# MULTI-AXIS ULTRASONIC WEDGE WIRE BONDING

## TECHNICAL FIELD

**[0001]** This document relates to wedge wire bonding.

## BACKGROUND

**[0002]** In recent years, the world has begun a transition away from using power primarily obtained from fossil fuels and toward more sustainable energy sources. One area where this change occurs involves the use of electric motors powered by on-board energy storages in vehicles. Vehicle makers are striving to increase efficiency and utility of such vehicles, including the performance of energy storages such as battery packs, which includes improving the quality of wedge wire bonds used to electrically interconnect components of such battery packs, such as terminals of electrochemical cells and busbars.

## SUMMARY

**[0003]** In a general aspect, an electrical device assembly (e.g., a battery module) can include a first electrical contact surface, a second electrical contact surface, and a ribbon wire extending along a longitudinal axis. The ribbon wire can include a first portion that is coupled with the first electrical contact surface via a first wedge bond. The ribbon wire can also include a second portion that is coupled with the second electrical contact surface via a second wedge bond. The ribbon wire can further include a third portion extending between the first portion and the second portion. The first portion of the ribbon wire can have a first width transverse to the longitudinal axis of the ribbon wire, and the third portion of the ribbon wire having a second width transverse to the longitudinal axis, the first width being greater than the second width.

**[0004]** Implementations can include one or more of the following features. For example, the second portion of the ribbon wire has a third width transverse to the longitudinal axis of the ribbon wire, the third width being approximately equal to the second width.

**[0005]** The second portion of the ribbon wire can have a third width transverse to the longitudinal axis of the ribbon wire, the third width being approximately equal to the first width.

**[0006]** Intermetallics of the first wedge bond on the first electrical contact surface can be, at least in part, circular. Intermetallics of the second wedge bond on the second electrical contact surface can be, at least in part, circular.

**[0007]** The first electrical contact surface and the second electrical contact surface can each be respectively included in one of a busbar of a battery module, or in a terminal located at an end of an electrochemical cell of the battery module. The terminal of the electrochemical cell can include one of a rim or a cap of the electrochemical cell. The ribbon wire can include a copper ribbon wire.

**[0008]** In another general aspect, an electrical device assembly (e.g., a battery module) can include an electrical contact surface, and a ribbon wire including a portion that is coupled with the electrical contact surface via a wedge bond. Intermetallics of the wedge bond on the electrical contact surface can define, at least in part, concentric circular patterns.

**[0009]** Implementations can include one or more of the following features. For example, the portion of the ribbon wire can be a first portion of the ribbon wire. The ribbon wire can extend along a longitudinal axis. The ribbon wire can include a second portion forming a wire loop. The first portion of the ribbon wire and the second portion of the ribbon wire can be electrically continuous. The first portion of the ribbon wire can have a first width transverse to the longitudinal axis of the ribbon wire. The second portion of the ribbon wire can have a second width transverse to the longitudinal axis of the ribbon wire, the first width being greater than the second width.

**[0010]** The electrical contact surface can be included in one of a busbar of a battery module, or in a terminal located at an end of an electrochemical cell of the battery module. The terminal of the electrochemical cell can include one of a rim or a cap of the electrochemical cell. The ribbon wire can include a copper ribbon wire.

**[0011]** In another general aspect, a method can include feeding a ribbon wire through a wedge bonder head, and positioning the wedge bonder head over an electrical contact surface, the electrical contact surface being arranged in a plane. The method can further include lowering the wedge bonder head, such that a first surface of the ribbon wire is in contact with the electrical contact surface and such that a wedge of the wedge bonder head is in contact with a second surface of the ribbon wire opposite the first surface of the ribbon wire. The method can also include forming a wedge bond between the ribbon wire and the electrical contact surface. Forming the wedge bond can include activating an ultrasonic transducer of the wedge bonder head with the wedge in contact with the ribbon wire, and rotating the wedge bonder head with the wedge in contact with the ribbon wire.

**[0012]** Implementations can include one or more of the following features. For example, activating the ultrasonic transducer can include activating the ultrasonic transducer when rotating the wedge bonder head.

**[0013]** Activating the ultrasonic transducer can include activating a plurality of ultrasonic transducers. A first ultrasonic transducer of the plurality of ultrasonic transducers can have an ultrasonic vibration axis that is parallel to the plane of the electrical contact surface, and a second ultrasonic transducer can have an ultrasonic vibration axis that is perpendicular to the plane of the electrical contact surface. A third ultrasonic transducer of the plurality of ultrasonic transducers can have an ultrasonic vibration axis that is parallel to the plane of the electrical contact surface and perpendicular to the ultrasonic vibration axis of the first ultrasonic transducer.

**[0014]** A first ultrasonic transducer of the plurality of ultrasonic transducers can have an ultrasonic vibration axis that is parallel to the plane of the electrical contact surface, and a second ultrasonic transducer of the plurality of ultrasonic transducers can have an ultrasonic vibration axis that is parallel to the plane of the electrical contact surface and non-parallel with the ultrasonic vibration axis of the first ultrasonic transducer. A third ultrasonic transducer of the plurality of ultrasonic transducers can have an ultrasonic vibration axis that is perpendicular to the plane of the electrical contact surface.

**[0015]** A first ultrasonic transducer of the plurality of ultrasonic transducers can have an ultrasonic vibration axis that is parallel to the plane of the electrical contact surface, and a second ultrasonic transducer of the plurality of ultrasonic transducers can have an ultrasonic vibration axis that is parallel to the plane of the electrical contact surface and parallel with the ultrasonic vibration axis of the first ultrasonic transducer. A third ultrasonic transducer of the plurality of ultrasonic transducers can have an ultrasonic vibration axis that is perpendicular to the plane of the electrical contact surface.

## BRIEF DESCRIPTION OF DRAWINGS

**[0016]** FIG. 1 is a block diagram illustrating an example wedge wire bonder.

**[0017]** FIG. 2 is a diagram illustrating an example of formation of a wire bond using multi-axis ultrasonic wedge bonding, such as using the wedge wire bonder illustrated in FIG. 1.

**[0018]** FIGs. 3A-3B are diagrams schematically illustrating example wedge bonded ribbon wires including wedge bonds formed using multi-axis ultrasonic wedge bonding.

**[0019]** FIGs. 4A-4C are diagrams schematically illustrating example battery modules that include wedge bonded ribbon wires having wedge wire bonds formed using multi-axis ultrasonic wedge bonding implemented in respective battery modules.

**[0020]** FIG. 5 is a diagram illustrating an example wedge bonder head for forming wedge wire bonds using multi-axis ultrasonic wedge bonding.

**[0021]** FIG. 6 is a diagram schematically illustrating example ultrasonic transducer arrangement.

**[0022]** FIG. 7 is flowchart illustrating an example method.

**[0023]** Like reference symbols in the various drawings indicate like elements.

## DETAILED DESCRIPTION

**[0024]** This document describes examples of systems and techniques directed to formation of a wedge wire bond using ultrasonic vibration along multiple axes, which can be referred to as multi-axis ultrasonic wedge bonding, or wedge bonding using multi-axis ultrasonics. In some implementations, forming a wedge wire bond can include, during formation of the bond, rotating a wire bonder head in conjunction with (e.g., contemporaneously with) activation of one or more ultrasonic transducers included in the wire bonder head. The subject matter described herein can improve the performance of corresponding electrical device assemblies, such as battery modules. For example, electrical interconnects to individual electrical contact surfaces (e.g., terminals of electrochemical cells and/or busbars of a battery module) can be provided with increased conductivity as a result of electrical resistance of associated wedge wire bonds being reduced. Such reduced resistance can be achieved as a result of increased bond area and/or due to improved adherence of bond wire material to a corresponding electrical contact surface, such as a busbar or a terminal of an electrochemical cell of a battery module. Stated another way, wedge wire bonds formed using the approaches described herein can have larger bond (e.g., contact) areas, and/or lower resistance per unit area than wedge wire bonds formed using current approaches.

**[0025]** Examples herein refer to forming wedge wire bonds using multi-axis ultrasonics to adhere, or ultrasonically weld a bond wire (e.g., a ribbon wire) to a corresponding electrical contact surface. As used herein, multi-axis ultrasonics can include in-plane ultrasonics and/or out-of-plane ultrasonics. In-plane ultrasonics can be implemented by ultrasonic transducers with vibration axes that are parallel with, and/or in-plane with an electrical contact surface on which a wedge wire bond is formed. Out-of-plane ultrasonics can be implemented by ultrasonic transducers with vibration axes that are non-parallel with (e.g., perpendicular to, or at a non-zero angle with) an electrical contact surface on which a corresponding wedge wire bond is formed. In example implementations, ultrasonic transducers with vibration frequencies in a range of 40 kHz and 160 kHz can be used.

**[0026]** Examples herein refer to bond wires (e.g., ribbon wires) that extend along respective longitudinal axes. As used herein, a bond wire can have any number of different geometries, can include one or more materials having respective conductivities. For instance, a bond wire can be a multi-layered bond wire that has a plurality of layer each having a respective conductivity. In some implementations, a bond wire can be a ribbon wire having a rectangular cross-section and having one or more layers, which can include one or more conductive materials, such as copper, aluminum, alloys of copper, alloys of aluminum, etc. As used herein, a longitudinal axis of a bond wire can be defined as being a mid-line of the bond wire that extends along a length of the bond wire. For instance, when a give bond wire is in a flat and linear configuration, its longitudinal axis, or mid-line will be a straight line. However, when the bond wire is in a non-flat and/or non-linear configuration (e.g., a curved or arced) configuration, the longitudinal axis, or mid-line will conform to the configuration or shape of the bond wire and, therefore, may not be situated along a straight line.

**[0027]** Examples herein refer to intermetallics of wedge bonds that are, at least in part, circular. As used herein, intermetallics are metallic compounds that are formed as a result of ultrasonic scrubbing of a bond wire on an electrical contact surface. As used herein, circular means curved in shape and can include concentric curved or circular patterns, partial curved or circular patterns, and so forth that can be observed on an upper surface of a bond wire in a wire bond and/or observed in intermetallics formed between a bond wire and a corresponding, underlying electrical contact surface. Accordingly, such intermetallics can be intermetallics having patterns on an electrical contact surface that are, at least in part, circular or curved in shape.

**[0028]** Examples herein refer to wire loops. As used herein, a wire loop is a portion of a ribbon wire that extends between two wedge wire bonds. For instance, a wire loop can electrically connect a first wedge wire bond and its corresponding electrical contact surface with

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