and not more than 6 mm. The outer diameter (the cross-sectional diameter) of the strand is, e.g., not less than 0.1 mm and not more than 0.5 mm. The material, structure and size, etc., of the conductor **2110** can be appropriately selected according to the characteristics required for the conductor **2110** of the insulated wire **2100**.

Cover layer

[0104] The cover layer **2120** has a laminated structure **2160** composed of a semiconducting layer **2130** arranged around the conductor **2110**, a high-electrical insulating layer **2140** arranged around the semiconducting layer **2130**, and a flame-retardant layer **2150** arranged around the high-electrical insulating layer **2140**.

Semiconducting layer

[0105] The semiconducting layer **2130** is formed of a polymer composition (A) containing a conductive agent and having a volume resistivity of not more than $1 \times 10^9 \Omega \text{cm}$. The semiconducting layer **2130** is formed by, e.g., extruding

the polymer composition (A) on the outer surface of the conductor **2110**.

[0106] A base polymer of the polymer composition (A) is, e.g., a polyolefin resin, etc. The polyolefin resin used here can be, e.g., a polyethylene-based resin, etc. Examples of the polyethylene-based resin used here include polyethylene such as low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), high-density polyethylene (HDPE), ethylene-vinyl acetate copolymer (EVA), ethylene-ethyl acrylate copolymer, ethylene-methyl acrylate copolymer, ethylene-glycidyl methacrylate copolymer, ethylene-butene copolymer, ethylene-butene hexene terpolymer, ethylene propylene diene terpolymer (EPDM), ethylene-octene copolymer (EOR), ethylene-propylene copolymer (EPR), ethylene-styrene copolymer, styrene-butadiene copolymer, and these polymers modified with an acid such as maleic acid. These polyolefin resins may be used alone or in combination of two or more.

[0107] The base polymer of the polymer composition (A) preferably contains, e.g., EVA. EVA is preferable since its relatively high filler acceptability allows a conductive agent to be added easily and the resin per se has some flame retardancy. The VA content of EVA is, e.g., preferably not less than **15%** in view of filler acceptability, and is, e.g., preferably not more than **80%** in view of manufacturability such as stickiness.

[0108] Examples of the conductive agent mixed in the polymer composition (A) include carbon black and carbon nanotube, etc., and it is possible to suitably use, e.g., carbon black. Examples of the carbon black used here include furnace black, channel black, acetylene black and thermal black, etc., and acetylene black can be preferably used since high conductivity can be imparted with a small amount. These conductive agents may be used alone or in combination of two or more.

[0109] The amount of conductive agent to be mixed is not specifically limited as long as the polymer composition (A) constituting the semiconducting layer **2130** has a volume resistivity of not more than **1x10⁹ Ωcm**. For example, the amount of carbon black mixed per **100** parts by mass of the base polymer is not less than **30** parts by mass. However, it is preferable that the mixed amount of the conductive agent be not excessive since it causes a decrease in, e.g., mechanical characteristics of the semiconducting layer **2130** and a resulting decrease in elongation percentage. For example, the amount of carbon black mixed per 100 parts by mass of the base polymer is not more than **150** parts by mass.

[0110] The semiconducting layer **2130** is preferably formed of the cross-linked polymer composition (A) to improve heat resistance. The crosslinking method can be, e.g., radiation crosslinking, chemical crosslinking or silane crosslinking, etc. The polymer composition (A) may contain a crosslinking aid or a cross-linking agent so as to be well cross-linked. Since radiation crosslinking is preferable to cross-link the high-electrical insulating layer **2140** as described later, it is efficient to cross-link the semiconducting layer **2130** by radiation crosslinking at the same time as radiation crosslinking of the high-electrical insulating layer **2140**, i.e., in the same process as radiation crosslinking of the high-electrical insulating layer **2140**.

[0111] When the semiconducting layer **2130** is formed of the cross-linked polymer composition (A), the volume resistivity of the polymer composition (A) is defined as the volume resistivity of the cross-linked polymer composition (A).

[0112] The polymer composition (A) may contain, if required, other additives, e.g., flame retardant, antioxidant, copper inhibitor, reinforcing agent and process oil, etc., as long as the characteristics of the semiconducting layer **2130** are not impaired.

High-electrical insulating layer

[0113] The high-electrical insulating layer **2140** is formed of a polymer composition (B) having a volume resistivity of not less than **1x10¹⁶ Ωcm**. The high-electrical insulating layer **2140** is formed by, e.g., extruding the polymer composition (B) on the outer surface of the semiconducting layer **2130**.

[0114] A base polymer of the polymer composition (B) is a polymer having a volume resistivity of not less than **1x10¹⁶ Ωcm**, e.g., polyolefin resin, etc. The polyolefin resin used here can be, e.g., polyethylene such as LDPE, LLDPE or HDPE. These polyolefin resins may be used alone or in combination of two or more.

[0115] The base polymer of the polymer composition (B) preferably contains, e.g., polyethylene. Polyethylene is preferable since its volume resistivity can be improved by cross-linking. The polyethylene used here may be any of LDPE, LLDPE and HDPE. LDPE may be used since it is easily cross-linked.

[0116] The high-electrical insulating layer **2140** is preferably formed of the cross-linked polymer composition (B) to improve the volume resistivity. The crosslinking method can be, e.g., radiation crosslinking, chemical crosslinking or silane crosslinking, etc. The polymer composition (B) may contain a crosslinking aid or a cross-linking agent so as to be well cross-linked. Particularly, radiation crosslinking not requiring addition of additives is preferable to prevent a decrease in electrical insulating properties.

[0117] When the high-electrical insulating layer **2140** is formed of the cross-linked polymer composition (B), the volume resistivity of the polymer composition (B) means the volume resistivity of the cross-linked polymer composition (B).

[0118] It is preferable that the polymer composition (B) contain as little additives as possible to suppress a decrease in the volume resistivity, but if required, various additives may be contained as long as the volume resistivity of not less than **1x10¹⁶ Ωcm** can be maintained. Examples of the additives include antioxidant and copper inhibitor, etc.

[0119] It is preferable that the polymer composition (B) do not contain, e.g., inorganic filler such as calcium carbonate, clay, talc, silica, wollastonite, zeolite, diatomaceous earth, silica sand, pumice powder, slate powder, alumina, aluminum sulfate, barium sulfate, lithopone, calcium sulfate and molybdenum disulfide, or flame retardant such as metal hydroxide to prevent a decrease in volume resistivity of the polymer composition (B).

Flame-retardant layer

[0120] The flame-retardant layer 2150 is formed of a polymer composition (C) containing a flame retardant. The flame-retardant layer 2150 is formed by, e.g., extruding the polymer composition (C) on the outer surface of the high-electrical insulating layer 2140.

[0121] A base polymer of the polymer composition (C) is, e.g., a polyolefin resin, etc. The polyolefin resin used here can be, e.g., a polyethylene-based resin, etc. Examples of the polyethylene-based resin used here include polyethylene such as LDPE, LLDPE and HDPE, EVA, ethylene-ethyl acrylate copolymer, ethylene-methyl acrylate copolymer, ethylene-glycidyl methacrylate copolymer, ethylene-butene copolymer, ethylene-butene hexene terpolymer, ethylene propylene diene terpolymer (EPDM), ethylene-octene copolymer (EOR), ethylene-propylene copolymer (EPR), ethylene-styrene copolymer, styrene-butadiene copolymer, and these polymers modified with and acid such as maleic acid. These polyolefin resins may be used alone or in combination of two or more.

[0122] The base polymer of the polymer composition (C) preferably contains, e.g., EVA. EVA is preferable since its relatively high filler acceptability allows a flame retardant to be added easily and the resin per se has some flame retardancy. The VA content of EVA is, e.g., preferably not less than 15% in view of filler acceptability, and is, e.g., preferably not more than 60% to suppress a decrease in low-temperature performance.

[0123] The flame retardant added to the polymer composition (C) is preferably a halogen-free flame retardant since it does not produce toxic gas, and for example, a metal hydroxide can be preferably used. As the metal hydroxide, it is possible to use, e.g., magnesium hydroxide, aluminum hydroxide, calcium hydroxide and these metal hydroxides with dissolved nickel. These flame retardants may be used alone or in a combination of two or more.

[0124] The flame retardant is preferably surface-treated with, e.g., a silane coupling agent, a titanate-based coupling agent, fatty acid such as stearic acid, fatty acid salt such as stearate, or fatty acid metal such as calcium stearate to control mechanical characteristics (a balance between tensile strength and elongation) of the flame-retardant layer 2150.

[0125] The amount of the flame retardant to be mixed is preferably, e.g., not less than 100 parts by mass and not more than 250 parts by mass with respect to 100 parts by mass of the base polymer. When the mixed amount is less than 100 parts by mass, desired high flame retardancy may not be obtained. When the mixed amount is more than 250 parts by mass, mechanical characteristics of the flame-retardant layer 2150 may decrease, resulting in a decrease in elongation percentage.

[0126] The flame-retardant layer 2150 is preferably formed of the cross-linked polymer composition (C) to improve flame retardancy and heat resistance. The crosslinking method can be, e.g., radiation crosslinking, chemical crosslinking or silane crosslinking, etc. The polymer composition (C) may contain a crosslinking aid or a cross-linking agent so as to be well cross-linked. Since radiation crosslinking is preferable to cross-link the high-electrical insulating layer 2140, it is efficient to cross-link the flame-retardant layer 2150 by radiation crosslinking at the same time as radiation crosslinking of the high-electrical insulating layer 2140, i.e., in the same process as radiation crosslinking of the high-electrical insulating layer 2140.

[0127] The flame-retardant layer 2150 is, e.g., an electrical insulating layer formed of the polymer composition (C) with a volume resistivity of about $1 \times 10^{14} \Omega \text{cm}$ (not less than $1 \times 10^{13} \Omega \text{cm}$, or not less than $1 \times 10^{14} \Omega \text{cm}$). In this regard, when the flame-retardant layer 2150 is formed of the cross-linked polymer composition (C), the volume resistivity of the polymer composition (C) means the volume resistivity of the cross-linked polymer composition (C).

[0128] The polymer composition (C) may contain, if required, other additives, e.g., antioxidant, copper inhibitor, lubricant, inorganic filler, compatibilizing agent, stabilizer, carbon black and colorant, etc., as long as the characteristics of the flame-retardant layer 2150 are not impaired.

Laminated structure of the cover layer

[0129] Next, the laminated structure 2160 of the cover layer 2120 composed of the semiconducting layer 2130, the high-electrical insulating layer 2140 and the flame-retardant layer 2150 will be further described.

[0130] The high-electrical insulating layer 2140 is formed thinner than the flame-retardant layer 2150. This reduces the thickness of the laminated structure 2160 and thus reduces the diameter of the insulated wire 2100, and at the same time, high flame retardancy is achieved since flammability of the laminated structure 2160 due to having the high-electrical insulating layer 2140 is reduced by the flame-retardant layer 2150.

[0131] In order to form the thin high-electrical insulating layer 2140 while achieving high insulating properties, the volume resistivity of the polymer composition (B) constituting the high-electrical insulating layer 2140 is preferably not

less than $1 \times 10^{16} \Omega\text{cm}$, more preferably not less than $1 \times 10^{17} \Omega\text{cm}$. The upper limit of the volume resistivity of the polymer composition (B) is not specifically limited.

[0132] To reduce the diameter while achieving high flame retardancy, the thickness of the high-electrical insulating layer **2140** is more preferably not more than half the thickness of the flame-retardant layer **2150**, further preferably not more than one-third of the thickness of the flame-retardant layer **2150**.

[0133] The semiconducting layer **2130** is arranged directly on the conductor **2110** (in contact with the conductor **2110**) and covers the bumps and recesses on the surface of the conductor **2110**, thereby serving as a bump-and-recess smoothing layer to prevent electric field concentration. Thus, the high-electrical insulating layer **2140** which is arranged on the semiconducting layer **2130** can have a reduced thickness. To increase conductivity of the semiconducting layer **2130**, the volume resistivity of the polymer composition (A) constituting the semiconducting layer **2130** is preferably not more than $1 \times 10^9 \Omega\text{cm}$. Meanwhile, the lower limit of the volume resistivity of the polymer composition (A) is not specifically limited.

[0134] The semiconducting layer **2130** needs to cover the bumps and recesses on the surface of the conductor **2110** (needs to fill the recesses to provide a smooth surface), but the semiconducting layer **2130** can have a desired small thickness. The thickness of the semiconducting layer **2130** here is expressed as a thickness on the bumps of the twist on the surface of the conductor **2110** (a thickness of the thinnest portion), i.e., a thickness from the outer diameter of the conductor **2110**.

[0135] However, too thick semiconducting layer **2130** prevents diameter reduction and impairs flame retardancy. For this reason, the thickness of the semiconducting layer **2130** is preferably smaller than the thickness of the flame-retardant layer **2150**, more preferably not more than half the thickness of the flame-retardant layer **2150**, and further preferably not more than one-third of the thickness of the flame-retardant layer **2150**.

[0136] To reduce the diameter while achieving high flame retardancy, the thickness of a laminated portion of the semiconducting layer **2130** and the high-electrical insulating layer **2140**, i.e., the sum of the thickness of the semiconducting layer **2130** and the thickness of the high-electrical insulating layer **2140** is more preferably smaller than the thickness of the flame-retardant layer **2150**, further preferably not more than two-third of the thickness of the flame-retardant layer **2150**.

[0137] The high-electrical insulating layer **2140** is configured to receive preferably not less than 80%, more preferably not less than 90%, further preferably not less than 95%, of voltage applied in the thickness direction of a laminated portion of the high-electrical insulating layer **2140** and the flame-retardant layer **2150**.

[0138] Thus, voltage applied to the flame-retardant layer **2150** can be reduced accordingly. In the flame-retardant layer **2150** which contains many additives such as flame retardant, insulation breakdown is more likely to occur than in the high-electrical insulating layer **2140**. High insulating properties of the insulated wire **2100** can be achieved by reducing voltage applied to the flame-retardant layer **2150**.

[0139] In order to form the thin high-electrical insulating layer **2140** which can receive not less than 80% of voltage applied to the laminated portion of the high-electrical insulating layer **2140** and the flame-retardant layer **2150**, the volume resistivity of the polymer composition (B) constituting the high-electrical insulating layer **2140** is preferably not less than $1 \times 10^{16} \Omega\text{cm}$, more preferably not less than $1 \times 10^{17} \Omega\text{cm}$.

[0140] In order to form the thin high-electrical insulating layer **2140** which can receive not less than 80% of voltage applied to the laminated portion of the high-electrical insulating layer **2140** and the flame-retardant layer **2150**, the volume resistivity of the polymer composition (B) constituting the high-electrical insulating layer **2140** is preferably not less than 10 times, more preferably not less than 50 times, further preferably not less than 100 times the volume resistivity of the polymer composition (C) constituting the flame-retardant layer **2150**.

[0141] To be a thin insulated wire, the outer diameter (the cross-sectional diameter) of the insulated wire **2100** is preferably not more than 7 mm. The rated (AC) voltage of the insulated wire **2100** is, e.g., not more than 3600V. Having a small diameter is also advantageous in that it is easy to simultaneously cross-link semiconducting layer **2130**, the high-electrical insulating layer **2140** and the flame-retardant layer **2150** by radiation crosslinking.

[0142] In view of diameter reduction, the upper limit of the thickness of the semiconducting layer **2130** (on the bumps of the twist on the surface of the conductor **2110**, the thickness of the thinnest portion) is preferably, e.g., not more than 0.10 mm. Meanwhile, the lower limit of the thickness of the semiconducting layer **2130** is not specifically limited as long as the bumps and recesses on the surface of the conductor **2110** are covered, but not less than 0.05 mm is preferable so that, for example, the semiconducting layer **2130** can have a highly uniform thickness and resulting stable voltage-resistant characteristics can be obtained. The thickness of the portion located above the recesses of the twist on the surface of the conductor **2110** and filling the recesses is preferably not less than half the strand outer diameter.

[0143] In view of diameter reduction, the upper limit of the thickness of the high-electrical insulating layer **2140** is, e.g., preferably not more than 0.15 mm, more preferably not more than 0.10 mm. Meanwhile, the lower limit of the thickness of the high-electrical insulating layer **2140** is not specifically limited as long as desired insulating properties are obtained, but not less than 0.05 mm is preferable so that, for example, the high-electrical insulating layer **2140** can have a highly uniform thickness and resulting stable insulating properties can be obtained.

[0144] In view of diameter reduction, the upper limit of the thickness of the flame-retardant layer **2150** is, e.g., preferably not more than **0.30 mm**. Meanwhile, the lower limit of the thickness of the flame-retardant layer **2150** is not specifically limited as long as it is determined according to the thickness of the high-electrical insulating layer **2140** (and the semiconducting layer **2130**) and flame retardancy can be obtained, but not less than **0.10 mm** is preferable so that, for example, the flame-retardant layer **2150** can have a highly uniform thickness and resulting stable flame retardancy can be obtained.

[0145] In view of diameter reduction, preferably, another layer is not arranged between the semiconducting layer **2130** and the high-electrical insulating layer **2140**. In other words, the high-electrical insulating layer **2140** is preferably arranged directly on the semiconducting layer **2130** (in contact with the semiconducting layer **2130**). Likewise, preferably, another layer is not arranged between the high-electrical insulating layer **2140** and the flame-retardant layer **2150**. In other words, the flame-retardant layer **2150** is preferably arranged directly on the high-electrical insulating layer **2140** (in contact with the high-electrical insulating layer **2140**). Furthermore, preferably, another layer is not arranged around the flame-retardant layer **2150**. In other words, it is preferable that the flame-retardant layer **2150** be the outermost layer of the cover layer **2120**, i.e., the outermost layer of the insulated wire **2100**.

[0146] The semiconducting layer **2130**, the high-electrical insulating layer **2140** and the flame-retardant layer **2150** are preferably simultaneously extruded on the conductor **2110**. In this case, air dust to be a cause of electric field concentration can be prevented from attaching to a boundary surface between the semiconducting layer **2130** and the high-electrical insulating layer **2140** and to a boundary surface between the high-electrical insulating layer **2140** and the flame-retardant layer **2150**.

[0147] Alternatively, the semiconducting layer **2130** may have, if required, a laminated structure composed of plural semiconducting layers (sub-semiconducting layers). Likewise, the high-electrical insulating layer **2140** may have, if required, a laminated structure composed of plural insulating layers (sub-insulating layers). Also, the flame-retardant layer **2150** may have, if required, a laminated structure composed of plural flame-retardant layers (sub-flame-retardant layers).

[0148] As described above, in the second embodiment, it is possible to reduce a diameter of the insulated wire while achieving high insulating properties and high flame retardancy.

[0149] The insulated wire in the second embodiment can be used alone, and also can be used, if required, in combination with another member, e.g., used as a core of a cable.

Other embodiments of the invention

[0150] Although the embodiments of the invention have been exemplary and specifically described, the invention is not limited to the above-mentioned embodiments, and can be appropriately changed without departing from the gist of the invention. For example, the following other embodiment can be implemented.

[0151] Next, the insulated wire **2100** in another embodiment will be described in reference to **FIG.4**. **FIG.4** is a cross sectional view showing an example of the structure of the insulated wire **2100** in another embodiment taken perpendicular to the longitudinal direction thereof.

[0152] In another embodiment of the invention, the cover layer **2120** arranged around the conductor **2110** has the laminated structure **2160** composed of the semiconducting layer **2130**, a flame-retardant layer **2150a** arranged around the semiconducting layer **2130**, the high-electrical insulating layer **2140** arranged around the flame-retardant layer **2150a** (arranged around the semiconducting layer **2130** via the flame-retardant layer **2150a**), and a flame-retardant layer **2150b** arranged around the high-electrical insulating layer **2140**. The combined flame-retardant layer **2150** is composed of the flame-retardant layer **2150a** and the flame-retardant layer **2150b**.

[0153] That is, in the other embodiment, the flame-retardant layer **2150** has the flame-retardant layer **2150a** arranged on the inner side (on the conductor **2110** side) of the high-electrical insulating layer **2140**, in addition to the flame-retardant layer **2150b** arranged on the outer side (on the opposite side to the conductor **2110**) of the high-electrical insulating layer **2140**. The flame-retardant layer **2150a** is formed of a polymer composition containing a flame retardant in the same manner as the flame-retardant layer **2150b** and is formed by, e.g., extruding the polymer composition on the outer surface of the semiconducting layer **2130**. The flame-retardant layer **2150** may have such a configuration, if required, to further increase, e.g., flame retardancy.

[0154] As such, the flame-retardant layer **2150** can be arranged only on the outer side of the high-electrical insulating layer **2140** or can be arranged on both the outer and inner sides of the high-electrical insulating layer **2140**. However, to increase flame retardancy of the insulated wire **2100**, the flame-retardant layer **2150** is preferably arranged at least on the outer side (on the outer surface) of the high-electrical insulating layer **2140**.

[0155] The invention will be described in more detail below in reference to Examples. However, the invention is not limited thereto.

Manufacturing of insulated wire

[0156] Insulated wires having the laminated structure shown in **FIG.3** were made as Examples **3** to **5** and Comparative Examples **5** to **7** by the following procedure.

[0157] The polymer composition (A) for forming a semiconducting layer, the polymer composition (B) for forming a high-electrical insulating layer and the polymer composition (C) for forming a flame-retardant layer were prepared. The mixing proportions for the polymer compositions (A) to (C) are shown in Tables **4** to **7**.

Table 4

Polymer composition (A) for forming Semiconducting layer		
Base polymer	EVA	100
Conductive agent	Carbon black	50
Antioxidant	Phenolic	1.5
Volume resistivity (Ωcm)		7.1E+03

Parts by mass

Table 5

Polymer composition (B) for forming High-electrical insulating layer		
Base polymer	High-density polyethylene	100
Antioxidant	Phenolic	1
Copper inhibitor	Hydrazine	0.5
Volume resistivity (Ωcm)		1.1E+17

Parts by mass

Table 6

Polymer composition (C) for forming Flame-retardant layer		
Base polymer	EVA	85
	Acid-modified polyolefin resin	15
Flame retardant	Magnesium hydroxide	200
Colorant	FT carbon	2
Lubricant	Zinc stearate	1
Volume resistivity (Ωcm)		4.0E+14

Parts by mass

[0158] Conductors having an outer diameter of **1.23** mm (each formed by twisting thirty-seven **0.18** mm-diameter tin-plated copper strands) were prepared. The polymer compositions (A), (B) and (C) were simultaneously extruded on each of the conductors and were cross-linked by electron beam irradiation to form the semiconducting layer, the high-electrical insulating layer and the flame-retardant layer, thereby obtaining each insulated wire.

[0159] In the insulated wires in Examples **3** to **5** and Comparative Examples **5** to **7**, the semiconducting layer, the high-electrical insulating layer and the flame-retardant layer were formed in various thicknesses. In Comparative Example **5**, the semiconducting layer was not formed. Table **7** shows the thickness of each layer and the total thickness of the cover layer.

Table 7

		Example 3	Example 4	Example 5	Comparative Example 5	Comparative Example 6	Comparative Example 7
5	Thickness of Semiconducting layer (mm)	0.10	0.05	0.10	-	0.10	0.20
10	Thickness of High-electrical insulating layer (mm)	0.11	0.15	0.08	0.11	0.20	0.10
	Thickness of Flame-retardant layer (mm)	0.29	0.30	0.29	0.40	0.20	0.20
15	Total thickness of Cover layer (mm)	0.50	0.50	0.47	0.41	0.50	0.50
	DC stability test	○	○	○	×	○	○
20	Flame retardancy	○	○	○	○	×	○
	VTFT	○	○	○	○	×	×
	Overall Evaluation	○	○	○	×	×	×

Evaluation of insulated wire

[0160] Insulating properties (electrical characteristics) and flame retardancy of the insulated wires in Examples 3 to 5 and Comparative Examples 5 to 7 were evaluated as follows. Table 7 shows the evaluation results.

DC stability test

[0161] To evaluate electrical characteristics, i.e., insulation reliability, of the insulated wires, a DC stability test was conducted by applying **300V** DC voltage to the insulated wires in **3%** NaCl solution at **85°C** in accordance with EN **50305.6.7**. The wires with no short-circuit for **10** days, i.e., time to short-circuit of not less than **240** hours, were regarded as "Pass (○)", and those short-circuited within **10** days, i.e., time to short-circuit of less than **240** hours, were regarded as "Fail (×)".

Flame-retardancy

[0162] Flame-retardancy of the insulated wires was evaluated by the following flame tests (vertical flame test: VFT and vertical tray flame test: VTFT).

[0163] VFT was conducted in accordance with the Test for vertical flame propagation for a single insulated wire or cable specified by EN **60332-1-2**. In detail, **600** mm-long insulated wires were held vertical and a flame was applied thereto for **60** seconds. The wires passed the test (○) when the fire was extinguished within **60** seconds after removing the flame, and the wires failed the test (×) when the fire was not extinguished within **60** seconds.

[0164] VTFT was conducted in accordance with the Test for vertical flame spread of vertically mounted bunched wires (Flame propagation in bunched cables) specified by EN **50266-2-4**. In detail, seven **3.5**-meter insulated wires were twisted into one bundle, and eleven bundles were vertically arranged at equal intervals and were burnt for **20** minutes. Then, a char length from the lower end after self-extinction was measured. The wires with a char length of not more than **2.5** m were regarded as "Pass (○)", and those with a char length of more than **2.5** m were regarded as "Fail (×)".

Overall evaluation

[0165] The overall evaluation was rated as "Pass (○)" for the insulated wires which passed both the electrical characteristic and flame retardant tests, and the others were rated as "Fail (×)".

Examples 3 to 5

[0166] In Example 3, the thickness of the semiconducting layer was **0.10** mm, the thickness of the high-electrical

insulating layer was **0.11** mm, and the thickness of the flame-retardant layer was **0.29** mm. In Example **4**, the thickness of the semiconducting layer was **0.05** mm, the thickness of the high-electrical insulating layer was **0.15** mm, and the thickness of the flame-retardant layer was **0.30** mm. In Example **5**, the thickness of the semiconducting layer was **0.10** mm, the thickness of the high-electrical insulating layer was **0.08** mm, and the thickness of the flame-retardant layer was **0.29** mm.

[0167] In Examples **3** to **5**, both flame retardancy and diameter reduction were achieved since the thickness of the high-electrical insulating layer was smaller than the thickness of the flame-retardant layer, and the thickness of the semiconducting layer was also smaller than the thickness of the flame-retardant layer. Good insulating properties were also obtained since the semiconducting layer was formed.

[0168] The thickness of the high-electrical insulating layer was not more than half the thickness of the flame-retardant layer in Examples **3** to **5**, and specifically not more than one-third of the thickness of the flame-retardant layer in Example **5**. The thickness of the semiconducting layer was not more than half the thickness of the flame-retardant layer in Examples **3** to **5**, and specifically not more than one-third of the thickness of the flame-retardant layer in Example **4**. The sum of the thickness of the semiconducting layer and the thickness of the high-electrical insulating layer was smaller than the thickness of the flame-retardant layer in Examples **3** to **5**, and specifically not more than two-third of the thickness of the flame-retardant layer in Examples **4** and **5**. In Example **5**, the high-electrical insulating layer was thinner than the semiconducting layer.

Comparative Examples 5 to 7

[0169] In Comparative Example **5**, the semiconducting layer was not formed, the thickness of the high-electrical insulating layer was **0.11** mm, and the thickness of the flame-retardant layer was **0.4** mm. In Comparative Example **6**, the thickness of the semiconducting layer was **0.10** mm, the thickness of the high-electrical insulating layer was **0.20** mm, and the thickness of the flame-retardant layer was **0.20** mm. In Comparative Example **7**, the thickness of the semiconducting layer was **0.20** mm, the thickness of the high-electrical insulating layer was **0.10** mm, and the thickness of the flame-retardant layer was **0.20** mm.

[0170] The insulated wire in Comparative Example **5** had good flame retardancy due to having a thin high-electrical insulating layer, but failed the insulating property test since the semiconducting layer was not formed.

The insulated wires in Comparative Examples **6** and **7** passed the insulating property test due to having the semiconducting layer, but failed the flame retardant test since the thickness of the high-electrical insulating layer was the same as the thickness of the flame-retardant layer in Comparative Example **6** and the thickness of the semiconducting layer was the same as the thickness of the flame-retardant layer in Comparative Example **7**.

[0171] Meanwhile, as other examples, insulated wires were made so that the respective layers had the same thicknesses as those in Example **5**, but the polymer composition (A) to form the semiconducting layer, the polymer composition (B) to form the high-electrical insulating layer and the polymer composition (C) to form the flame-retardant layer were prepared with various mixing proportions. As a result, the similar characteristics as those described in Examples **3** to **5** were obtained. For example, one of the insulated wires had a high-electrical insulating layer formed of the polymer composition (B) having a volume resistivity of the order of $10^{16} \Omega\text{cm}$, and this shows that the polymer composition (B) having a volume resistivity of not less than $1 \times 10^{16} \Omega\text{cm}$ can be used. Meanwhile, for example, one of the insulated wires had a semiconducting layer formed of the polymer composition (A) having a volume resistivity of the order of $10^8 \Omega\text{cm}$, and this shows that the polymer composition (A) having a volume resistivity of not more than $1 \times 10^9 \Omega\text{cm}$ can be used.

[0172] Although the invention has been described in reference to the second embodiment, the invention is not limited thereto. It will be obvious for those skilled in the art that various changes, modifications and combinations, etc., can be implemented.

Preferred embodiments of the invention

[0173] Preferred embodiments of the invention will be described below.

[0174] An insulated wire, comprising:

a conductor; and

a cover layer arranged around the conductor,

wherein the cover layer comprises a semiconducting layer, a high-electrical insulating layer and a flame-retardant layer, the semiconducting layer being arranged around the conductor and comprising a polymer composition (A) containing a conductive agent and having a volume resistivity of not more than $1 \times 10^9 \Omega\text{cm}$, the high-electrical insulating layer being arranged around the semiconducting layer and comprising a polymer composition (B) having a volume resistivity of not less than $1 \times 10^{16} \Omega\text{cm}$, and the flame-retardant layer being arranged at least around the high-electrical insulating layer and comprising a polymer composition (C) containing a flame retardant, and the

thickness of the high-electrical insulating layer and the thickness of the semiconducting layer are smaller than the thickness of the flame-retardant layer.

[0175] The insulated wire defined by **[18]**, wherein the thickness of the high-electrical insulating layer is more preferably not more than half the thickness of the flame-retardant layer, further preferably not more than one-third of the thickness of the flame-retardant layer.

[0176] The insulated wire defined by **[18]** or **[19]**, wherein the thickness of the semiconducting layer is more preferably not more than half the thickness of the flame-retardant layer, further preferably not more than one-third of the thickness of the flame-retardant layer.

[0177] The insulated wire defined by any one of **[18]** to **[20]**, wherein the sum of the thickness of the semiconducting layer and the thickness of the high-electrical insulating layer is preferably smaller than the thickness of the flame-retardant layer, more preferably not more than two-third of the thickness of the flame-retardant layer.

[0178] The insulated wire defined by any one of **[18]** to **[21]**, wherein the high-electrical insulating layer receives preferably not less than **80%**, more preferably not less than **90%**, further preferably not less than **95%** of voltage applied in a thickness direction of a laminated portion of the high-electrical insulating layer and the flame-retardant layer.

[0179] The insulated wire defined by any one of **[18]** to **[22]**, wherein the polymer composition (B) has a volume resistivity of not less than $1 \times 10^{17} \Omega \text{cm}$.

[0180] The insulated wire defined by any one of **[18]** to **[23]**, wherein the volume resistivity of the polymer composition (B) constituting the high-electrical insulating layer is preferably not less than **10** times, more preferably not less than **50** times, further preferably not less than **100** times the volume resistivity of the polymer composition (C) constituting the flame-retardant layer.

[0181] The insulated wire defined by any one of **[18]** to **[24]**, wherein the outer diameter of the insulated wire is not more than **7 mm**.

[0182] The insulated wire defined by any one of **[18]** to **[25]**, wherein the thickness of the semiconducting layer is not more than **0.10 mm**.

[0183] The insulated wire defined by any one of **[18]** to **[26]**, wherein the thickness of the high-electrical insulating layer is preferably not more than **0.15 mm**, more preferably not more than **0.10 mm**.

[0184] The insulated wire defined by any one of **[18]** to **[27]**, wherein the thickness of the flame-retardant layer is not more than **0.30 mm**.

[0185] The insulated wire defined by any one of **[18]** to **[28]**, wherein the semiconducting layer is arranged directly on the conductor (in contact with the conductor).

[0186] The insulated wire defined by any one of **[18]** to **[29]**, wherein the high-electrical insulating layer is arranged directly on the semiconducting layer (in contact with the semiconducting layer).

[0187] The insulated wire defined by any one of **[18]** to **[30]**, wherein the flame-retardant layer is also arranged between the semiconducting layer and the high-electrical insulating layer.

[0188] The insulated wire defined by any one of **[18]** to **[31]**, wherein the flame-retardant layer is arranged directly on the high-electrical insulating layer (in contact with the high-electrical insulating layer).

[0189] The insulated wire defined by any one of **[18]** to **[32]**, wherein the flame-retardant layer is the outermost layer of the insulated wire.

[0190] The insulated wire defined by any one of **[18]** to **[33]**, wherein the conductor is a twisted wire formed by twisting plural strands.

[0191] The insulated wire defined by any one of **[18]** to **[34]**, wherein the flame-retardant layer is an electrical insulating layer formed of the polymer composition (C) having a volume resistivity of not less than $1 \times 10^{13} \Omega \text{cm}$ or not less than $1 \times 10^{14} \Omega \text{cm}$.

Claims

1. An insulated wire, comprising:

a conductor; and
a cover layer arranged around the conductor,
wherein the cover layer comprises a laminated structure formed by laminating an inner flame-retardant layer,
a high-electrical insulating layer and an outer flame-retardant layer,
wherein the inner flame-retardant layer is arranged around the conductor and comprises a polymer composition (A) comprising a flame retardant,
wherein the high-electrical insulating layer is arranged around the inner flame-retardant layer and comprises a polymer composition (B) having a volume resistivity of not less than $1 \times 10^{16} \Omega \text{cm}$,

wherein the outer flame-retardant layer is arranged around the high-electrical insulating layer and comprises a polymer composition (C) comprising a flame retardant,
 wherein the high-electrical insulating layer receives not less than 80% of voltage applied in a thickness direction of the laminated structure, and
 wherein the thickness of the high-electrical insulating layer is smaller than at least one of the thickness of the inner flame-retardant layer and the thickness of the outer flame-retardant layer.

2. The insulated wire according to claim 1, wherein the thickness of the high-electrical insulating layer is not more than half the sum of the thickness of the inner flame-retardant layer and the thickness of the outer flame-retardant layer.

3. The insulated wire according to claim 1 or 2, wherein the thickness of the high-electrical insulating layer is not more than half of at least one of the thickness of the inner flame-retardant layer and the thickness of the outer flame-retardant layer.

4. An insulated wire, comprising:

a conductor; and
 a cover layer arranged around the conductor,
 wherein the cover layer comprises a semiconducting layer, a high-electrical insulating layer and a flame-retardant layer,
 wherein the semiconducting layer is arranged around the conductor and comprises a polymer composition (A) comprising a conductive agent and having a volume resistivity of not more than $1 \times 10^9 \Omega \text{cm}$,
 wherein the high-electrical insulating layer is arranged around the semiconducting layer and comprises a polymer composition (B) having a volume resistivity of not less than $1 \times 10^{16} \Omega \text{cm}$.
 wherein the flame-retardant layer is arranged at least around the high-electrical insulating layer and comprises a polymer composition (C) comprising a flame retardant, and
 wherein the thickness of the high-electrical insulating layer and the thickness of the semiconducting layer are each smaller than the thickness of the flame-retardant layer.

5. The insulated wire according to claim 4, wherein the thickness of the high-electrical insulating layer is not more than half the thickness of the flame-retardant layer.

6. The insulated wire according to claim 4 or 5, wherein the thickness of the semiconducting layer is not more than half the thickness of the flame-retardant layer.

FIG.1

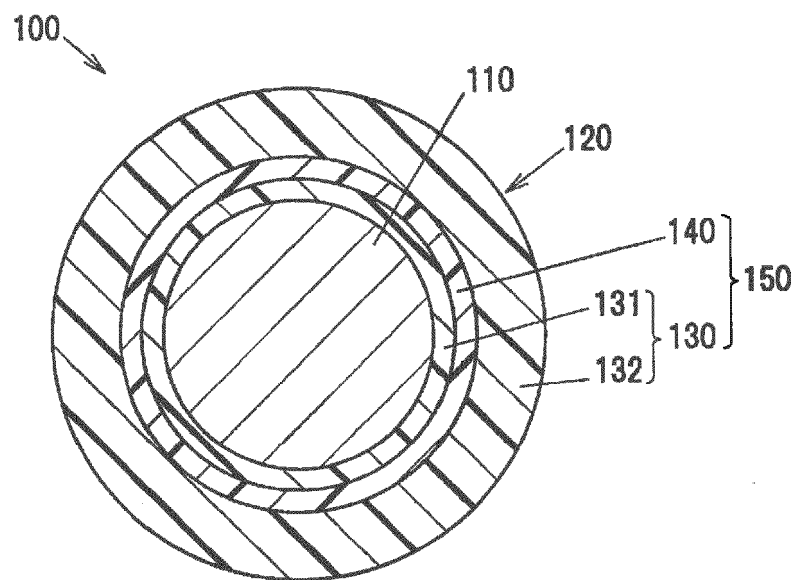


FIG.2

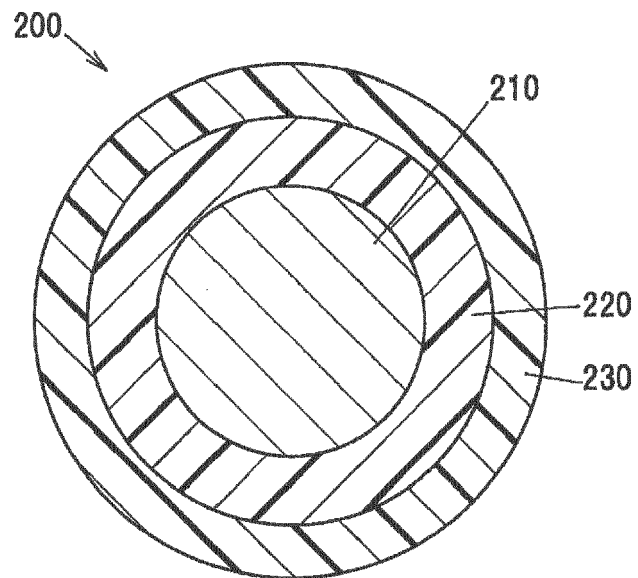


FIG.3

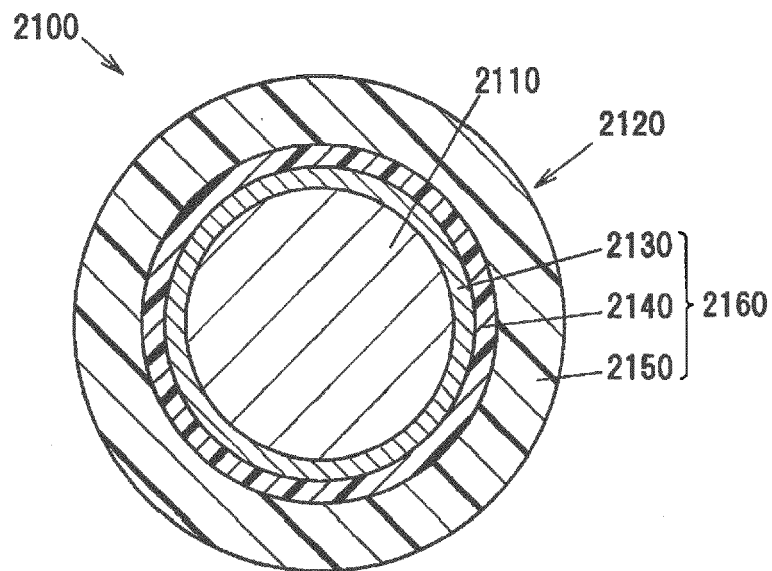


FIG.4

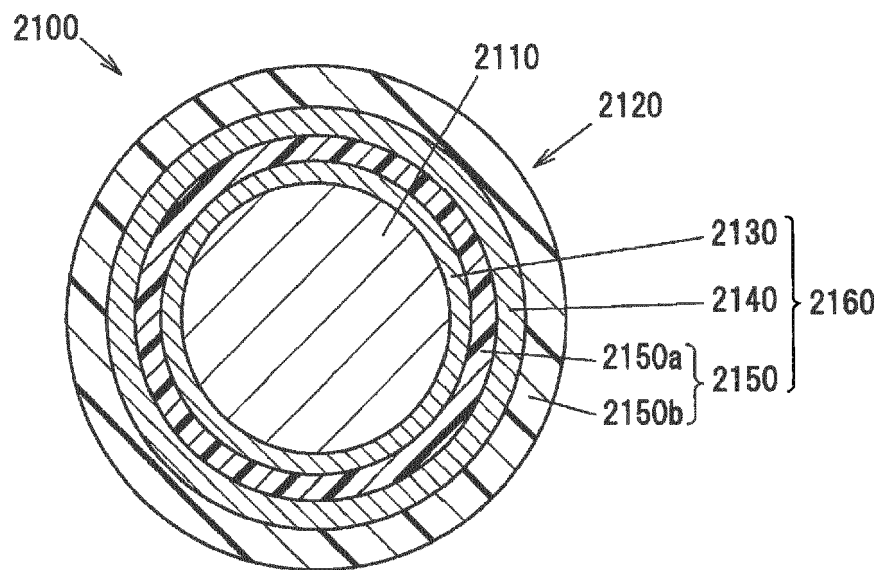
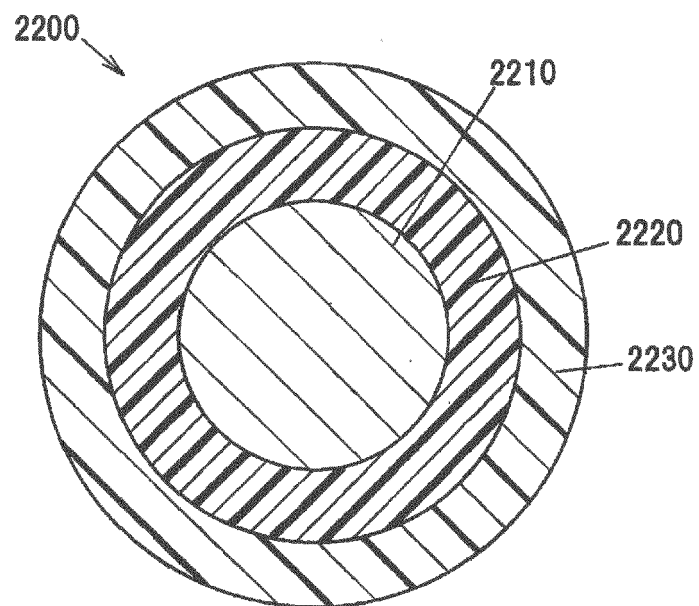


FIG.5



**PARTIAL EUROPEAN SEARCH REPORT**

Application Number

under Rule 62a and/or 63 of the European Patent Convention.
This report shall be considered, for the purposes of
subsequent proceedings, as the European search report

EP 17 17 6008

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INCOMPLETE SEARCH

The Search Division considers that the present application, or one or more of its claims, does/do not comply with the EPC so that only a partial search (R.62a, 63) has been carried out.

Claims searched completely :

Claims searched incompletely :

Claims not searched :

Reason for the limitation of the search:

see sheet C

1

Place of search	Date of completion of the search	Examiner
The Hague	17 May 2018	Kövecs, Monika
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document		

EPO FORM 1503 03/82 (P04E07)

**INCOMPLETE SEARCH
SHEET C**

Application Number

EP 17 17 6008

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Claim(s) completely searchable:
4-6

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Claim(s) not searched:
1-3

Reason for the limitation of the search:

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The search has been restricted to the subject-matter indicated by the applicant in his letter of 16.02.2018 filed in reply to the invitation pursuant to Rule 62a(1)EPC, namely claim 4 and its dependent claims. The applicant is invited to restrict the claims to the subject-matter searched.

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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17-05-2018

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