

Description

SILVER CONDUCTIVE FILM AND METHOD FOR PRODUCING SAME

5 Technical Field

The present invention relates generally to a silver conductive film and a method for producing the same. More specifically, the present invention relates to a silver conductive film used for forming
10 conductive circuits, such as antennas for IC tags for radio communication, and a method for producing the same.

Background Art

15 IC tags for radio communication (which will be hereinafter referred to as "IC tags") utilize a kind of RFID (Radio Frequency Identification (Identification Technique based on Radio Communication)), and are thin, light and small
20 electronic devices, each of which has a semiconductor chip for storing data, such as an identification number, and an antenna for transmitting and receiving radio waves.

Such IC tags are expected to be widely utilized
25 in various service environments in various fields, such as physical distribution management, and are desired to be mass-produced to reduce the production costs thereof to be spread. Antennas for IC tags are required to have a low electrical resistance in
30 order to increase the data transmittable/receivable range (communication range) thereof and to reduce data loss during transmit/receive. Moreover, IC

tags are used in various fields, such as physical distribution management (e.g., management of tracking of shipping containers, traceability and positional information, and management of closing
5 by laundry, such as laundry tags), so that they are often repeatedly bent in service environment. Therefore, even if IC tags are repeatedly bent, it is required to prevent them from being unserviceable as IC tags by the deterioration of characteristics
10 of antennas, such as breaking and increasing of electrical resistance due to metal fatigue of antennas, so that they are required to have good flexibility.

As methods for forming antenna circuits
15 (conductive circuits) for IC tags, there are a method for utilizing a copper coil or wire as an antenna, a method for transferring a metal foil, such a copper or aluminum foil, to a substrate, a method for printing an etching resistant ink as an antenna
20 circuit pattern on a metal foil, which is laminated on a substrate such as a plastic film, to mask it to etch the metal foil, and so forth.

However, since these methods are not suit for mass production due to the limitation of their
25 productivity, it is difficult to further reduce the production costs. In the method for transferring a metal foil to a substrate and in the method for etching a metal foil among the above-described methods, the metal foil is produced by rolling or
30 the like, and the percentage of a metal in the metal foil is a high percentage which is approximately 100 %. For that reason, there is a problem in that an IC

tag having an antenna circuit formed by a metal foil has bad flexibility although it has good electrical characteristics. In addition, although a metal foil having a thickness of about 10 to 50 μm is generally used for forming an antenna circuit for an IC tag, if the metal foil is too thick, the characteristics of the metal foil approach those of a metal plate for deteriorating the adhesion thereof to a substrate, so that there is some possibility that the metal foil may be stripped from the substrate when the IC tag is bent. Moreover, since the percentage of the metal in the metal foil is high, when the IC tag is bent, stress concentrates on the bent surface thereof, so that cracks are easy to be generated on the bent surface thereof. As a result, the electrical characteristics thereof are deteriorated, and the breaking thereof is caused, so that it does not function as an antenna for an IC tag. On the other hand, if the percentage of a metal is decreased by using a conductive film of the metal component and a resin component in place of the metal foil in order to improve the flexibility of the IC tag, it is possible to generally improve the flexibility by stress relaxation, but the amount of the metal component is decreased for deteriorating the electrical characteristics thereof, so that it does not have sufficient characteristics as those of an antenna for an IC tag.

As a method for producing an antenna for an IC tag wherein a conductive circuit is formed on a substrate so as to have good adhesion thereto without the use of any metal foils, there is proposed a method

for applying a water based conductive ink containing 40 % or less by weight of silver particles on the surface of a film substrate by the flexographic printing to dry the ink to form a conductive film
5 having a thickness of 0.1 to 0.5 μ m on the surface of the film substrate to produce an antenna for an IC tag (see, e.g., Japanese Patent Laid-Open No. 2010-268073).

In the method disclosed in Japanese Patent
10 Laid-Open No. 2010-268073, it is possible to mass-produce antennas for IC tags, which have a low electrical resistance, to reduce the production costs thereof. However, the conductive ink containing the small amount of silver particles is
15 used for forming the thin conductive film having the thickness of 0.1 to 0.5 μ m, and the percentage of silver in the conductive film is a high percentage which is approximately 100 %, so that there is a problem in that the flexibility of the IC tags is
20 bad similar to that in the method for transferring a metal foil to a substrate and in the method for etching a metal foil.

Disclosure of the Invention

25 It is therefore an object of the present invention to eliminate the aforementioned conventional problems and to provide a silver conductive film capable of inexpensively mass-producing conductive circuits, such as
30 antennas for IC tags, which have excellent electrical characteristics and flexibility, and a method for producing the same.

In order to accomplish the aforementioned object, the inventors have diligently studied and found that it is possible to produce a silver conductive film capable of inexpensively mass-producing conductive circuits, such as antennas for IC tags, which have excellent electrical characteristics and flexibility, by producing a silver conductive film which contains 10-50 % by volume of a sintered body of silver particles and which has a volume resistivity of 3-100 $\mu \Omega \cdot \text{cm}$.

According to the present invention, there is provided a silver conductive film which contains 10-50 % by volume of a sintered body of silver particles and which has a volume resistivity of 3-100 $\mu \Omega \cdot \text{cm}$. The amount of the sintered body of silver particles contained in the silver conductive film is preferably 30-50 % by volume. The surface resistivity of the silver conductive film is preferably 0.5 $\Omega / \square$ or less. The thickness of the silver conductive film is preferably 1-6 μm .

According to the present invention, there is provided a method for producing a silver conductive film, the method comprising the steps of: preparing a silver particle dispersing solution which contains 50-70 % by weight of silver particles; applying the silver particle dispersing solution on a substrate; and calcining the silver particle dispersing solution on the substrate to form the above-described silver conductive film. In this method for producing a silver conductive film, the applying of the silver particle dispersing solution on the substrate is preferably carried out by the

flexographic printing. The applying of the silver particle dispersing solution on the substrate is preferably carried out by repeating the flexographic printing a plurality of times, and more preferably
5 by repeating the flexographic printing twice to four times. The average particle diameter of the silver particles is preferably 20 nm or less.

According to the present invention, there is provided an antenna for RFID tag, which is formed
10 of the above-described silver conductive film. According to the present invention, there is provided an RFID tag comprising an antenna for RFID tag, which is formed of the above-described silver conductive film, and an IC chip.

15 Throughout the specification, the expression "the average particle diameter of silver particles" means an average primary particle diameter which is an average value of primary particle diameters of silver particles based on a transmission electron
20 microphotograph (TEM image).

According to the present invention, it is possible to produce a silver conductive film capable of inexpensively mass-producing conductive circuits, such as antennas for IC tags, which have
25 excellent electrical characteristics and flexibility.

Brief Description of the Drawings

FIG. 1 is a view for explaining the shape of
30 an Ag ink printed on a substrate in Examples and Comparative Examples;

FIG. 2 is a schematic view showing a dipole

antenna produced by using a conductive film produced in Examples and Comparative Examples;

FIG. 3 is a schematic view showing a bending test sample used in Examples and Comparative
5 Examples; and

FIG. 4 is a view for explaining a bending test carried out in Examples and Comparative Examples, wherein FIG. 4(b) is an enlarged view schematically showing a portion of the bending test sample
10 surrounded by a circular dotted line in FIG. 4(a).

Best Mode for Carrying Out the Invention

The preferred embodiment of a silver conductive film according to the present invention
15 contains 10-50 % by volume of a sintered body of silver particles and has a volume resistivity of $3-100 \mu \Omega \cdot \text{cm}$. If the amount of the sintered body of silver particles in the silver conductive film is less than 10 % by volume, it is too small, so that the electrical
20 characteristics thereof are deteriorated. Thus, when the silver conductive film is used for forming antennas for IC tags, they do not function as antennas for IC tags. On the other hand, if the amount of the sintered body of silver particles in the silver
25 conductive film exceeds 50 % by volume, when the silver conductive film is used for forming antennas for IC tags and when the IC tags are bent, stress concentrates on the bent surface thereof, so that cracks are easy to be generated on the bent surface
30 thereof. As a result, the deterioration of electrical characteristics thereof and the breaking thereof are easy to be caused, so that there is

increased the possibility that they do not function as antennas for IC tags. In particular, if the amount of the silver particles contained in the silver conductive film is 30-50 % by volume, when the silver
 5 conductive film is used for forming antennas for IC tags, the communication range thereof at a frequency of 955 MHz is 4.0 m or more (which is equal to or longer than the conventional communication range), and the flexibility thereof is good. For that reason,
 10 the amount of the silver particles contained in the silver conductive film is more preferably 30-50 % by volume. If the volume resistivity of the silver conductive film is in the range of from $3 \mu \Omega \cdot \text{cm}$ to $100 \mu \Omega \cdot \text{cm}$, when the silver conductive film is
 15 used for forming antennas for IC tags, the communication range thereof can be increased to ensure the transmit/receive of data between each of the antennas for IC tags and a reader/writer, so that it is difficult for the antennas for IC tags to cause
 20 data loss during transmit/receive.

The surface resistivity of the silver conductive film is preferably $0.5 \Omega / \square$ or less. If the surface resistivity of the silver conductive film is $0.5 \Omega / \square$ or less, when the silver conductive film
 25 is used for forming antennas for IC tags, the communication range thereof can be increased to ensure the transmit/receive of data between each of the antennas for IC tags and a reader/writer, so that it is difficult for the antennas for IC tags to cause
 30 data loss during transmit/receive.

The thickness of the silver conductive film is preferably in the range of from $1 \mu \text{m}$ to $6 \mu \text{m}$

m. As the silver conductive film is thinner, the costs thereof are lower. However, if the thickness of the silver conductive film is less than 1 μ m, when the silver conductive film is used for forming
5 antennas for IC tags, the electrical resistance thereof in the UHF band is increased due to conductor skin effect, so that the communication range thereof is decreased.

In the preferred embodiment of a method for
10 producing a silver conductive film according to the present invention, the above-described silver conductive film is formed by calcining a silver particle dispersing solution, which contains 50-70 % by weight of silver particles, after applying the
15 silver particle dispersing solution on a substrate. If the content of the silver particles in the silver particle dispersing solution is less than 50 % by weight, it is difficult to form the above-described silver conductive film on the substrate, and the
20 electrical conductivity of the film is deteriorated to increase the electrical resistance thereof since the amount of the sintered body of silver particles in the silver conductive film is too small. If the content of the silver particles exceeds 70 % by weight,
25 the viscosity of the silver particle dispersing solution is increased, so that it is difficult to apply it on the substrate by the flexographic printing or the like.

In this method for producing a silver
30 conductive film, the applying of the silver particle dispersing solution on the substrate is preferably carried out by the flexographic printing. The

flexographic printing is preferably repeated. In particular, if the flexographic printing is repeated twice to four times, the balance between the amount of the sintered body of silver particles in the silver conductive film formed on the substrate and the electrical resistance of the silver conductive film is good, so that the flexographic printing is more preferably repeated twice to four times.

In this method for producing a silver conductive film, the average particle diameter of the silver particles is preferably 20 nm or less, and more preferably in the range of from 5 nm to 15 nm. If the average particle diameter of the silver particles is in the range of from about a few nanometers to about over ten nanometers, the specific surface area thereof increases, so that the melting point thereof dramatically decreases. For that reason, even if the silver particles are calcined at a low temperature of not higher than 300 °C, it is possible to sinter the silver particles with each other (that is, it is possible to obtain the degree of sintering at a low temperature). However, if the average particle diameter of the silver particles is greater than 20 nm, it is difficult to obtain the degree of sintering at a low temperature, which is expected as silver nanoparticles (fine silver particles).

Furthermore, the average particle diameter (average primary particle diameter) of the silver particles can be calculated as follows. For example, 2 parts by weight of an Ag ink containing silver particles, such as an Ag ink (PFI-700 produced by

PChem Associates Inc.), which contains 60 % by weight of Ag particles (silver particles having an average particle diameter of 10 nm), 3.0 % by weight of polyvinyl chloride copolymer latex, 2.0 % by weight of polyurethane thickener and 2.5 % by weight of polypropylene glycol, is added to a mixed solution of 96 parts by weight of cyclohexane and 2 parts by weight of oleic acid, and is dispersed by ultrasonic. Then, the fluid dispersion thus obtained is allowed to drop onto a Cu microgrid having a supporting film to be dried. Then, an image obtained by observing the silver particles on the microgrid in a bright field at an accelerating voltage of 100 kV by means of a transmission electron microscope (JEM-100 CX Mark-II produced by Japan Electron Optics Laboratory Ltd.) is taken at a magnification of 300,000. From the TEM image thus obtained, the average particle diameter (average primary particle diameter) of the silver particles can be calculated. The calculation of the average primary particle diameter of the silver particles can be carried out by, e.g., an image analysis software (A-image-kun (registered trademark) produced by Asahi Kasei Engineering Corporation). This image analysis software is designed to identify and analyze each of particles with the gradation of color. For example, with respect to the TEM image having the magnification of 300,000, a circular particle analysis is carried out on such conditions that "the brightness of particles" is set to be "dark", "the noise removing filter" is used, "the circular threshold value" is set to be "20", and "the overlapping degree" is set

to be "50". Thus, the primary particle diameters of 200 or more of particles are measured, and the number average diameter thereof can be obtained as the average primary particle diameter. If the TEM image
5 has a large number of sintered particles and deformed particles, it may be impossible measurement (no measured).

Examples of a silver conductive film and a method for producing the same according to the
10 present invention will be described below in detail.
Examples 1-4

First, there was prepared an Ag ink (PFI-700 produced by PChem Associates Inc.) containing 60 % by weight of Ag particles (silver particles having
15 an average particle diameter of 10 nm), 3.0 % by weight of polyvinyl chloride copolymer latex, 2.0 % by weight of polyurethane thickener and 2.5 % by weight of propylene glycol.

Then, a flexographic printing machine
20 (multipurpose fine printing machine JEM Flex produced by Nihon Denshi Seiki Co., Ltd.) and a flexographic printing plate (produced by Watanabe Gosando Co., Ltd., Material of Printing Plate: Photosensitive Resin Plate AWP produced by Asahi
25 Kasei Corporation, Grade DEF, Surface Processing 150 lines, 96 DOT%) were used for printing the above-described Ag ink on a substrate (PET (polyethylene terephthalate) film, Melinex (registered trademark) 545 produced by DuPont Teijin
30 Films Limited) 10 at an anilox volume of 8 cc/m² (400 lines/inch) and at a printing speed of 20 m/min. once (Example 1), twice (Example 2), three times (Example

3) and four times (Example 4) as the number of printing times, respectively, so as to form five films 12 having a substantially rectangular shape having a size of about 3 cm x 15 cm as shown in FIG. 1, and
5 then, the printed matter was heat-treated on a hot plate at 140 °C for 30 minutes to be calcined to obtain a conductive film (silver conductive film).

Then, after the produced conductive film, together with the substrate, was cut to form two
10 substantially-rectangular pieces having a size of 5.0 mm x 78.5 mm to be applied on a pressure sensitive adhesive release film (Type PET 38 produced by Lintec Corporation) to produce a dipole antenna 14 as shown in FIG. 2, a thin layer of an anisotropic conducting
15 paste (ACP) (TAP0604C (Au/Ni Coat Polymer Particles) produced by Kyocera Chemical Corporation) was applied on the IC chip mounting portion of the dipole antenna 14. Then, an IC chip (Monza 2 produced by Impinj, Inc.)
16 was arranged on the ACP to be
20 compression-bonded thereto by applying a pressure of 1.0 N at a temperature of 160 °C for ten seconds by means of a thermal compression bonding apparatus (TTS 300 produced by Muhlbauer GmbH). The IC chip
16 was thus fixed and connected to the dipole antenna
25 14, so that the IC chip 16 was mounted to the dipole antenna 14.

With respect to the IC chip-mounted dipole antenna thus produced, the thickness, electrical resistance (line resistance) and surface
30 resistivity of the conductive film were measured, and the volume resistivity of the conductive film and the percentage of the metal (Ag) in the conductive

film were calculated.

The thickness of the conductive film was obtained by measuring a difference of elevation at each of 100 points between the surface of the substrate, on which the conductive film was formed, and the surface of the conductive film by means of a laser microscope (Model VK-9700 produced by KEYENCE CORPORATION) to calculate an average value thereof. As a result, the thickness of the conductive film was 1.4 μm (Example 1), 2.1 μm (Example 2), 3.0 μm (Example 3) and 3.6 μm (Example 4), respectively.

The electrical resistance (line resistance) of the conductive film was obtained by measuring the electrical resistance in longitudinal directions of one conductive film (5.0 mm x 78.5 mm) of the dipole antenna by means of a tester (Model CDM-03D produced by CUSTOM Corporation). As a result, the electrical resistance of the conductive film was 5.0 Ω (Example 1), 1.3 Ω (Example 2), 0.8 Ω (Example 3) and 0.6 Ω (Example 4), respectively.

A piece having a size of 2.0 cm x 2.0 cm was cut out of the conductive film for measuring the surface resistivity of the conductive film by the four-terminal method by means of a surface resistivity measuring apparatus (Loresta GP produced by Mitsubishi Chemical Analytech Co., Ltd.). As a result, the surface resistivity of the conductive film was 0.25 $\Omega/\square$ (Example 1), 0.06 $\Omega/\square$ (Example 2), 0.03 $\Omega/\square$ (Example 3) and 0.02 $\Omega/\square$ (Example 4), respectively.

The volume resistivity of the conductive film was derived from the thickness, electrical

resistance and area (the area of the one conductive film (5.0 mm x 78.5 mm) of the dipole antenna) of the conductive film. As a result, the volume resistivity of the conductive film was $44.6 \mu \Omega \cdot \text{cm}$ (Example 1), $17.4 \mu \Omega \cdot \text{cm}$ (Example 2), $15.3 \mu \Omega \cdot \text{cm}$ (Example 3) and $13.6 \mu \Omega \cdot \text{cm}$ (Example 4), respectively.

The percentage of the metal (Ag) in the conductive film was obtained as follows. First, the conductive film having a printed area of 2.6 cm x 13.1 cm was dissolved in a concentrated nitric acid solution (having a known weight), and the concentration of Ag in the solution was obtained by the inductively coupled plasma (ICP) emission spectral analysis method to calculate the weight (g) of Ag in the conductive film. Then, the volume (cm^3) of Ag was derived from the density (10.5 g/cm^3) of Ag, and the volume of the conductive film was derived from the thickness and printed area (2.6 cm x 13.1 cm) of the conductive film to calculate the percentage of Ag in the conductive film from the expression "volume (cm^3) of Ag x 100 / volume (cm^3) of conductive film". As a result, the percentage of Ag in the conductive film was 22.4 % by volume (Example 1), 31.0 % by volume (Example 2), 37.1 % by volume (Example 3) and 48.3 % by volume (Example 4), respectively.

With respect to the produced IC chip-mounted dipole antenna, the communication range (theoretical read range forward) at a frequency domain of 800 to 1100 MHz (based on ISO/IEC 18000-6C Standard) was measured by a communication range

measuring apparatus (tagformance produced by
Voyantic Corporation) in an electromagnetic
anechoic box (MY1530 produced by Micronics
Corporation). Furthermore, prior to this
5 measurement, environment setting (setting by a
reference tag attached to tagformance) on this
condition was carried out. As a result, the
communication range at a frequency of 955 MHz was
3.8 m (Example 1), 4.2 m (Example 2), 4.4 m (Example
10 3) and 4.2 m (Example 4), respectively.

As shown in FIG. 3, a rectangular conductive
film 12' having a size of 5.0 mm x 20.0 mm was cut
out of the conductive film produced in this example,
to be applied on a pressure sensitive adhesive
15 release film (Type PET 38 produced by Lintec
Corporation) 18 to produce a bending test sample 20.
As shown in FIG. 4, the conductive film 12' of the
bending test sample 20 was pressed at 5.0 N on a pole
22 of iron having $R=0.5$ mm to be caused to slide in
20 directions of the arrow by 10 cm while being bent
by 90 degrees. After this sliding movement was
repeated 10 times, 100 times and 500 times,
respectively, the line resistance (tester) was
measured to obtain a resistance deteriorated rate
25 (100 % when the line resistance is not changed) from
the expression "line resistance after sliding
movement x 100 / line resistance before test". As
a result, in Examples 1 and 2, the resistance
deteriorated rate was 100% after the sliding movement
30 was repeated 10 times, 100 times and 500 times,
respectively. In Example 3, the resistance
deteriorated rate was 100 % after the sliding

movement was repeated 10 times and 100 times, respectively, and 125 % after it was repeated 500 times. In Example 4, the resistance deteriorated rate was 100 % after the sliding movement was repeated 10 times, 150 % after it was repeated 100 times, and 180 % after it was repeated 500 times.

The conditions and results in Examples 1-4 are shown in Tables 1-3.

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Table 1

	Film Forming Method	Concentration of Ag in Ink (wt.%)	<u>Printing Conditions</u>	
			Anilox Volume (cc/m ²)	Number of Printing Times
Ex.1	Print	60	8	1
Ex.2	Print	60	8	2
Ex.3	Print	60	8	3
Ex.4	Print	60	8	4
Comp.1	Print	50	8	1
Ex.5	Print	50	8	2
Ex.6	Print	50	8	3
Ex.7	Print	50	8	4
Ex.8	Print	70	8	1
Ex.9	Print	70	8	2
Ex.10	Print	70	8	3
Comp.2	Print	70	8	4
Ex.11	Print	60	20	1
Ex.12	Print	60	20	2
Ex.13	Print	60	20	3
Comp.3	Print	60	20	4
Comp.4	Print	60	20	8
Comp.5	Print	40	8	1
Comp.6	Print	40	8	2
Comp.7	Print	40	8	3
Comp.8	Print	40	8	4
Comp.9	Foil	—	—	—
Comp.10	Foil	—	—	—
Comp.11	Foil	—	—	—
Comp.12	Foil	—	—	—
Comp.13	Foil	—	—	—

Table 2

	Thick- ness (μm)	Elec- trical Resis- tance (Ω)	Surface Resis- tivity ($\Omega/\square$)	Volume Resis- tivity ($\mu\Omega \cdot \text{cm}$)	Per- cent- age of Metal (vol.%)
Ex.1	1.4	5.0	0.25	44.6	22.4
Ex.2	2.1	1.3	0.06	17.4	31.0
Ex.3	3.0	0.8	0.03	15.3	37.1
Ex.4	3.6	0.6	0.02	13.6	48.3
Comp.1	1.7	OL	OL	OL	8.5
Ex.5	2.5	5.0	0.43	78.7	15.5
Ex.6	3.4	2.5	0.18	53.5	17.5
Ex.7	4.8	1.5	0.10	46.1	18.8
Ex.8	1.7	3.1	0.19	32.8	25.6
Ex.9	2.5	1.1	0.06	17.4	32.7
Ex.10	2.8	0.6	0.03	10.8	43.3
Comp.2	3.1	0.4	0.01	7.9	54.7
Ex.11	2.2	1.1	0.06	15.4	28.5
Ex.12	3.6	0.5	0.02	11.5	38.5
Ex.13	5.6	0.1	0.01	3.6	49.2
Comp.3	7.5	0.1	0.01	4.8	54.9
Comp.4	11.4	0.1	0.01	7.3	70.1
Comp.5	1.5	OL	OL	OL	5.7
Comp.6	2.4	280.0	114.0	4280	6.4
Comp.7	3.6	75.0	35.5	1705	5.9
Comp.8	5.0	36.0	7.4	1140	7.0
Comp.9	1	0.2	0.01	1.6	100
Comp.10	3	0.1	0.01	1.9	100
Comp.11	3	0.2	0.01	3.8	100
Comp.12	6	0.2	0.01	7.6	100
Comp.13	12	0.2	0.01	15.3	100

Table 3

	Flexibility (Resistance Deteriorated Rate %)			Communi- cation Range (m)
	<u>10 times</u>	<u>100 times</u>	<u>500 times</u>	
Ex.1	100	100	100	3.8
Ex.2	100	100	100	4.2
Ex.3	100	100	125	4.4
Ex.4	100	150	180	4.2
Comp.1	No	No	No	0.0
	Measured	Measured	Measured	
Ex.5	100	100	100	3.7
Ex.6	100	100	100	3.7
Ex.7	100	100	100	3.8
Ex.8	100	100	100	3.8
Ex.9	100	100	120	4.2
Ex.10	100	110	150	4.2
Comp.2	100	350	1200	4.4
Ex.11	100	100	100	3.9
Ex.12	100	100	125	4.2
Ex.13	100	150	180	4.5
Comp.3	200	400	1400	4.5
Comp.4	Breaking	Breaking	Breaking	4.7
Comp.5	No	No	No	0.0
	Measured	Measured	Measured	
Comp.6	100	100	100	0.0
Comp.7	100	100	100	1.8
Comp.8	100	100	100	2.1
Comp.9	100	200	800	4.0
Comp.10	100	150	400	4.4
Comp.11	167	633	Breaking	4.4
Comp.12	100	100	1200	4.4
Comp.13	100	100	800	4.4

Comparative Example 1, Examples 5-7

- 5 First, polyvinyl chloride copolymer latex, polyurethane thickener and propylene glycol were added to the Ag ink used in Examples 1-4, to prepare an Ag ink containing 50 % by weight of Ag particles (silver particles having an average particle
- 10 diameter of 10 nm), 18.4 % by weight of polyvinyl chloride copolymer latex, 2.0 % by weight of

polyurethane thickener and 2.5 % by weight of propylene glycol.

By the same method as that in Examples 1-4 except that the Ag ink thus prepared was used to be printed
5 once (Comparative Example 1), twice (Example 5), three times (Example 6) and four times (Example 7), respectively, a conductive film was obtained, and then, an IC chip-mounted dipole antenna and a bending test sample were produced. Then, by the same method
10 as that in Examples 1-4, the thickness, electrical resistance and surface resistivity of the conductive film were measured, and the volume resistivity of the conductive film and the percentage of Ag in the conductive film were calculated. Also, by the same
15 method as that in Examples 1-4, the communication range of the IC chip-mounted dipole antenna was measured, and the resistance deteriorated rate of the bending test sample was obtained.

As a result, the thickness of the conductive
20 film was 1.7 μm (Comparative Example 1), 2.5 μm (Example 5), 3.4 μm (Example 6) and 4.8 μm (Example 7), respectively. The electrical resistance of the conductive film was not able to be measured due to overload (OL) (Comparative Example 1), 5.0 Ω
25 (Example 5), 2.6 Ω (Example 6) and 1.5 Ω (Example 7), respectively. The surface resistivity of the conductive film was not able to be measured due to overload (OL) (Comparative Example 1), 0.43 $\Omega/\square$ (Example 5), 0.18 $\Omega/\square$ (Example 6) and 0.10 $\Omega/\square$
30 (Example 7), respectively. The volume resistivity of the conductive film was not able to be calculated due to overload (OL) (Comparative Example 1), 78.7

$\mu \Omega \cdot \text{cm}$ (Example 5), $53.5 \mu \Omega \cdot \text{cm}$ (Example 6) and $46.1 \mu \Omega \cdot \text{cm}$ (Example 7), respectively. The percentage of Ag in the conductive film was 8.5 % by volume (Comparative Example 1), 15.5 % by volume (Example 5), 17.5 % by volume (Example 6) and 18.8 % by volume (Example 7), respectively. The communication range at a frequency of 955 MHz was 0.0 m (Comparative Example 1), 3.7 m (Example 5), 3.7 m (Example 6) and 3.8 m (Example 7), respectively.

The resistance deteriorated rate was not able to be calculated due to overload (OL) in Comparative Example 1. In Examples 5-7, the resistance deteriorated rate was 100% after the sliding movement was repeated 10 times, 100 times and 500 times, respectively.

The conditions and results in Examples 5-7 and Comparative Example 1 are shown in Tables 1-3.

Examples 8-10, Comparative Example 2

First, after the Ag ink used in Examples 1-4 was centrifuged at 3000 rpm for 10 minutes, the supernatant liquid was removed to prepare an Ag ink wherein the concentration of Ag particles was adjusted to be 70 % by weight.

By the same method as that in Examples 1-4 except that the Ag ink thus prepared was used to be printed once (Example 8), twice (Example 9), three times (Example 10) and four times (Comparative Example 2), respectively, a conductive film was obtained, and then, an IC chip-mounted dipole antenna and a bending test sample were produced. Then, by the same method as that in Examples 1-4, the thickness, electrical resistance and surface resistivity of the conductive

film were measured, and the volume resistivity of the conductive film and the percentage of Ag in the conductive film were calculated. Also, by the same method as that in Examples 1-4, the communication
 5 range of the IC chip-mounted dipole antenna was measured, and the resistance deteriorated rate of the bending test sample was obtained.

As a result, the thickness of the conductive film was 1.7 μm (Example 8), 2.5 μm (Example 9),
 10 2.8 μm (Example 10) and 3.1 μm (Comparative Example 2), respectively. The electrical resistance of the conductive film was 3.1 Ω (Example 8), 1.1 Ω (Example 9), 0.6 Ω (Example 10) and 0.4 Ω (Comparative Example 2), respectively. The surface
 15 resistivity of the conductive film was 0.19 $\Omega/\square$ (Example 8), 0.06 $\Omega/\square$ (Example 9), 0.03 $\Omega/\square$ (Example 10) and 0.01 $\Omega/\square$ (Comparative Example 2), respectively. The volume resistivity of the conductive film was 32.8 $\mu\Omega \cdot \text{cm}$ (Example 8), 17.4
 20 $\mu\Omega \cdot \text{cm}$ (Example 9), 10.8 $\mu\Omega \cdot \text{cm}$ (Example 10) and 7.9 $\mu\Omega \cdot \text{cm}$ (Comparative Example 2), respectively. The percentage of Ag in the conductive film was 25.6 % by volume (Example 8), 32.7 % by volume (Example 9), 43.3 % by volume (Example 10) and 54.7 % by volume
 25 (Comparative Example 2), respectively. The communication range at a frequency of 955 MHz was 3.8 m (Example 8), 4.2 m (Example 9), 4.2 m (Example 10) and 4.4 m (Comparative Example 2), respectively. In Example 8, the resistance deteriorated rate was
 30 100% after the sliding movement was repeated 10 times, 100 times and 500 times, respectively. In Example 9, the resistance deteriorated rate was 100 % after

the sliding movement was repeated 10 times and 100 times, respectively, and 120 % after it was repeated 500 times. In Example 10, the resistance deteriorated rate was 100 % after the sliding movement was repeated 10 times, 110 % after it was repeated 100 times, and 150 % after it was repeated 500 times. In Comparative Example 2, the resistance deteriorated rate was 100 % after the sliding movement was repeated 10 times, 350 % after it was repeated 100 times, and 1200 % after it was repeated 500 times.

The conditions and results in Examples 8-10 and Comparative Example 2 are shown in Tables 1-3. Examples 11-13, Comparative Examples 3-4

By the same method as that in Examples 1-4 except that the Ag ink was printed at an anilox volume of 20 cc/m² (150 lines/inch) once (Example 11), twice (Example 12), three times (Example 13), four times (Comparative Example 3) and eight times (Comparative Example 4), respectively, a conductive film was obtained, and then, an IC chip-mounted dipole antenna and a bending test sample were produced. Then, by the same method as that in Examples 1-4, the thickness, electrical resistance and surface resistivity of the conductive film were measured, and the volume resistivity of the conductive film and the percentage of Ag in the conductive film were calculated. Also, by the same method as that in Examples 1-4, the communication range of the IC chip-mounted dipole antenna was measured, and the resistance deteriorated rate of the bending test sample was obtained.

As a result, the thickness of the conductive film was 2.2 μm (Example 11), 3.6 μm (Example 12), 5.6 μm (Example 13), 7.5 μm (Comparative Example 3) and 11.4 μm (Comparative Example 4), respectively.

5 The electrical resistance of the conductive film was 1.1 Ω (Example 11), 0.5 Ω (Example 12), 0.1 Ω (Example 13), 0.1 Ω (Comparative Example 3) and 0.1 Ω (Comparative Example 4), respectively. The surface resistivity of the conductive film was 0.06

10 $\Omega/\square$ (Example 11), 0.02 $\Omega/\square$ (Example 12), 0.01 $\Omega/\square$ (Example 13), 0.01 $\Omega/\square$ (Comparative Example 3) and 0.01 $\Omega/\square$ (Comparative Example 4), respectively. The volume resistivity of the conductive film was 15.4 $\mu\Omega \cdot \text{cm}$ (Example 11), 11.5 $\mu\Omega \cdot \text{cm}$ (Example 12),

15 3.6 $\mu\Omega \cdot \text{cm}$ (Example 13), 4.8 $\mu\Omega \cdot \text{cm}$ (Comparative Example 3) and 7.3 $\mu\Omega \cdot \text{cm}$ (Comparative Example 4), respectively. The percentage of Ag in the conductive film was 28.5 % by volume (Example 11), 38.5 % by volume (Example 12), 49.2 % by volume

20 (Example 13), 54.9 % by volume (Comparative Example 3) and 70.1 % by volume (Comparative Example 4), respectively. The communication range at a frequency of 955 MHz was 3.9 m (Example 11), 4.2 m (Example 12), 4.5 m (Example 13), 4.5 m (Comparative

25 Example 3) and 4.7 m (Comparative Example 4), respectively. In Example 11, the resistance deteriorated rate was 100% after the sliding movement was repeated 10 times, 100 times and 500 times, respectively. In Example 12, the resistance

30 deteriorated rate was 100 % after the sliding movement was repeated 10 times and 100 times, respectively, and 125 % after it was repeated 500

times. In Example 13, the resistance deteriorated rate was 100 % after the sliding movement was repeated 10 times, 150 % after it was repeated 100 times, and 180 % after it was repeated 500 times. In Comparative
5 Example 3, the resistance deteriorated rate was 200 % after the sliding movement was repeated 10 times, 400 % after it was repeated 100 times, and 1400 % after it was repeated 500 times. Furthermore, in Comparative Example 4, the resistance deteriorated
10 rate was not able to be obtained since the conductive film was broken before the sliding movement was repeated 10 times.

The conditions and results in Examples 11-13 and Comparative Examples 3-4 are shown in Tables 1-3.

15 Comparative Examples 5-8

First, polyvinyl chloride copolymer latex, polyurethane thickener and propylene glycol were added to the Ag ink used in Examples 1-4, to prepare an Ag ink containing 40 % by weight of Ag particles
20 (silver particles having an average particle diameter of 10 nm), 33.8 % by weight of polyvinyl chloride copolymer latex, 2.0 % by weight of polyurethane thickener and 2.5 % by weight of propylene glycol.

25 By the same method as that in Examples 1-4 except that the Ag ink thus prepared was used to be printed once (Comparative Example 5), twice (Comparative Example 6), three times (Comparative Example 7) and four times (Comparative Example 8), respectively,
30 a conductive film was obtained, and then, an IC chip-mounted dipole antenna and a bending test sample were produced. Then, by the same method as that in

Examples 1-4, the thickness, electrical resistance and surface resistivity of the conductive film were measured, and the volume resistivity of the conductive film and the percentage of Ag in the conductive film were calculated. Also, by the same method as that in Examples 1-4, the communication range of the IC chip-mounted dipole antenna was measured, and the resistance deteriorated rate of the bending test sample was obtained.

As a result, the thickness of the conductive film was 1.5 μm (Comparative Example 5), 2.4 μm (Comparative Example 6), 3.6 μm (Comparative Example 7) and 5.0 μm (Comparative Example 8), respectively. The electrical resistance of the conductive film was not able to be measured due to overload (OL) (Comparative Example 5), 280.0 Ω (Comparative Example 6), 75.0 Ω (Comparative Example 7) and 36.0 Ω (Comparative Example 8), respectively. The surface resistivity of the conductive film was not able to be measured due to overload (OL) (Comparative Example 5), 114.0 $\Omega/\square$ (Comparative Example 6), 35.5 $\Omega/\square$ (Comparative Example 7) and 7.4 $\Omega/\square$ (Comparative Example 8), respectively. The volume resistivity of the conductive film was not able to be calculated due to overload (OL) (Comparative Example 5), 4280 $\mu\Omega \cdot \text{cm}$ (Comparative Example 6), 1705 $\mu\Omega \cdot \text{cm}$ (Comparative Example 7) and 1140 $\mu\Omega \cdot \text{cm}$ (Comparative Example 8), respectively. The percentage of Ag in the conductive film was 5.7 % by volume (Comparative Example 5), 6.4 % by volume (Comparative Example 6), 5.9 % by volume (Comparative

Example 7) and 7.0 % by volume (Comparative Example 8), respectively. The communication range at a frequency of 955 MHz was 0.0 m (Comparative Example 5), 0.0 m (Comparative Example 6), 1.8 m (Comparative Example 7) and 2.1 m (Comparative Example 8), respectively. The resistance deteriorated rate was not able to be calculated due to overload (OL) in Comparative Example 5. In Comparative Examples 6-8, the resistance deteriorated rate was 100% after the sliding movement was repeated 10 times, 100 times and 500 times, respectively.

The conditions and results in Comparative Examples 5-8 are shown in Tables 1-3.

Comparative Examples 9-10

By the same method as that in Examples 1-4 except that there were used conductive films (having an Ag percentage of 100 % therein and a size of 100 mm x 100 mm) which were cut out of Ag foils (produced by Takeuchi Corporation) having a thickness of 1 μ m (Comparative Example 9) and 3 μ m (Comparative Example 10), respectively, in place of the conductive film obtained in Examples 1-4, an IC chip-mounted dipole antenna and a bending test sample were produced. Then, by the same method as that in Examples 1-4, the electrical resistance and surface resistivity of the conductive film were measured, and the volume resistivity of the conductive film was calculated. Also, by the same method as that in Examples 1-4, the communication range of the IC chip-mounted dipole antenna was measured, and the resistance deteriorated rate of the bending test sample was obtained.

As a result, the electrical resistance of the conductive film was 0.2Ω (Comparative Example 9) and 0.1Ω (Comparative Example 10), respectively. The surface resistivity of the conductive film was $0.01 \Omega/\square$ (Comparative Example 9) and $0.01 \Omega/\square$ (Comparative Example 10), respectively. The volume resistivity of the conductive film was $1.6 \mu\Omega \cdot \text{cm}$ (Comparative Example 9) and $1.9 \mu\Omega \cdot \text{cm}$ (Comparative Example 10), respectively. The communication range at a frequency of 955 MHz was 4.0 m (Comparative Example 9) and 4.4 m (Comparative Example 10), respectively. In Comparative Example 9, the resistance deteriorated rate was 100 % after the sliding movement was repeated 10 times, 200 % after it was repeated 100 times, and 800 % after it was repeated 500 times. In Comparative Example 10, the resistance deteriorated rate was 100 % after the sliding movement was repeated 10 times, 150 % after it was repeated 100 times, and 400 % after it was repeated 500 times.

The conditions and results in Comparative Examples 9-10 are shown in Tables 1-3.

Comparative Examples 11-13

By the same method as that in Examples 1-4 except that there were used conductive films (having an Al percentage of 100 % and a size of 100 mm x 100 mm) which were cut out of Al foils (produced by Takeuchi Corporation) having a thickness of $3 \mu\text{m}$ (Comparative Example 11), $6 \mu\text{m}$ (Comparative Example 12) and $12 \mu\text{m}$ (Comparative Example 13), respectively, in place of the conductive film obtained in Examples 1-4, an IC chip-mounted dipole antenna and a bending test

sample were produced. Then, by the same method as that in Examples 1-4, the electrical resistance and surface resistivity of the conductive film were measured, and the volume resistivity of the conductive film was calculated. Also, by the same method as that in Examples 1-4, the communication range of the IC chip-mounted dipole antenna was measured, and the resistance deteriorated rate of the bending test sample was obtained.

As a result, the electrical resistance of the conductive film was $0.2 \, \Omega$ (Comparative Example 11), $0.2 \, \Omega$ (Comparative Example 12) and $0.2 \, \Omega$ (Comparative Example 13), respectively. The surface resistivity of the conductive film was $0.01 \, \Omega / \square$ (Comparative Examples 11-13). The volume resistivity of the conductive film was $3.8 \, \mu \Omega \cdot \text{cm}$ (Comparative Example 11), $7.6 \, \mu \Omega \cdot \text{cm}$ (Comparative Example 12) and $15.3 \, \mu \Omega \cdot \text{cm}$ (Comparative Example 13), respectively. The communication range at a frequency of 955 MHz was 4.4 m (Comparative Example 11), 4.4 m (Comparative Example 12) and 4.4 m (Comparative Example 13), respectively. In Comparative Example 11, the resistance deteriorated rate was 167 % after the sliding movement was repeated 10 times, 100 % after it was repeated 100 times, and not able to be obtained due to the breaking of the conductive film after it was repeated 500 times. In Comparative Example 12, the resistance deteriorated rate was 100 % after the sliding movement was repeated 10 times, 100 % after it was repeated 100 times, and 1200 % after it was repeated 500 times. In Comparative Example 13, the

resistance deteriorated rate was 100 % after the sliding movement was repeated 10 times, 100 % after it was repeated 100 times, and 800 % after it was repeated 500 times.

5 The conditions and results in Comparative Examples 11-13 are shown in Tables 1-3.

 If a silver conductive film according to the present invention is used for forming an antenna for an RFID tag, such as an IC tag, which is incorporated
10 to produce an inlay (comprising an IC chip and an antenna), it is possible to produce an FEID tag, such as an IC tag, which has a practical communication range.

Claims

1. An antenna for an RFID tag which comprises the antenna and an IC chip connected directly thereto, the antenna being formed of a silver conductive film which contains 30-50 % by volume of a sintered body of silver particles and which has a thickness of 1.4-6 μm , a surface resistivity of 0.01-0.43 $\Omega/\square$ and a volume resistivity of 3-100 $\mu\Omega \cdot \text{cm}$.

2. A method for producing an antenna for RFID tag formed of a silver conductive film, the method comprising the steps of:

preparing a silver particle dispersing solution which contains 50-70 % by weight of silver particles;

applying the silver particle dispersing solution on a substrate; and

sintering the silver particle dispersing solution on the substrate to form a silver conductive film as set forth in claim 1.

3. A method for producing an antenna for RFID tag formed of a silver conductive film as set forth in claim 2, wherein said applying of said silver particle dispersing solution on the substrate is carried out by flexographic printing.

4. A method for producing an antenna for RFID tag formed of a silver conductive film as set forth in claim 3, wherein said applying of said silver particle dispersing solution on the substrate is carried out by repeating the flexographic printing a plurality of times.

5. A method for producing an antenna for RFID tag formed of a silver conductive film as set forth in claim 3, wherein said applying of said silver particle dispersing solution on the substrate is carried out by repeating the flexographic printing twice to four times.

6. A method for producing an antenna for RFID tag formed of a silver conductive film as set forth in any one of claims 2 through 5, wherein said silver particles have an average particle diameter of 20 nm or less.