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(54) **ELECTRODE MANUFACTURING APPARATUS**

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(57) **ABSTRACT**

An electrode manufacturing apparatus includes a shaping roll and an opposed roll that sandwich an electrode therebetween and rotate in opposite directions, and a temperature adjusting unit. The temperature adjusting unit reduces a temperature difference between a central portion and an end portion in an axial direction, of at least one roll of the shaping roll and the opposed roll.

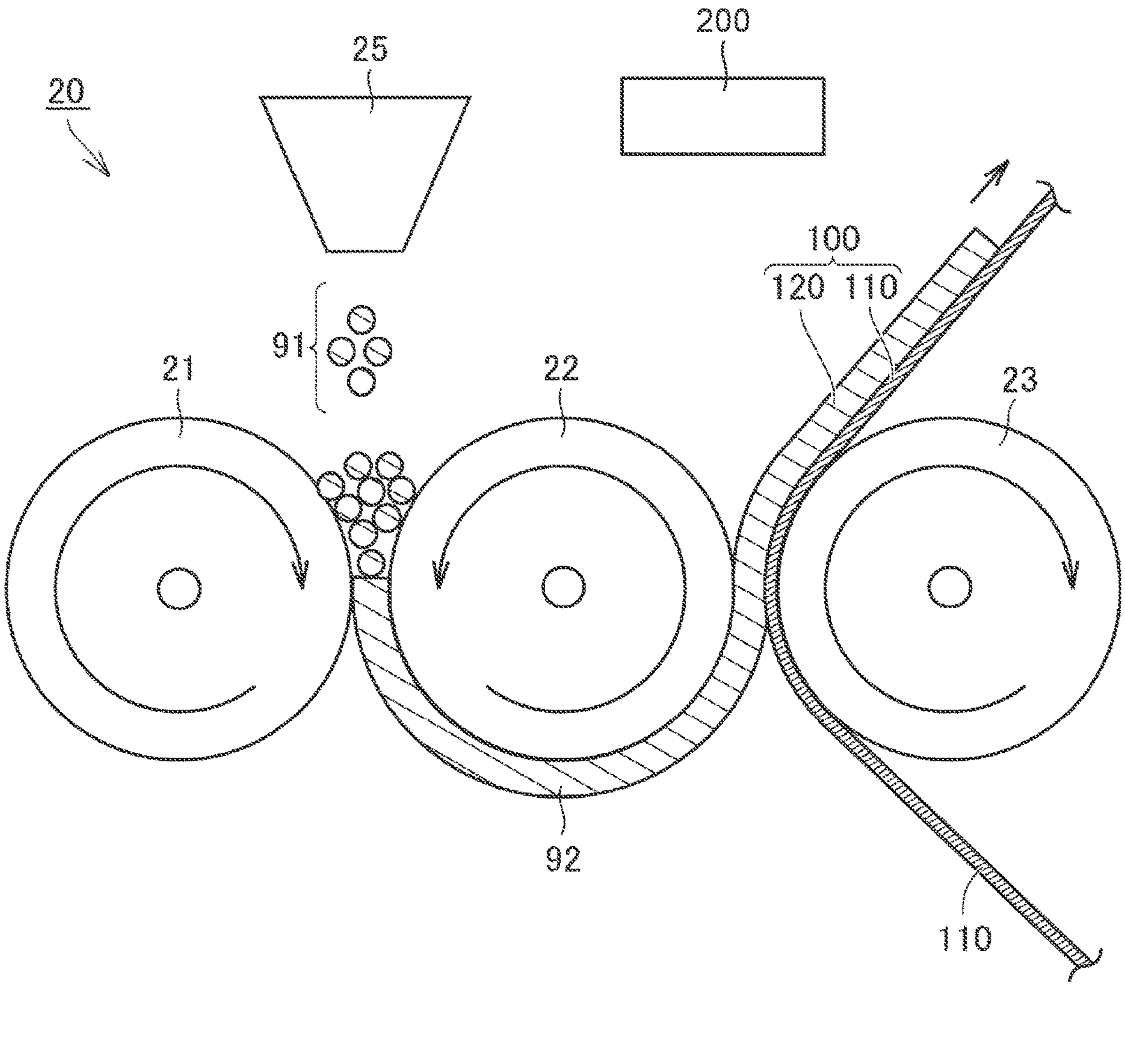


FIG. 1

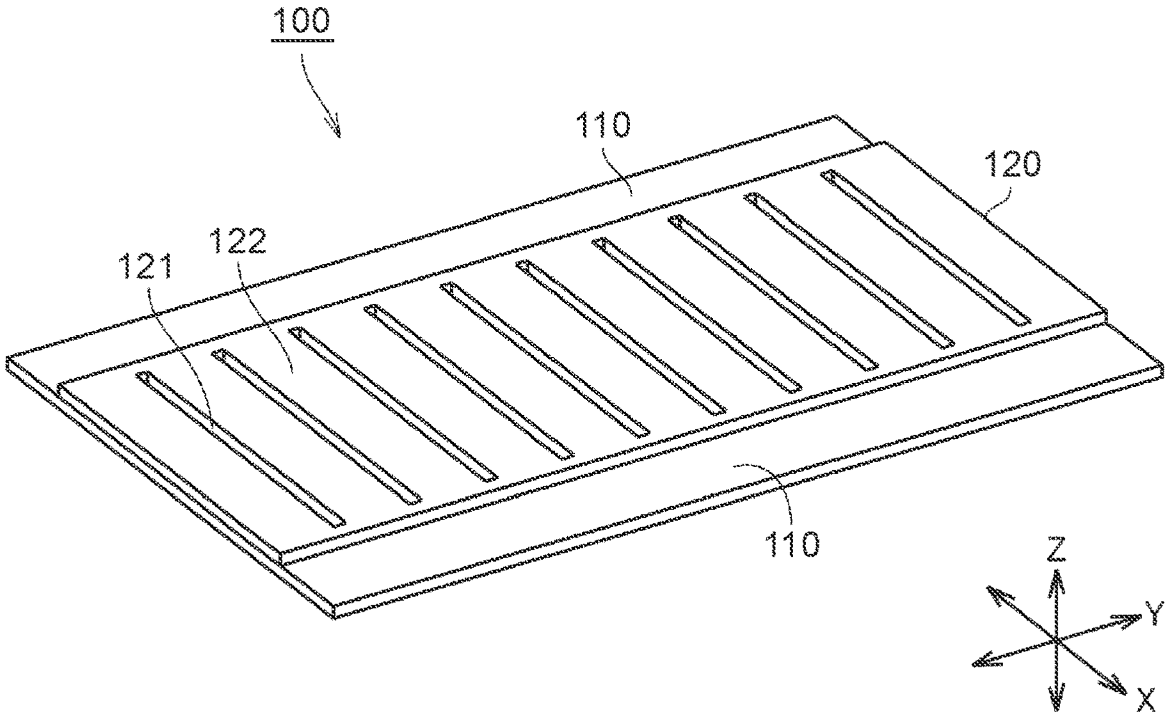


FIG. 2

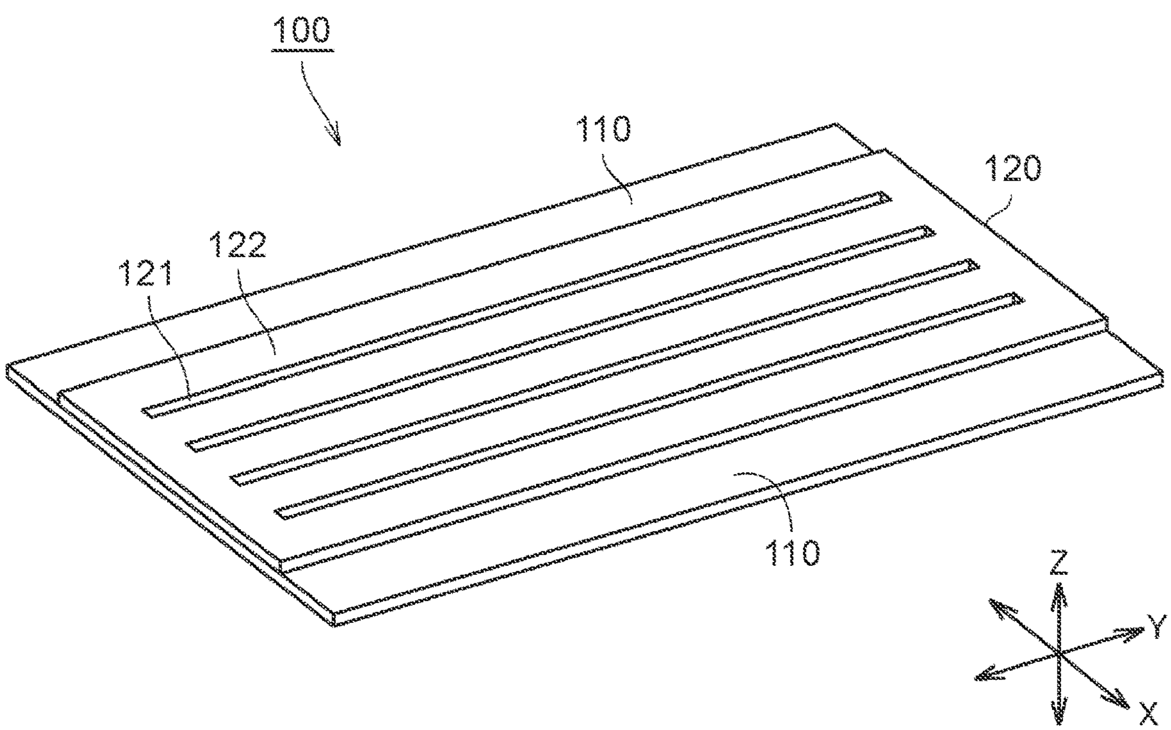
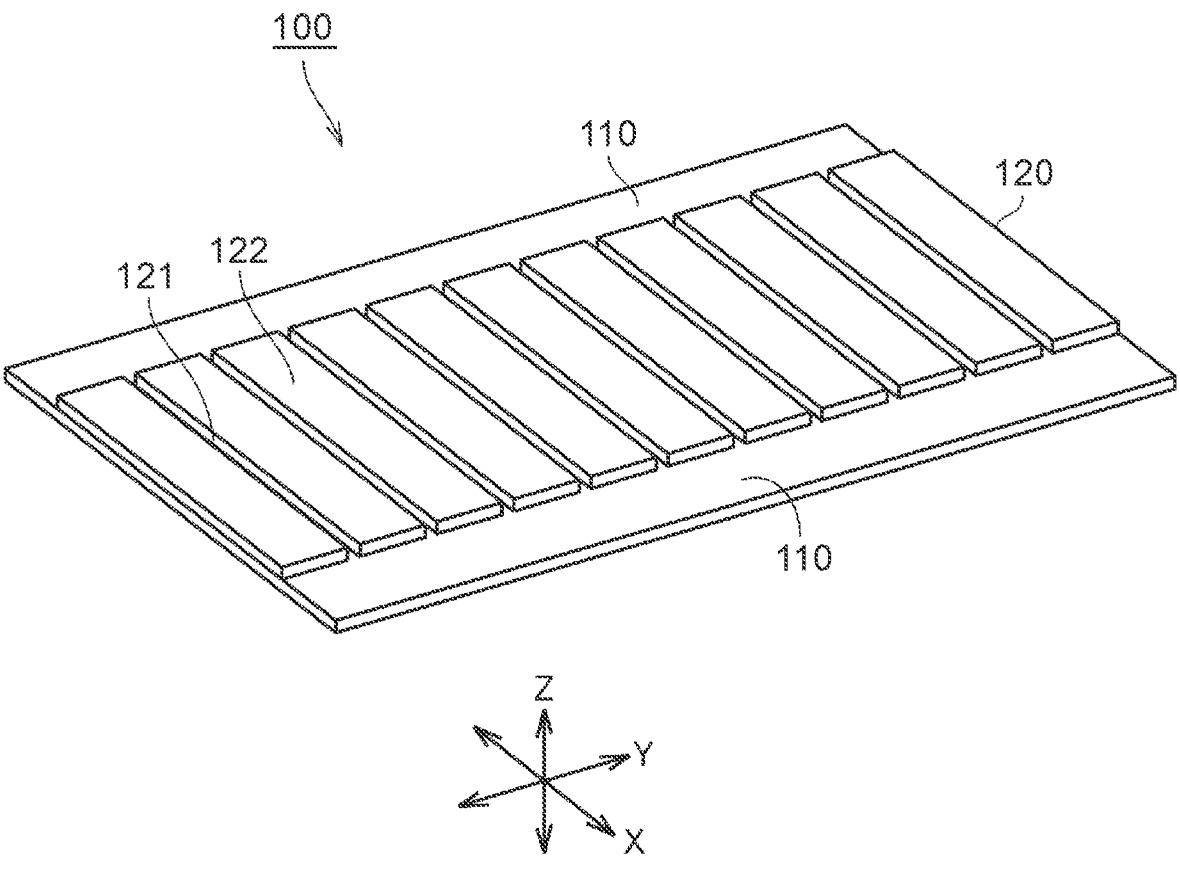


FIG. 3



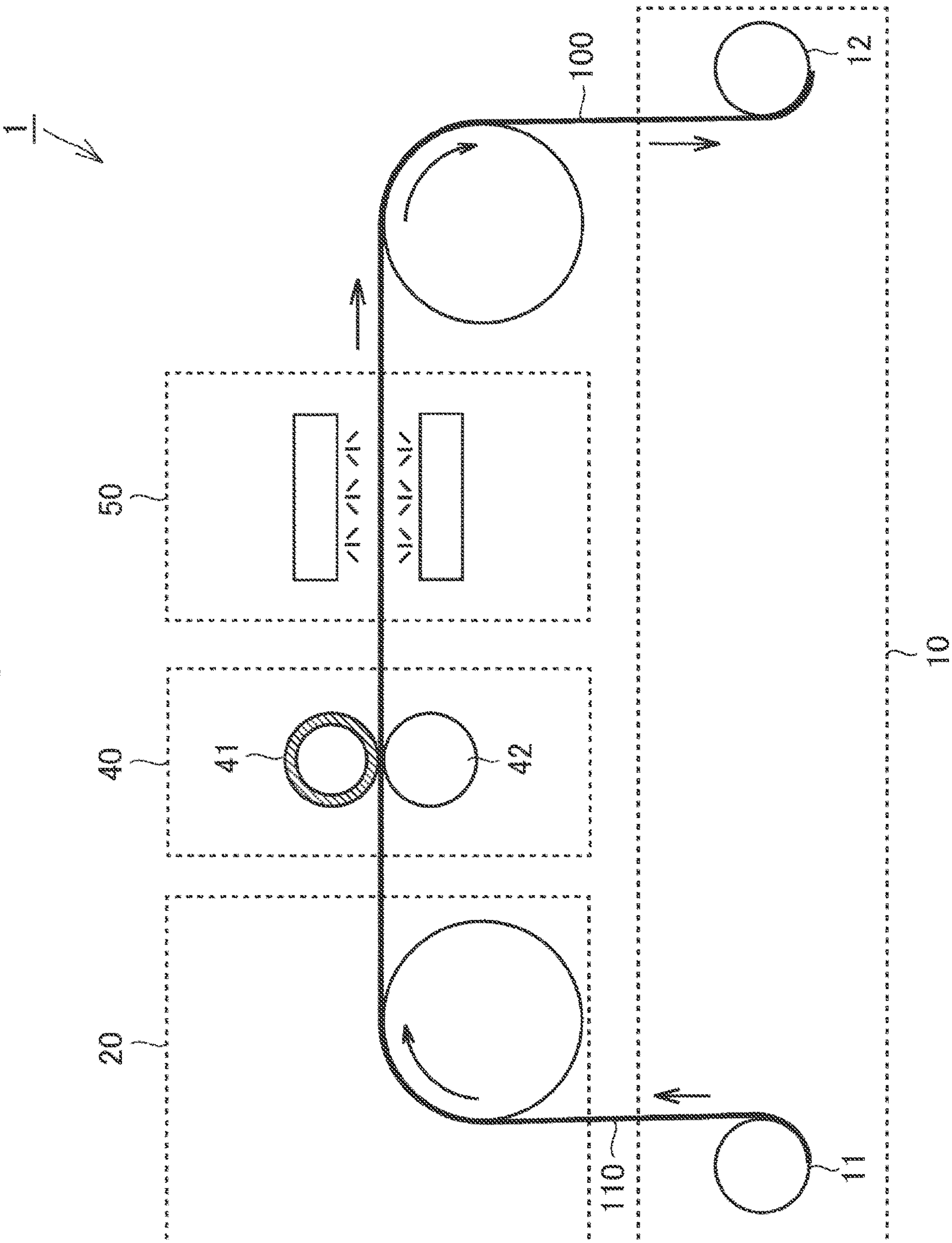


FIG. 4

FIG. 5

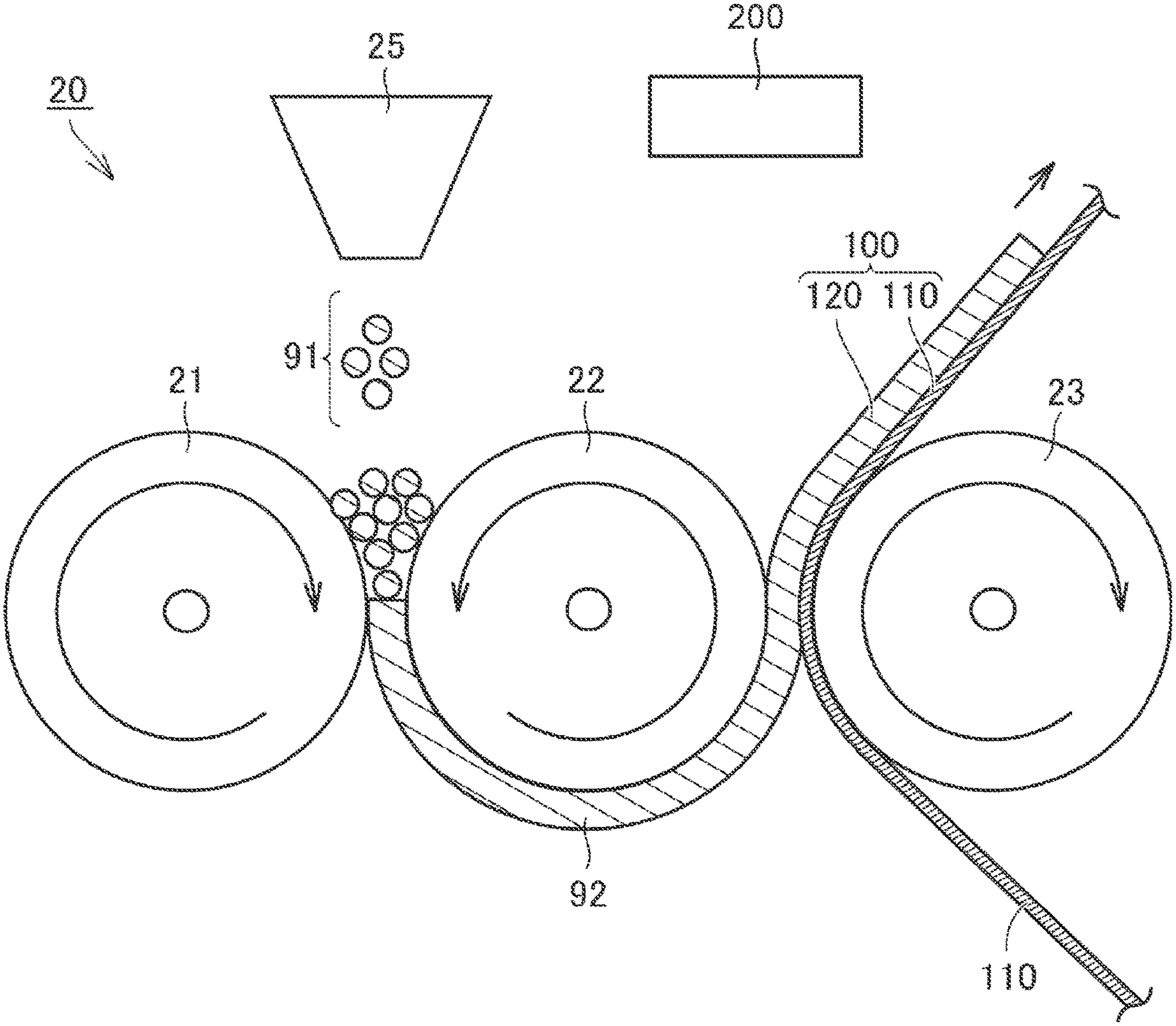


FIG. 6

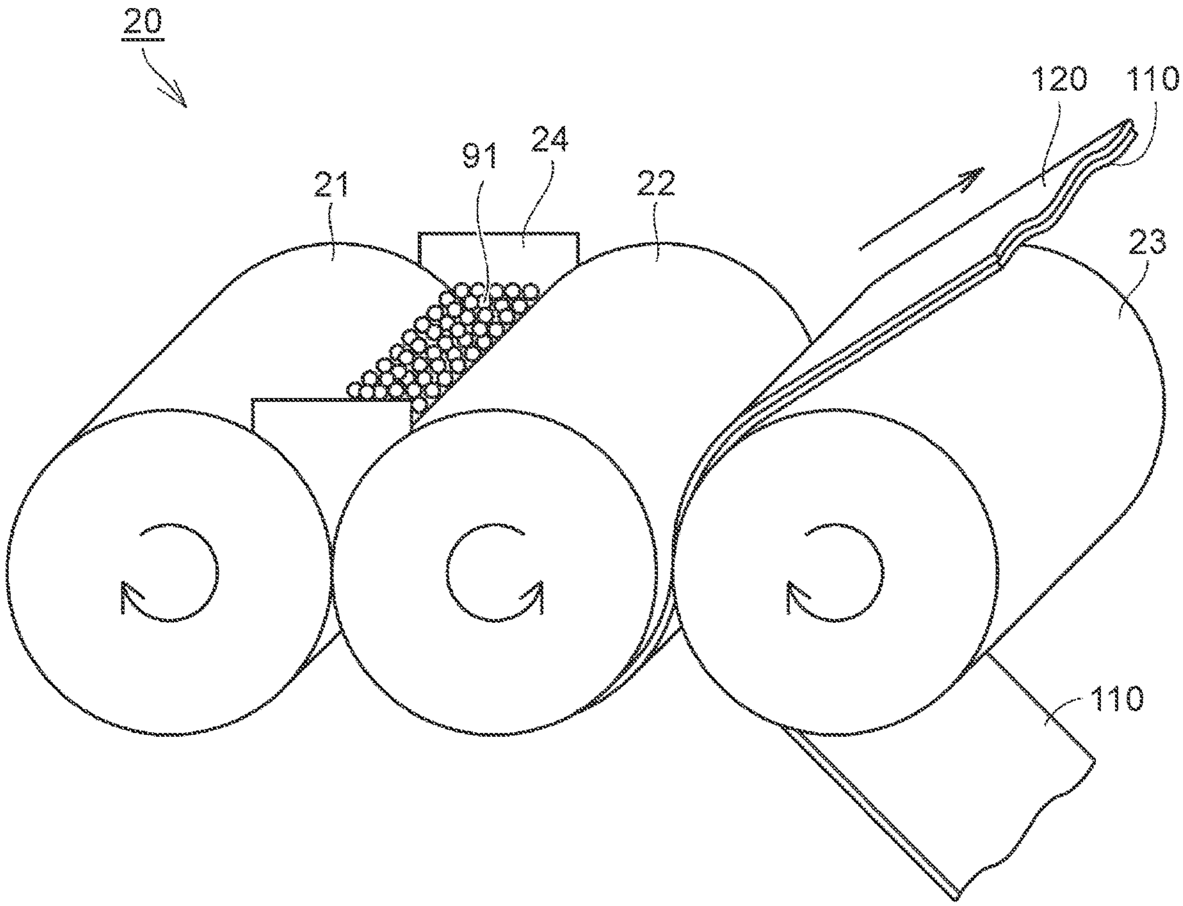

20
21
91
24
22
120
110
23
110

FIG. 7

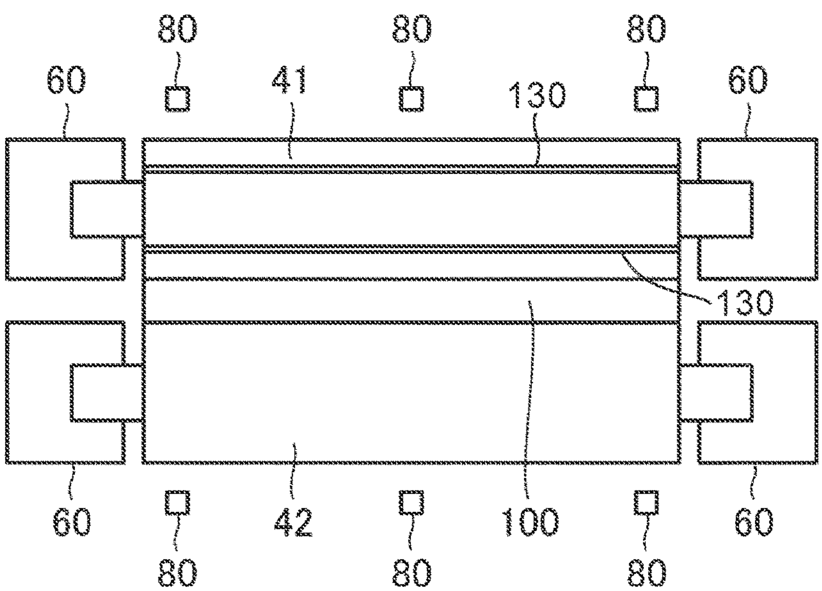

80
80
80
60
41
130
60
130
100
60
42
60
80
80
80

FIG. 8

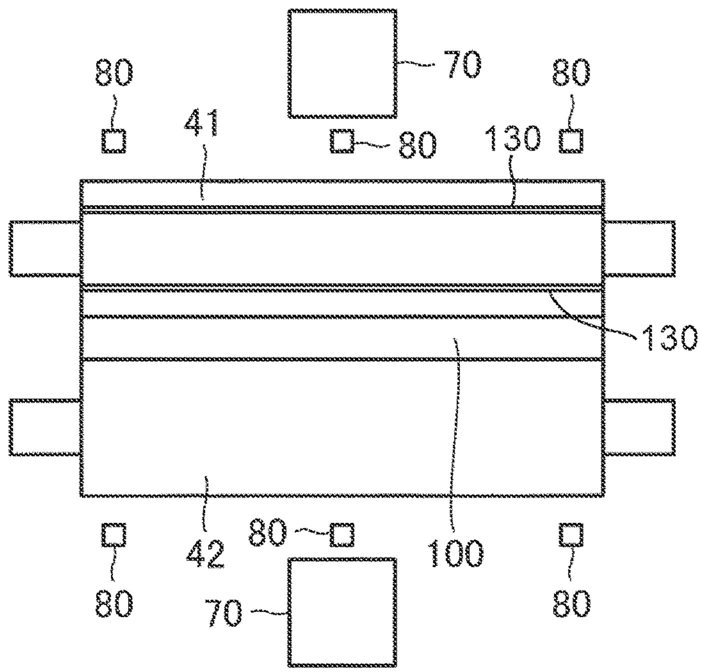

70
80
80
41
80
130
80
130
100
42
80
80
80
70
80

FIG. 9

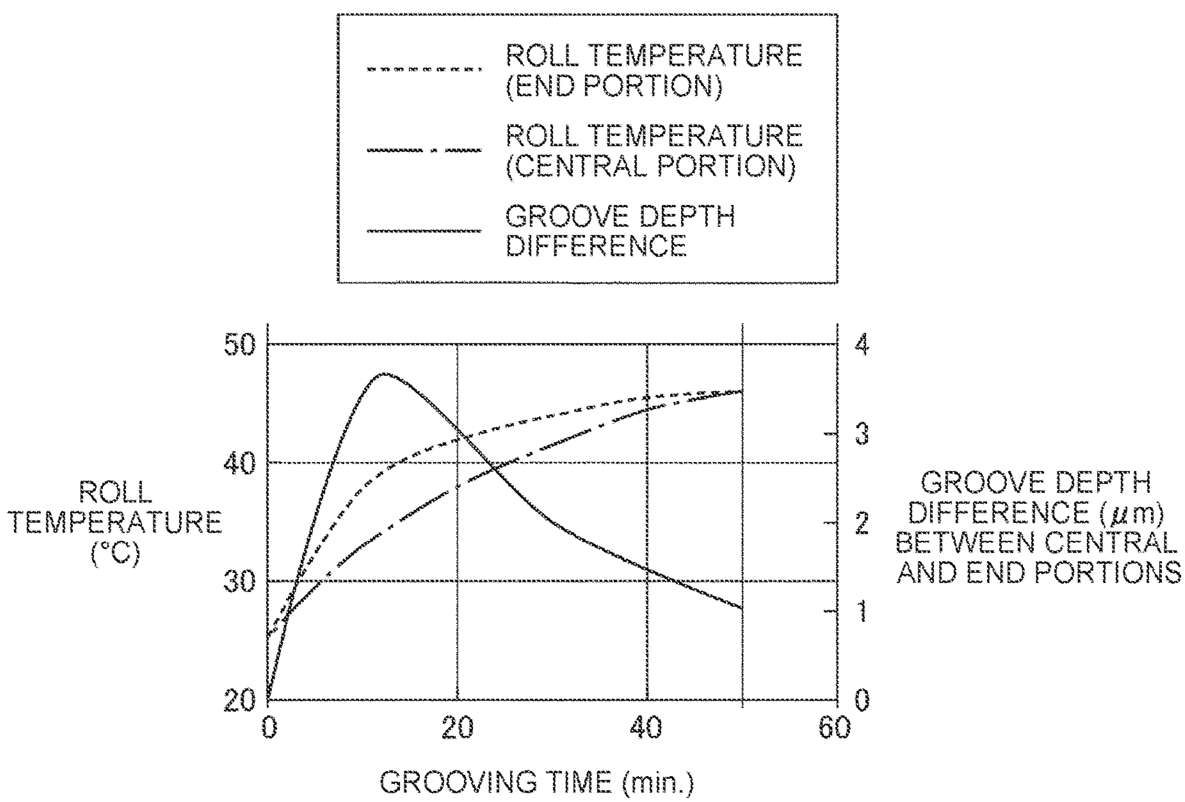
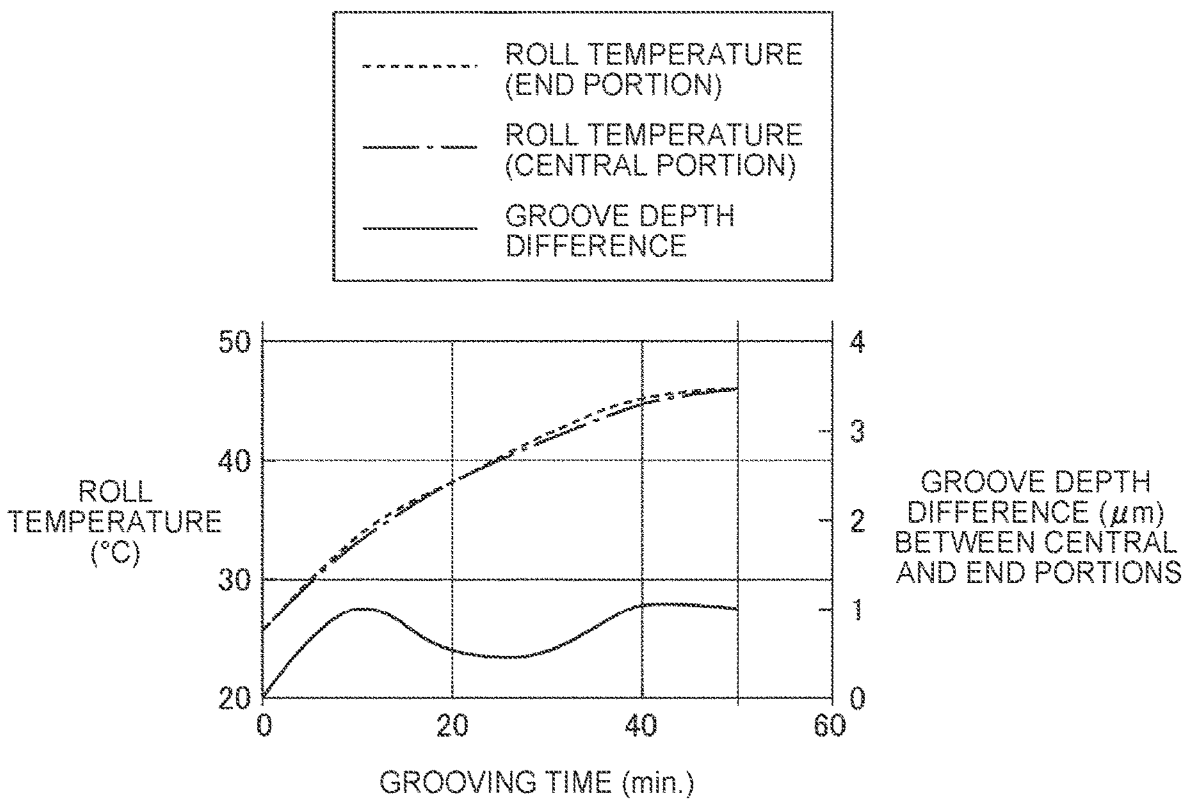

ROLL TEMPERATURE (END PORTION)
ROLL TEMPERATURE (CENTRAL PORTION)
GROOVE DEPTH DIFFERENCE
50
40
30
20
ROLL TEMPERATURE (°C)
4
3
2
1
0
GROOVE DEPTH DIFFERENCE (μm) BETWEEN CENTRAL AND END PORTIONS
0
20
40
60
GROOVING TIME (min.)

FIG. 10


ROLL TEMPERATURE (END PORTION)
ROLL TEMPERATURE (CENTRAL PORTION)
GROOVE DEPTH DIFFERENCE
ROLL TEMPERATURE (°C)
50
40
30
20
GROOVE DEPTH DIFFERENCE (μm) BETWEEN CENTRAL AND END PORTIONS
4
3
2
1
0
0
20
40
60
GROOVING TIME (min.)

ELECTRODE MANUFACTURING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to Japanese Patent Application No. 2021-185891 filed on Nov. 15, 2021, incorporated herein by reference in its entirety.

BACKGROUND

1. Technical Field

[0002] The disclosure relates to an electrode manufacturing apparatus.

2. Description of Related Art

[0003] Japanese Unexamined Patent Application Publication No. 2002-015764 (JP 2002-015764 A) describes a battery including positive and negative electrodes each having electrode active material layers on opposite surfaces of a current collector plate, in which grooves are formed in the electrode active material layers of either the positive or negative electrode.

SUMMARY

[0004] When large-area batteries are manufactured by an apparatus described in JP 2002-015764 A, it is difficult to maintain the uniformity of the groove depth in the width direction.

[0005] The disclosure proposes an electrode manufacturing apparatus capable of maintaining the uniformity of the groove depth of an electrode.

[0006] According to the disclosure, an electrode manufacturing apparatus including a pair of rolls that sandwich an electrode and rotate in opposite directions, and a temperature adjusting unit, is proposed. The temperature adjusting unit is configured to reduce a temperature difference between a central portion and an end portion in an axial direction, of at least one roll of the pair of rolls.

[0007] With the temperature adjusting unit thus configured to reduce the temperature difference between the central portion and the end portion of the roll, the uniformity of the thermal expansion between the central portion and the end portion of the roll can be improved, and the uniformity of the outside diameter of the roll between the central portion and the end portion of the roll can be improved. Accordingly, the uniformity of the groove depth of the electrode in the width direction can be maintained.

[0008] In the above electrode manufacturing apparatus, the electrode may have a substrate and an electrode layer formed on a surface of the substrate, and the pair of rolls may have a shaping roll configured to form an uneven shape on a surface of the electrode layer, and an opposed roll that is opposed to the shaping roll such that the electrode is sandwiched between the shaping roll and the opposed roll. By adjusting the temperature of at least one roll of the shaping roll and the opposed roll, the uniformity of the groove depth of the electrode in the width direction can be maintained.

[0009] In the above electrode manufacturing apparatus, the shaping roll may be configured to form recesses in a form of grooves extending in a width direction of the electrode, in the surface of the electrode layer. The recesses extending in the width direction of the electrode give flexibility to the electrode, so that cracking of the electrode layer during conveyance of the electrode can be curbed.

[0010] In the above electrode manufacturing apparatus, the shaping roll may be configured to form the recesses extending over an entire length of the electrode layer in the width direction. The recesses communicate with the opposite edges of the electrode layer in the width direction, and liquid can flow in the recesses, so that the penetration time in the subsequent electrolyte injection process can be reduced.

[0011] In the above electrode manufacturing apparatus, the temperature adjusting unit may be configured to adjust a temperature of the opposed roll. By adjusting the temperature of the opposed roll, it is possible to efficiently maintain the uniformity of the groove depth of the electrode in the width direction.

[0012] In the above electrode manufacturing apparatus, the temperature adjusting unit may have a cooling device that cools the end portion. With this arrangement, the temperature difference between the central portion and the end portion of the roll can be reliably reduced.

[0013] In the above electrode manufacturing apparatus, the temperature adjusting unit may have a heating device that heats the central portion. With this arrangement, the temperature difference between the central portion and the end portion of the roll can be reliably reduced.

[0014] The above electrode manufacturing apparatus may further include temperature sensors that detect a temperature of the central portion and the temperature of the end portion. The temperature adjusting unit can efficiently reduce the temperature difference between the central portion and the end portion of the roll, based on the temperature difference between the central portion and the end portion of the roll.

[0015] According to the electrode manufacturing apparatus of the disclosure, even when large-area batteries are manufactured, the uniformity of the groove depth of the electrode can be maintained.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Features, advantages, and technical and industrial significance of exemplary embodiments of the disclosure will be described below with reference to the accompanying drawings, in which like signs denote like elements, and wherein:

[0017] FIG. **1** is a perspective view schematically showing the configuration of a first example of an electrode in an embodiment;

[0018] FIG. **2** is a perspective view schematically showing the configuration of a second example of the electrode in the embodiment;

[0019] FIG. **3** is a perspective view schematically showing the configuration of a third example of the electrode in the embodiment;

[0020] FIG. **4** is a conceptual diagram showing an electrode manufacturing apparatus according to the embodiment;

[0021] FIG. **5** is a conceptual diagram showing details of the configuration of a film forming device;

[0022] FIG. **6** is a conceptual, perspective view showing details of the configuration of the film forming device;

[0023] FIG. **7** is a schematic view showing a first example of a temperature adjusting unit;

[0024] FIG. **8** is a schematic view showing a second example of the temperature adjusting unit;

[0025] FIG. **9** is a graph showing the temperature difference and the groove depth difference between a central portion and end portions of a roll in a comparative example; and

[0026] FIG. **10** is a graph showing the temperature difference and the groove depth difference between a central portion and end portions of a roll in an example.

DETAILED DESCRIPTION OF EMBODIMENTS

[0027] One embodiment will be described based on the drawings. In the following description, the same reference signs are assigned to the same components. The names and functions of these components are identical. Thus, detailed description of the components will not be repeated.

Electrode **100**

[0028] FIG. **1** is a perspective view schematically showing the configuration of a first example of an electrode **100** in the embodiment. The electrode **100** is used, for example, as an electrode of a lithium-ion secondary battery (non-aqueous electrolyte secondary battery). The lithium-ion secondary battery can be used, for example, as a power supply of a hybrid electric vehicle (HEV), battery electric vehicle (BEV), plug-in hybrid electric vehicle (PHEV), or the like. However, the electrode **100** of this disclosure is not limited to such automotive applications, but can be applied to any use.

[0029] As shown in FIG. **1**, the electrode **100** has a substrate **110** and an electrode layer **120**. The substrate **110** is a support for the electrode layer **120**. The substrate **110** may be in the form of a sheet, for example. The substrate **110** may be in the form of a strip, for example. The substrate **110** may have electrical conductivity. The substrate **110** may function as a current collector. The substrate **110** may include, for example, a metal foil. When the electrode **100** is a positive electrode, the substrate **110** may include, for example, an aluminum foil. When the electrode **100** is a negative electrode, the substrate **110** may include, for example, a copper foil.

[0030] The electrode layer **120** is formed on a surface of the substrate **110**. The electrode layer **120** may be formed on only one surface of the substrate **110** as shown in FIG. **1**, or may be formed on both the front and back surfaces of the substrate **110**.

[0031] The electrode layer **120** is an electrode active material layer containing electrode active material. The electrode active material may be a positive-electrode active material or a negative-electrode active material. The positive-electrode active material may be selected from, for example, lithium-containing metal oxides, lithium-containing phosphates, etc. The negative-electrode active material may be selected from, for example, carbon-based negative-electrode active materials such as graphite, easily graphitizable carbon, and non-graphitizable carbon, and alloy-based negative-electrode active materials containing silicon, tin, etc.

[0032] Recesses **121** (grooves) are formed in the electrode layer **120**. At least one recess **121** is formed in the electrode layer **120**. The recess **121** has any cross-sectional shape. The bottom of the recess **121** may be flat, curved, or inclined. The recess **121** may be U-shaped or V-shaped in cross-section. Raised portions **122** are formed between adjacent ones of the recesses **121**.

[0033] The electrode **100** has a long-side or longitudinal direction (Y-direction) and a short-side direction (X-direction). The longitudinal direction corresponds to the conveying direction in the manufacturing process of the electrode **100**. The short-side direction is perpendicular to the longitudinal direction, and may also be referred to as the "width direction" of the electrode **100**. The electrode **100** also has a thickness direction (Z-direction). The thickness direction is perpendicular to the XY plane. The recess **121** is formed such that a part of the electrode layer **120** is recessed from the surface of the electrode layer **120**, to extend in the Z-direction.

[0034] In the example shown in FIG. **1**, the recesses **121** and the raised portions **122** extend in the short-side direction. The recesses **121** are formed at equal intervals in the longitudinal direction. The groove-like recesses **121** extending in the short-side direction of the electrode **100** are formed in the electrode layer **120**, to give flexibility to the electrode **100**. Thus, cracking of the electrode layer **120** during conveyance of the electrode **100** is curbed, and the conveyability of the electrode **100** is improved.

[0035] FIG. **2** is a perspective view schematically showing the configuration of a second example of the electrode **100** in the embodiment. In the example shown in FIG. **2**, the recesses **121** and the raised portions **122** extend in the longitudinal direction. The recesses **121** are formed at equal intervals in the width direction. The recesses **121** extending in the longitudinal direction of the electrode **100** are formed in the electrode layer **120**, to reduce the difference in the amount of shrinkage between the substrate **110** and the electrode layer **120** during drying. Thus, warpage of the electrode **100** after drying is curbed.

[0036] FIG. **3** is a perspective view schematically showing the configuration of a third example of the electrode **100** in the embodiment. In the example shown in FIG. **3**, the recesses **121** extend in the width direction of the electrode **100** as in the example of FIG. **1**, and extend over the entire length of the electrode layer **120** in the width direction. The recesses **121** extending continuously from one edge to the other edge of the electrode layer **120** in the width direction are formed, so as to give flexibility to the electrode **100**, and reduce the penetration time in the subsequent electrolyte injection process because the recesses **121** communicate with the opposite edges of the electrode layer **120** in the width direction, thus allowing liquid to flow in the recesses **121**.

[0037] The electrode **100** may have both the recesses **121** and raised portions **122** extending in the longitudinal direction as shown in FIG. **2**, and the recesses **121** and raised portions **122** extending in the short-side direction as shown in FIG. **1** and FIG. **3**. The shape of each of the recesses **121** is not limited to the straight line shown in FIG. **1** to FIG. **3**, but may be curved, wavy, or dotted. The planar pattern of the recesses **121** may be a set of numerous parallel lines or a grid.

Electrode Manufacturing Apparatus **1**

[0038] FIG. **4** is a conceptual diagram showing the electrode manufacturing apparatus **1** according to the embodiment. As shown in FIG. **4**, the electrode manufacturing apparatus **1** includes a conveyor device **10**, film forming device **20**, shaping device **40**, and drying device **50**.

[0039] The conveyor device **10** has a feed roll **11** and a take-up roll **12**. The feed roll **11** is formed such that the substrate **110** is wound around its core material. The substrate **110** is rolled out from the feed roll **11**. The take-up roll **12** takes up the substrate **110** (electrode **100**). The conveyor device **10** conveys the substrate **110** such that it passes through the film forming device **20**, shaping device **40**, and drying device **50** in this order, and conveys the electrode **100** as a laminate formed by laminating the electrode layer **120** on the substrate **110**.

[0040] The film forming device **20** forms the electrode layer **120** on the surface of the substrate **110**. Details of the film forming device **20** will be described later.

[0041] The shaping device **40** forms an uneven shape on the surface of the electrode layer **120**. The shaping device **40** forms the recesses **121** and the raised portions **122** in the electrode layer **120**. The shaping device **40** has a shaping roll **41** and an opposed roll **42**, for example. The shaping roll **41** and the opposed roll **42** constitute a pair of rolls that rotate in opposite directions while sandwiching the electrode **100** therebetween. The shaping roll **41** forms the uneven shape on the surface of the electrode layer **120**. The opposed roll **42** is opposed to the shaping roll **41** with the electrode **100** sandwiched therebetween.

[0042] One or more protrusion molds are formed on the outer circumferential surface of the shaping roll **41**. For example, in order to form the recesses **121** extending in the width direction of the electrode **100** over the entire length of the electrode layer **120** as shown in FIG. **3**, protrusion molds **130** extending straight in the width direction of the shaping roll **41** are formed on the outer circumferential surface of the shaping roll **41**, as shown in FIG. **7** and FIG. **8**. Similarly, in order to form the groove-like recesses **121** extending in the short-side direction of the electrode **100** as shown in FIG. **1**, protrusion molds (not shown) extending in the width direction and having the same width as the recesses **121** are formed on the outer circumferential surface of the shaping roll **41**. The shaping device **40** forms the recesses **121** and the raised portions **122** in the surface of the electrode layer **120**, by sandwiching the electrode **100** carried by the conveyor device **10** in the longitudinal direction (Y-direction) between the shaping roll **41** and the opposed roll **42**, and pressing the protrusion molds of the shaping roll **41** against the surface of the electrode layer **120** at this time. The shaping device **40** is located on the upstream side of the drying device **50** in the conveying direction of the electrode **100**, and is arranged to process the surface of the electrode layer **120** that is in a wet state before drying. This makes it easy to form the uneven shape.

[0043] When the recesses and raised portions extending in the longitudinal direction of the electrode **100** and the recesses and raised portions extending in the short-side direction are both formed in the electrode layer **120**, the shaping device **40** may have one shaping roll that forms both the recesses and raised portions extending in the longitudinal direction and the recesses and raised portions extending in the short-hand direction.

[0044] Alternatively, the shaping device **40** may have a shaping roll that forms the recesses and raised portions extending in the longitudinal direction of the electrode **100**, and a shaping roll that forms the recesses and raised portions extending in the short-hand direction of the electrode **100**, respectively.

[0045] The drying device **50** dries the electrode layer **120** after the recesses and raised portions are formed. The drying device **50** can dry the electrode layer **120** by any given method. For example, the drying device **50** may include a hot air dryer, an infrared dryer, etc. Drying conditions (drying temperature, drying time, etc.) in the drying device **50** are adjusted so that the electrode layer **120** is brought into a dry state.

[0046] After the electrode layer **120** is dried, the electrode **100** is cut to a predetermined size using, for example, a slitter, to produce a sheet-like electrode **100** as shown in FIG. **1** to FIG. **3**.

Film Forming Device **20**

[0047] In the film forming device **20**, the electrode material is supplied between a pair of rolls that are arranged in parallel with each other with a spacing therebetween and are respectively driven to be rotated, and the electrode material is compressed and formed by the pair of rolls to form a sheet-like coating film.

[0048] FIG. **5** is a conceptual diagram showing details of the configuration of the film forming device **20**. FIG. **6** is a conceptual perspective view showing details of the configuration of the film forming device **20**. As shown in FIG. **5** and FIG. **6**, the film forming device **20** has a first roll **21**, second roll **22**, and third roll **23**. The first roll **21**, second roll **22**, and third roll **23** have a generally cylindrical shape having substantially the same diameter.

[0049] The first roll **21**, second roll **22**, and third roll **23** are respectively driven to be rotated. In FIG. **5** and FIG. **6**, a curved arrow depicted in each roll indicates the rotational direction of the roll. The second roll **22** rotates in the opposite direction of the first roll **21**. The third roll **23** rotates in the opposite direction of the second roll **22**. In FIG. **5** and FIG. **6**, the first roll **21** rotates in the clockwise direction, the second roll **22** rotates in the counterclockwise direction, and the third roll **23** rotates in the clockwise direction.

[0050] The second roll **22** is spaced apart from and arranged in parallel with the first roll **21**. The outer circumferential surfaces of the first roll **21** and the second roll **22** are opposed to each other via a first gap, which is a gap between the first roll **21** and the second roll **22**. The axes of the first roll **21** and the second roll **22** are fixed so that the distance between these rolls is kept constant.

[0051] The third roll **23** is spaced apart from and arranged in parallel with the second roll **22**. The outer circumferential surfaces of the second roll **22** and the third roll **23** are opposed to each other via a second gap, which is a gap between the second roll **22** and the third roll **23**. The axis of the third roll **23** is fixed so that the distance between the third roll **23** and the second roll **22** is kept constant.

[0052] A feeder **25** is located right above the first gap between a pair of rolls, specifically, between the first roll **21** and the second roll **22**. The feeder **25** supplies electrode material **91** to the first gap between the first roll **21** and the second roll **22**. The electrode material **91** is, for example, powder.

[0053] As shown in FIG. **6**, the film forming device **20** further has a pair of partition walls **24**. The partition walls **24** are arranged in parallel with each other, with a given spacing in the axial direction of each roll. The partition walls **24** put a limit to the width dimension of the electrode material **91** supplied to the gap between the first roll **21** and the second roll **22**.

[0054] As the first roll **21** and the second roll **22** rotate, the electrode material **91** passes through the first gap between the first roll **21** and the second roll **22**, and is drawn downward of the first gap. The electrode material **91** is consolidated (compressed) and formed into a sheet as it passes through the first gap between the first roll **21** and the second roll **22**. In this manner, a thin coating film **92** is formed from the electrode material **91**. By changing the dimensions of the first gap between the first roll **21** and the second roll **22**, it is possible to adjust the thickness of the coating film **92** and the mass per unit area of the coating film **92**.

[0055] After passing through the first gap between the first roll **21** and the second roll **22**, the coating film **92** is conveyed while adhering to the second roll **22**, and fed to the second gap between the second roll **22** and the third roll **23**.

[0056] The substrate **110** is conveyed to the third roll **23** after it is rolled out from the feed roll **11** (FIG. **4**). The substrate **110** is conveyed on the third roll **23**, and fed to the second gap between the second roll **22** and the third roll **23**.

[0057] The coating film **92** and the substrate **110** are supplied between the second roll **22** and the third roll **23**. In the second gap, the coating film **92** is pressed against the substrate **110**, and the coating film **92** is pressed onto the surface of the substrate **110**, away from the second roll **22**. Namely, the coating film **92** is transferred from the second roll **22** to the substrate **110**. In this manner, the electrode **100** is formed in which the sheet-like electrode layer **120** is laminated at a predetermined position on the surface of the substrate **110**. The second roll **22** and the third roll **23** constitute a pair of rolls that rotate in opposite directions while sandwiching the electrode **100** therebetween.

[0058] Since the film forming device **20** has the pair of partition walls **24**, which put a limit to the width dimension of the electrode layer **120**, the electrode **100** is provided with exposed portions (see FIG. **1** to FIG. **3**) on which the electrode layer **120** is not formed, on the opposite sides of the electrode layer **120** in the width direction (X-direction) of the electrode **100**. The recesses **121** shown in FIG. **3** communicate with the exposed portions on the opposite sides of the electrode layer **120**.

[0059] In the example shown in FIG. **5** and FIG. **6**, the first roll **21**, second roll **22**, and third roll **23** are arranged side by side, and the rotation axes of the first roll **21**, second roll **22**, and third roll **23** are on the same plane. The first roll **21**, second roll **22**, and third roll **23** are not limited to those of the example shown in FIG. **5** and FIG. **6**, but may be located as desired. For example, the third roll **23** may be located right below the second roll **22** with a spacing between the third roll **23** and the second roll **22**.

Temperature Adjusting Unit

[0060] The electrode manufacturing apparatus **1** of the embodiment further has a temperature adjusting unit. The temperature adjusting unit has the function of reducing a temperature difference between a central portion and an end portion in the axial direction, of at least one roll of the pair of rolls (i.e., the shaping roll **41** and the opposed roll **42**) that rotate in opposite directions while sandwiching the electrode **100** therebetween in the shaping device **40**.

[0061] FIG. **7** is a schematic view showing a first example of the temperature adjusting unit. The temperature adjusting unit shown in FIG. **7** adjusts the temperature of the shaping roll **41**, and adjusts the temperature of the opposed roll **42**. More specifically, the temperature adjusting unit has cooling devices **60**. The cooling devices **60** cool the opposite end portions of the shaping roll **41**. The cooling devices **60** cool the opposite end portions of the opposed roll **42**.

[0062] The cooling device **60** is realized, for example, by a flow channel of cooling medium formed in a housing that supports the end portions of the rolls. The cooling medium is, for example, water. The housing rotatably supports the end portions of the rolls via bearings. The flow channels of the cooling medium are formed around the bearings, and the cooling medium circulates in the flow channels. The cooling medium of which the temperature was increased by heat transferred from the end portion of the roll is cooled at a position away from the end portion of the roll, and returns to the end portion of the roll. The cooling device **60** is not limited to this example, but may cool the end portion of the roll by any means, for example, a Peltier element, heat pipe, etc.

[0063] FIG. **8** is a schematic view showing a second example of the temperature adjusting unit. The temperature adjusting unit shown in FIG. **8** adjusts the temperature of the shaping roll **41** and adjusts the temperature of the opposed roll **42**. More specifically, the temperature adjusting unit has heating devices **70**. The heating device **70** heats the central portion of the shaping roll **41**. The heating device **70** heats the central portion of the opposed roll **42**.

[0064] The heating device **70** is realized, for example, by an electric heater. The heating device **70** may have two or more heaters arranged in the axial direction of the roll. Which one or ones of the two or more heaters are caused to generate heat, or the amount of heat generated by the heater or heaters, may be controlled according to the temperature distribution of the roll in the axial direction.

[0065] As shown in FIG. **7** and FIG. **8**, the shaping device **40** further has temperature sensors **80**. The temperature sensor **80** may be a non-contact sensor, such as an infrared sensor. The temperature sensor **80** that detects the temperature of the central portion of the roll and the temperature sensors **80** that detect the temperatures of the end portions of the roll may be provided. The temperature sensor **80** that scans in the axial direction may detect the temperatures of the central portion and end portions of the roll. A controller **200** (see FIG. **4**) obtains the detection results of the temperature sensors **80**. A temperature difference between the central portion and the end portions of the roll is obtained from the detection results of the temperature sensors **80**. The controller **200** performs feedback control on the temperature adjusting unit based on the temperature difference between the central portion and the end portions of the roll, so that the temperature adjusting unit can efficiently reduce the temperature difference between the central portion and the end portions of the roll.

Operation and Effects

[0066] The characteristic configuration and effects of the above embodiment will be summarized and described as follows.

[0067] As shown in FIG. **4**, the electrode manufacturing apparatus **1** includes the shaping device **40**. The shaping device **40** has the shaping roll **41** that forms the recesses and raised portions in the surface of the electrode layer **120**, and the opposed roll **42** that is opposed to the shaping roll **41** with the electrode **100** sandwiched therebetween. The shaping roll **41** and the opposed roll **42** rotate in opposite directions while sandwiching the electrode **100** therebetween. As shown in FIG. **7** and FIG. **8**, the electrode manufacturing apparatus **1** has the temperature adjusting unit that reduces the temperature difference between the central portion and the end portions in the axial direction, of at least one roll of the shaping roll **41** and the opposed roll **42**.

[0068] The end portions of the roll are supported by the housing. When the roll rotates relative to the housing, friction heat is generated. The friction heat is transferred to the roll, and the temperature at the end portions of the roll is more likely to rise to be higher than at the central portion of the roll. Where wide electrodes **100** are manufactured, the temperature difference between the central portion and the end portions of the roll may become significantly large, and the thermal expansion of the end portions of the roll may become larger than that of the central portion of the roll due to the influence of the temperature difference. The diameters of the end portions of the roll become larger than that of the central portion, and the gap between the pair of opposed rolls in the central portion of the roll is broadened. As a result, the grooving pressure is weakened at the central portion of the roll, and the depth of the recesses **121** (grooves) formed in the electrode layer **120** is reduced. Consequently, the uniformity of the groove depth of the electrode layer **120** between the central portion and the end portions in the width direction of the electrode **100** may not be maintained.

[0069] In the electrode manufacturing apparatus **1** of the embodiment, the shaping device **40** has the temperature adjusting unit, which is configured to reduce the temperature difference between the central portion and the end portions of the roll. The uniformity of the thermal expansion between the central portion and the end portions of the roll can be improved, and the uniformity of the outside diameter of the roll between the central portion and the end portions of the roll can be improved. Accordingly, the electrode manufacturing apparatus **1** of the embodiment can maintain the uniformity of the groove depth of the electrode layer **120** in the width direction even when wide electrodes **100** are manufactured.

[0070] As shown in FIG. **1** and FIG. **3**, the shaping roll **41** may form the groove-like recesses **121** extending in the width direction of the electrode **100**, in the surface of the electrode layer **120**. In the case where the thickness of the electrode layer **120** is equal to or larger than a given value, cracks may appear in the electrode layer **120** when the electrode **100** passes over a roll with a large hugging angle during conveyance of the electrode **100**. The recesses **121** extending in the short-side direction of the electrode **100** are formed in the electrode layer **120**, to give the flexibility to the electrode **100**, so that cracking of the electrode layer **120** during conveyance of the electrode **100** can be curbed, and the conveyability of the electrode **100** is improved.

[0071] As shown in FIG. **3**, the shaping roll **41** may form the recesses **121** extending over the entire length of the electrode layer **120** in the width direction. The recesses **121** communicate with the opposite edges of the electrode layer **120** in the width direction, and the recesses **121** communicate with the opposite exposed portions in the width direction of the electrode layer **120**. Since the liquid can flow in the recesses **121**, the penetration time in the subsequent electrolyte injection process can be reduced. Thus, the productivity of batteries using the electrodes **100** can be improved.

[0072] As shown in FIG. **7** and FIG. **8**, the temperature adjusting unit may adjust the temperature of the opposed roll **42**. The load applied to the shaping roll **41** may vary depending on the relationship between the shape of the protrusion mold of the shaping roll **41** and the depth of the recess **121** formed in the electrode layer **120**. On the other hand, the load applied to the opposed roll **42** is kept relatively constant, irrespective of the relationship between the shape of the protrusion mold of the shaping roll **41** and the depth of the recess **121** formed in the electrode layer **120**. Therefore, it is possible to efficiently maintain the uniformity of the groove depth of the electrode layer **120**, by adjusting the temperature of the opposed roll **42** and improving the uniformity of the outside diameter between the central portion and the end portions of the opposed roll **42**.

[0073] By providing both the shaping roll **41** and the opposed roll **42** that constitute the shaping device **40** with the temperature adjusting units, as shown in FIG. **7** and FIG. **8**, the uniformity of the groove depth of the electrode layer **120** can be further improved.

[0074] As shown in FIG. **7**, the temperature adjusting unit may have the cooling devices **60** for cooling the end portions of the rolls. The cooling devices **60** cool the end portions of the roll, so that the temperature difference between the central portion and the end portions of the roll can be reliably reduced. The shaping device **40** is located upstream of the drying device **50** for drying the electrode layer **120** in the conveying direction of the electrode **100**, and the electrode layer **120** is in a wet state before drying when it passes through the shaping device **40**. When the roll is heated, the water in the electrode layer **120** evaporates faster, and the moisture content of the electrode layer **120** may be reduced, thus making it difficult to handle the electrode layer **120**. When the end portions of the roll are cooled to adjust the temperature of the roll, the water in the electrode layer **120** is less likely or unlikely to evaporate, and changes in the properties of the electrode **100** due to changes in the moisture content of the electrode **100** can be reduced.

[0075] As shown in FIG. **8**, the temperature adjusting unit may have the heating devices **70** for heating the central portions of the rolls. The heating device **70** heats the central portion of the roll, so that the temperature difference between the central portion and the end portions of the roll can be reliably reduced. By controlling the amount of heat generated by the heating device **70**, the temperature difference between the central portion and the end portions of the roll can be precisely reduced. When the heating device **70** consists of two or more heaters arranged in the axial direction of the roll, and the two or more heaters are controlled according to the temperature distribution in the axial direction of the roll, the temperature difference between the central portion and the end portions of the roll can be further reduced.

[0076] As shown in FIG. **7** and FIG. **8**, the shaping device **40** may have the temperature sensors **80** for detecting the temperatures of the central portions and the end portions of the rolls. By feedback controlling the temperature adjusting unit based on the temperature difference between the central portion and the end portions of each roll, the temperature adjusting unit can efficiently reduce the temperature difference between the central portion and the end portions of the roll.

[0077] In the description of the embodiment, the example in which the temperature adjusting unit has the cooling devices **60** is shown in FIG. **7**, and the example in which the temperature adjusting unit has the heating devices **70** is shown in FIG. **8**. The temperature adjusting unit may have both the cooling devices **60** and the heating devices **70**.

[0078] While the shaping device **40** has the temperature sensors **80** in the examples of FIG. **7** and FIG. **8**, the temperature sensors **80** may not necessarily be provided. For example, by verifying in advance how the temperature of the roll varies according to grooving conditions, and controlling the temperature adjusting unit according to a program created based on the verification result to reduce the temperature difference between the central portion and the end portions of the roll, it is possible to similarly achieve the effects of the above embodiment.

[0079] An example will be described. By using the shaping device **40** equipped with the temperature adjusting unit, as described above in the embodiment, the recesses **121** were formed in the surface of the electrode layer. The roll temperature during grooving and the difference in the groove depth between the central portion and the end portions of the roll were measured. As a comparative example, shaping was performed in a similar manner, using a shaping device that is not equipped with the temperature adjusting unit, and the roll temperature during grooving and the difference in the groove depth were measured.

[0080] FIG. **9** is a graph showing the temperature difference between the central portion and the end portions of the roll and the groove depth difference in the comparative example. In the comparative example, a temperature difference appeared between the central portion and the end portions of the roll after a lapse of 10 min. from the start of grooving. The outside diameter of the end portions of the roll became larger than the outside diameter of the central portion due to thermal expansion. As a result, the groove depth difference between the central portion and the end portions exceeded 3 μm, and the uniformity of the groove depth of the electrode **100** could not be maintained.

[0081] FIG. **10** is a graph showing the temperature difference between the central portion and the end portions of the roll and the groove depth difference, in the example of the embodiment. In the example, the temperature difference between the central portion and the end portions of the roll during the temperature increase was smaller than that of the comparative example. The difference in the outside diameter between the central portion and the end portions of the roll was reduced; as a result, the maximum difference in the groove depth between the central portion and the end portions was kept at about 1 μm. Accordingly, it became apparent that the uniformity of the groove depth of the electrode **100** can be maintained by reducing the temperature difference between the central portion and the end portions of the roll.

[0082] It is to be understood that the embodiment disclosed herein is exemplary in all respects, and is not restrictive. The scope of this disclosure is indicated by the claims, rather than the above description, and is intended to include all changes within the claims and the meaning and range of equivalents thereof

What is claimed is:

1. An electrode manufacturing apparatus comprising:

a pair of rolls that sandwich an electrode and rotate in opposite directions; and

a temperature adjusting unit configured to reduce a temperature difference between a central portion and an end portion in an axial direction, of at least one roll of the pair of rolls.

2. The electrode manufacturing apparatus according to claim **1**, wherein:

the electrode has a substrate and an electrode layer formed on a surface of the substrate; and

the pair of rolls have a shaping roll configured to form an uneven shape on a surface of the electrode layer, and an opposed roll that is opposed to the shaping roll such that the electrode is sandwiched between the shaping roll and the opposed roll.

3. The electrode manufacturing apparatus according to claim **2**, wherein the shaping roll is configured to form recesses in a form of grooves extending in a width direction of the electrode, in the surface of the electrode layer.

4. The electrode manufacturing apparatus according to claim **3**, wherein the shaping roll is configured to form the recesses extending over an entire length of the electrode layer in the width direction.

5. The electrode manufacturing apparatus according to claim **1**, wherein the pair of rolls have a shaping roll having one or more protrusion molds on an outer surface, at positions corresponding to positions at which recesses are to be formed in a surface of an electrode layer of the electrode, and an opposed roll that is opposed to the shaping roll such that the electrode is sandwiched between the shaping roll and the opposed roll.

6. The electrode manufacturing apparatus according to claim **2**, wherein the temperature adjusting unit is configured to adjust a temperature of the opposed roll.

7. The electrode manufacturing apparatus according to claim **1**, wherein the temperature adjusting unit has a cooling device that cools the end portion.

8. The electrode manufacturing apparatus according to claim **1**, wherein the temperature adjusting unit has a heating device that heats the central portion.

9. The electrode manufacturing apparatus according to claim **1**, further comprising temperature sensors that detect a temperature of the central portion and the temperature of the end portion.

10. The electrode manufacturing apparatus according to claim **9**, further comprising a controller configured to perform feedback control on the temperature adjusting unit, based on a difference between the temperature of the central portion and the temperature of the end portion detected by the temperature sensors.

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