October 2023

Piezeoelectric-based asphalt layer for energy harvesting roadway

Qing Lu

Lukai Guo

US011773542B1

(12) **United States Patent**
Lu et al.

(10) **Patent No.: US 11,773,542 B1**
(45) **Date of Patent: Oct. 3, 2023**

(54) **PIEZOELECTRIC-BASED ASPHALT LAYER FOR ENERGY HARVESTING ROADWAY**

(71) Applicant: **University of South Florida**, Tampa, FL (US)

(72) Inventors: **Qing Lu**, Tampa, FL (US); **Lukai Guo**, Tampa, FL (US)

(73) Assignee: **UNIVERSITY OF SOUTH FLORIDA**, Tampa, FL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 627 days.

(21) Appl. No.: **16/840,832**

(22) Filed: **Apr. 6, 2020**

Related U.S. Application Data

(60) Provisional application No. 62/830,722, filed on Apr. 8, 2019.

(51) **Int. Cl.**
E01C 1/00 (2006.01)
H02N 2/18 (2006.01)

(52) **U.S. Cl.**
CPC ***E01C 1/002*** (2013.01); ***H02N 2/183*** (2013.01)

(58) **Field of Classification Search**
CPC H02N 2/183; E01C 1/002
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2005/0127677 A1* 6/2005 Luttrull .... H02N 2/18 290/1 R
2009/0195124 A1 8/2009 Abramovich et al.
2010/0045111 A1* 2/2010 Abramovich E01B 26/00 307/43
2011/0302858 A1* 12/2011 Siewert H02S 20/10 52/173.3
2012/0049692 A1* 3/2012 Boyd H01L 41/183 310/319
2013/0175902 A1* 7/2013 Abu Al-Rubb E01C 11/00 310/339
2014/0300250 A1* 10/2014 Marin Ramirez H02N 2/18 310/319
2019/0275897 A1* 9/2019 Ayoub E01C 9/00

OTHER PUBLICATIONS

Shu, Y. C., and I. C. Lien. "Analysis of power output for piezoelectric energy harvesting systems." Smart materials and structures 15 6 (2006): 1499.

Roshani, Hossein, et al. "Energy harvesting from asphalt pavement roadways vehicle-induced stresses: A feasibility study." Applied Energy 182 (2016): 210-218.

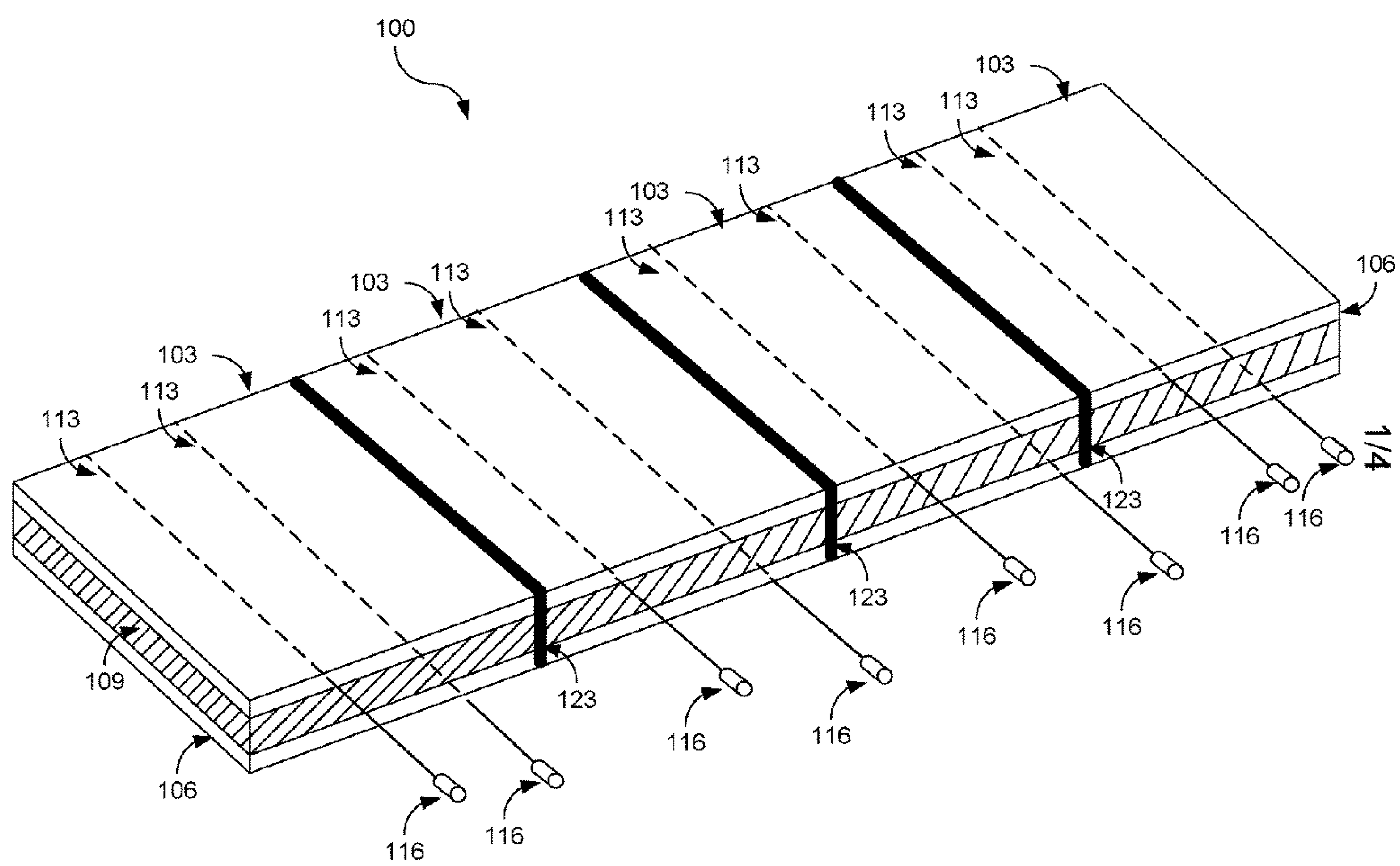
(Continued)

Primary Examiner — J. San Martin
(74) *Attorney, Agent, or Firm* — QUARLES & BRADY

(57) **ABSTRACT**

An energy harvesting roadway that includes a plurality of road segments and a power storage device electrically coupled to the plurality of road segments. Each of the plurality of road segments can include a surface asphalt layer, a first conductive asphalt layer located under the surface asphalt layer, a piezoelectric-based asphalt layer located between the first conductive layer and a second conductive layer located above a base asphalt layer. The piezoelectric-based asphalt layer can include a plurality of rigid piezoelectric elements and an insulating filler.

12 Claims, 4 Drawing Sheets



(56) **References Cited**

OTHER PUBLICATIONS

Guo, Lukai,; et al. “Numerical analysis of a new piezoelectric-based energy harvesting pavement system: Lessons from laboratory-based and field-based simulations.” Applied Energy 235 (2019): 963-977.
Guo, Lukai; et al. “Modeling a new energy harvesting pavement system with experimental verification.” Applied energy 208 (2017): 1071-1082.
Guo, Lukai. “Development of a New Piezoelectric-based Energy Harvesting Pavement System.” (2018).

* cited by examiner

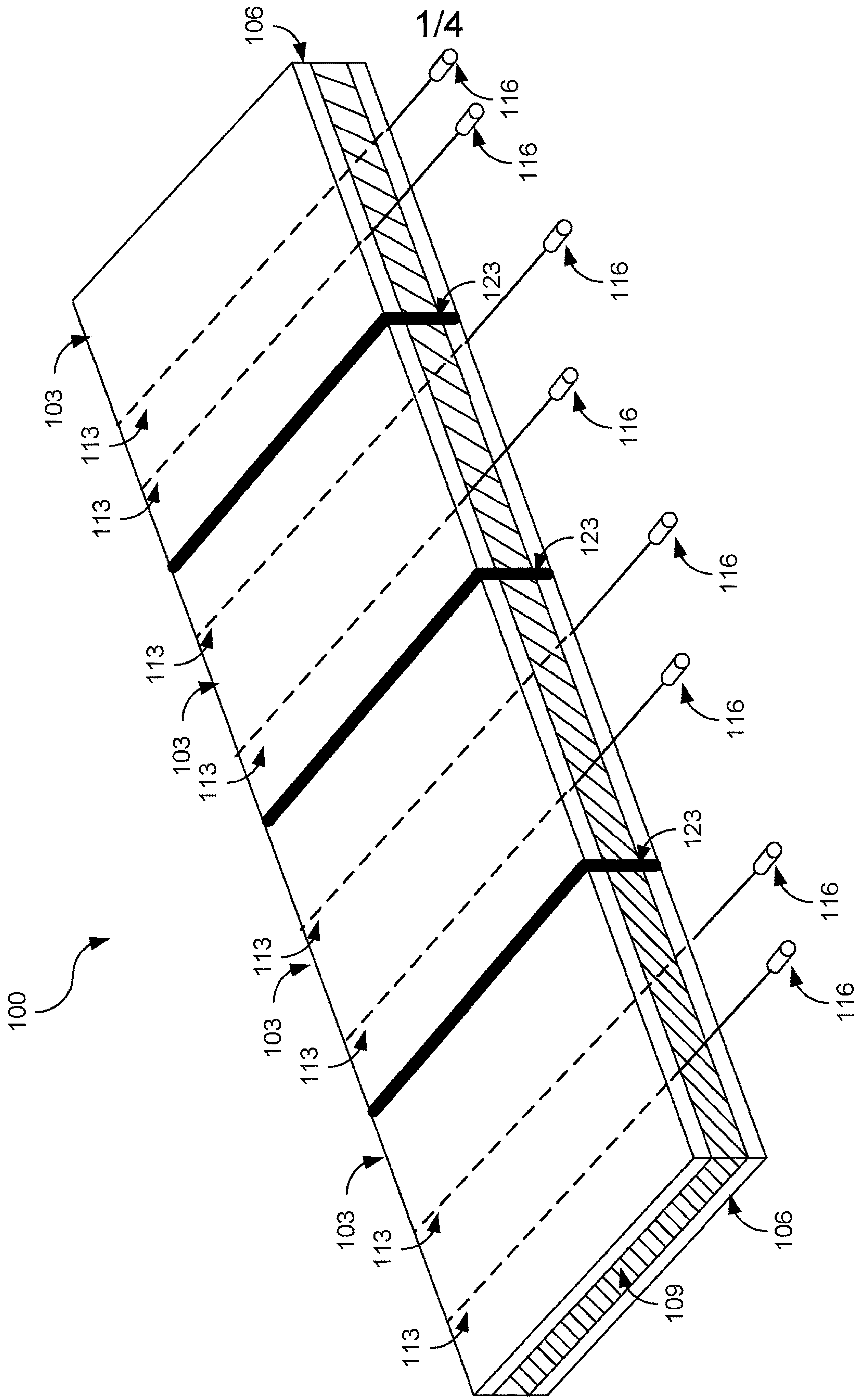


FIG. 1

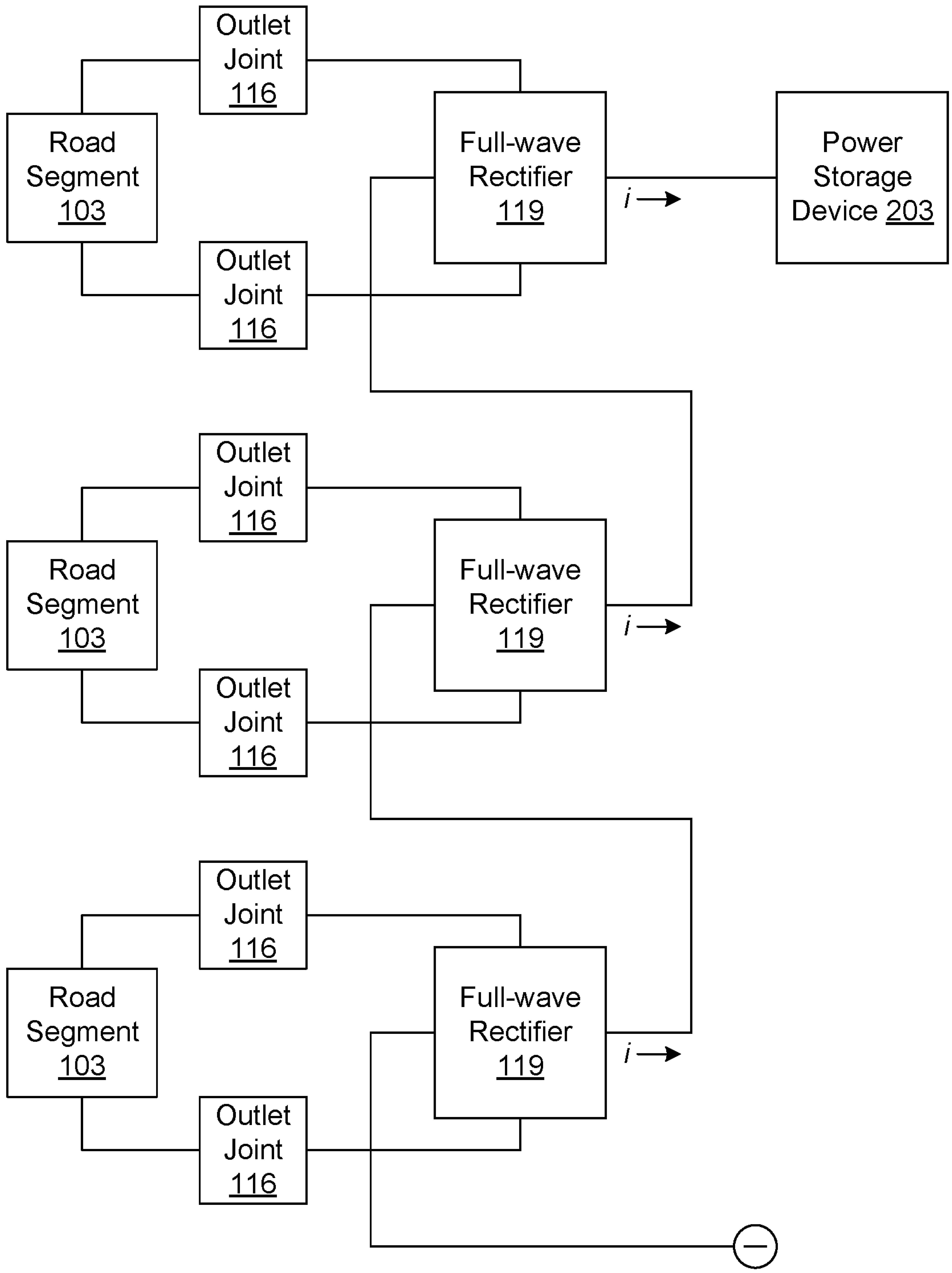

Outlet Joint 116
Road Segment 103
Outlet Joint 116
Full-wave Rectifier 119
i
Power Storage Device 203
Outlet Joint 116
Road Segment 103
Outlet Joint 116
Full-wave Rectifier 119
i
Outlet Joint 116
Road Segment 103
Outlet Joint 116
Full-wave Rectifier 119
i

FIG. 2

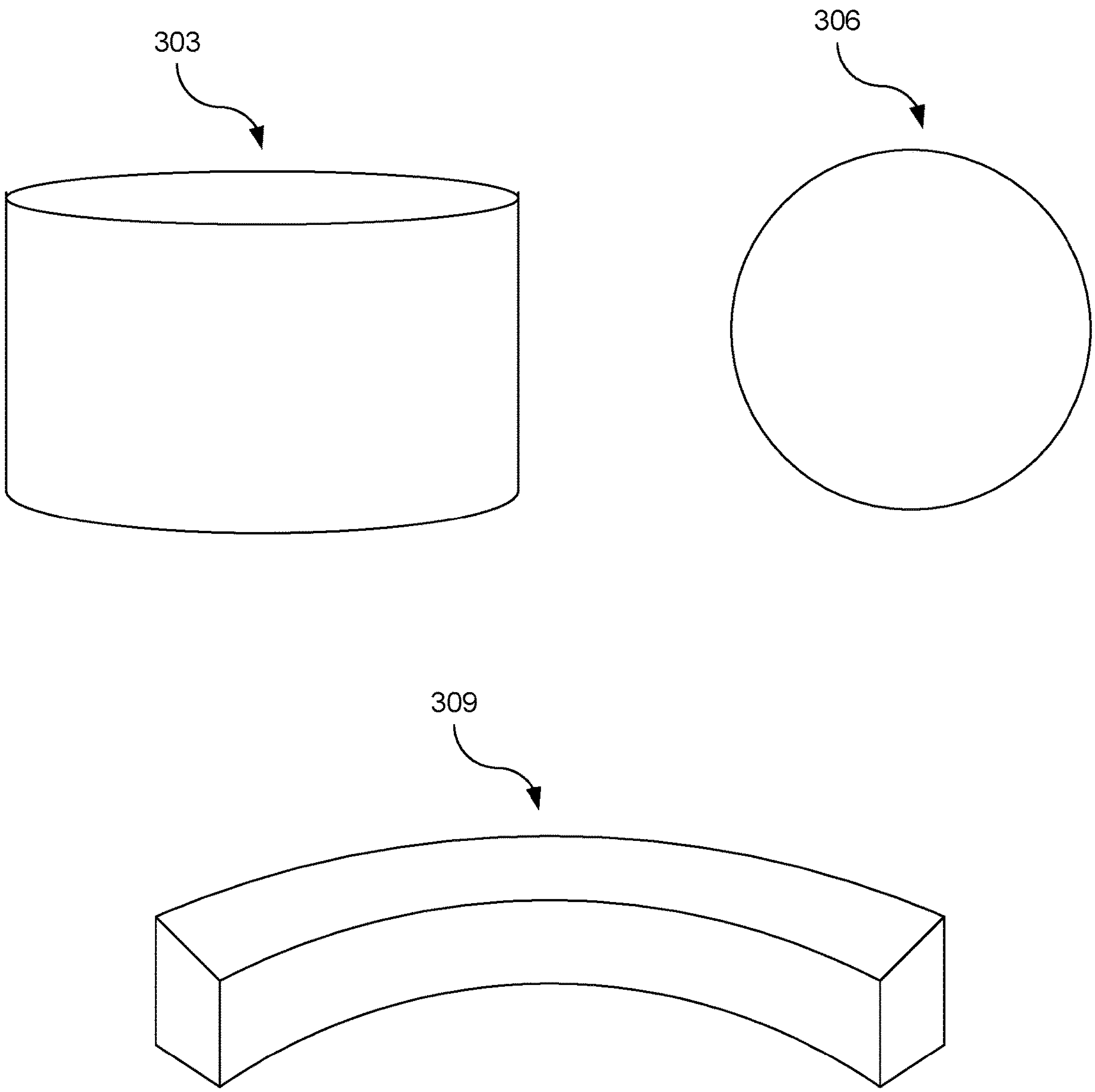


FIG. 3

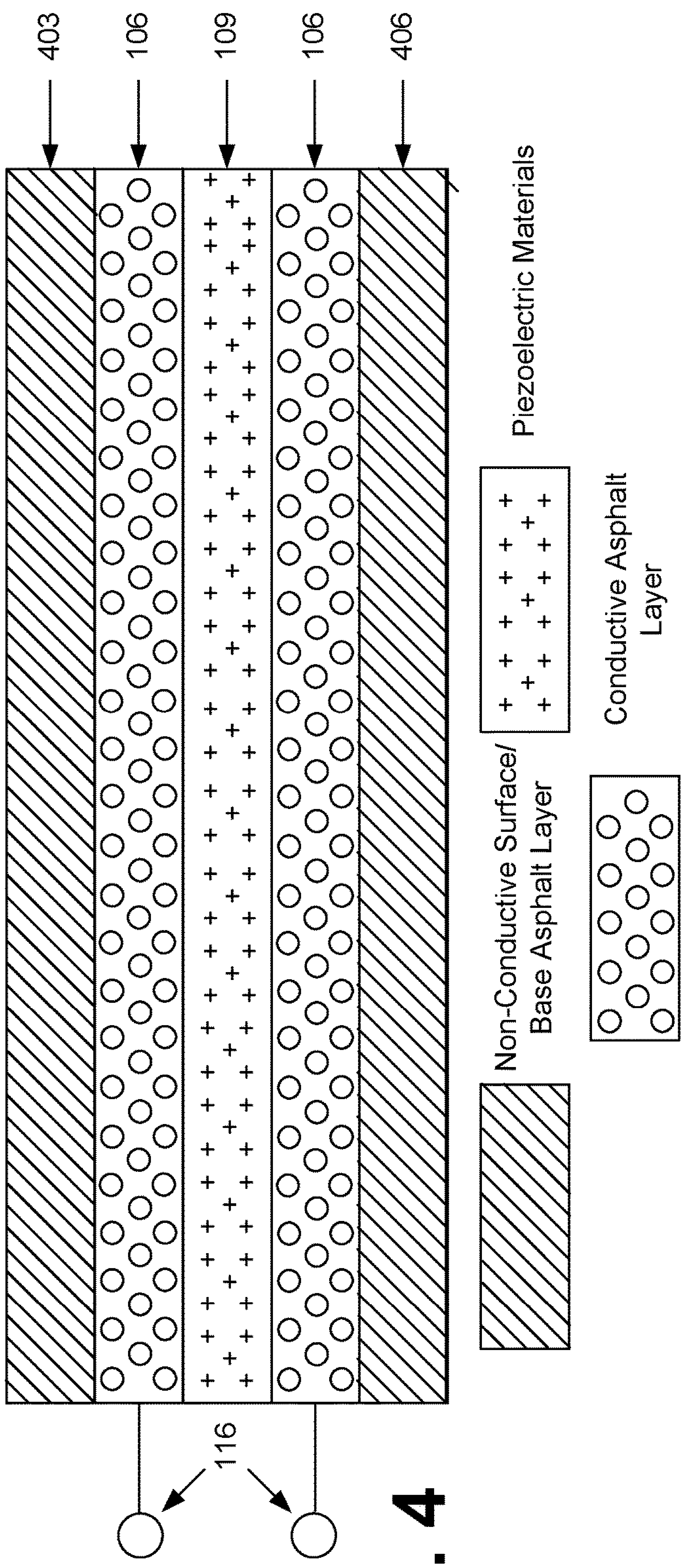


FIG. 4

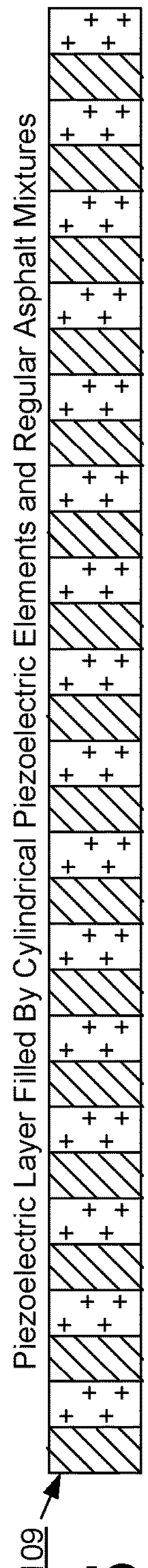


FIG. 5

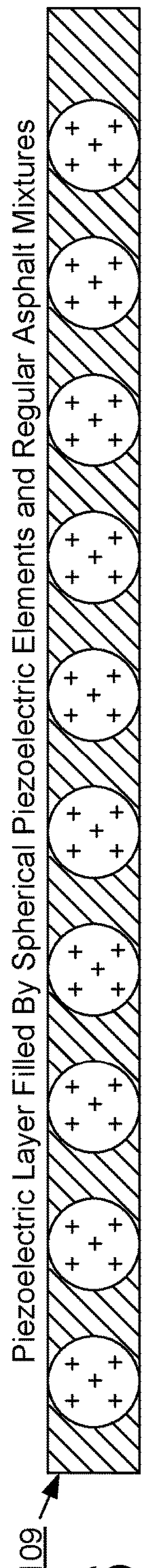


FIG. 6

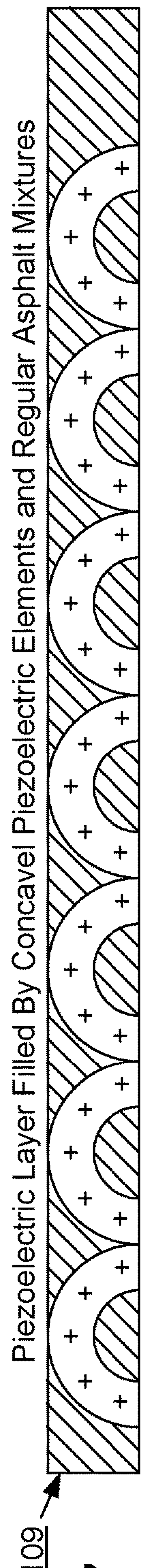


FIG. 7

PIEZOELECTRIC-BASED ASPHALT LAYER FOR ENERGY HARVESTING ROADWAY

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to, and the benefit of, U.S. Provisional Patent Application No. 62/830,722, filed on Apr. 8, 2019 and entitled "PIEZOELECTRIC-BASED ASPHALT LAYER FOR ENERGY HARVESTING ROADWAY," of which APPENDIX A is incorporated by reference as if set forth herein in its entirety.

BACKGROUND

Roadways often involve large amounts of waste energy. For example, the friction of car tires driving over asphalt results in waste heat. Likewise, the weight of a vehicle temporarily stresses and deforms the asphalt as the vehicle travels over the asphalt. In both cases, the heat from friction or the deformation of the asphalt is energy that is not normally recovered during use of the roadway.

BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the present disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, with emphasis instead being placed upon clearly illustrating the principles of the disclosure. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. **1** depicts an example of an energy harvesting roadway according to various embodiments of the present disclosure.

FIG. **2** depicts an example of an interconnection between outlet joints according to various embodiments of the present disclosure.

FIG. **3** depicts examples of various piezoelectric elements that may be used according to various embodiments of the present disclosure.

FIG. **4** depicts a cross-section of an energy harvesting roadway according to various embodiments of the present disclosure.

FIG. **5** depicts a cross-section of a piezoelectric-based asphalt layer including cylindrical piezoelectric elements according to various embodiments of the present disclosure.

FIG. **6** depicts a cross-section of a piezoelectric-based asphalt layer including spherical piezoelectric elements according to various embodiments of the present disclosure.

FIG. **7** depicts a cross-section of a piezoelectric-based asphalt layer including concave piezoelectric elements according to various embodiments of the present disclosure.

DETAILED DESCRIPTION

Disclosed are various approaches for an energy harvesting roadway manufactured using piezoelectric-based asphalt layers, which includes a mixture or combination of piezoelectric materials with conventional paving materials such as asphalt. The energy harvesting roadway can be paved using piezoeoelectric-based asphalt layer, which can be connected using wires to an energy storage device. As vehicles travel across the piezeoelectric-based asphalt layer, the deformation of the piezeoelectric-based asphalt layer creates electricity as a result of the piezoelectric effect. This energy can then be stored in an energy storage device for subsequent

use. In the following discussion, a general description of the system and its components is provided, followed by a discussion of the operation of the same.

FIG. **1** depicts an initial design of an energy harvesting roadway **100**, which is formed from a plurality of road segments **103**. Each road segment **103** has at least two conductive asphalt layers **106** and a piezoelectric-based asphalt layer **109** between the two conductive asphalt layers **106**. Embedded in the conductive asphalt layers **106** are transmission lines **113**. To minimize the voltage offset caused by adjacent tires on different axles of vehicles travelling across the energy harvesting roadway **100**, the transmission lines **113** can be laid in a direction perpendicular to the flow of traffic. The transmission lines **113** can extend out from the conductive asphalt layers **106** to create outlet joints **116**. Connected to the outlet joints **116** can be full-wave rectifiers, as discussed later.

The plurality of road segments **103** may be separated by non-conductive asphalt layers **123**. The separation of the individual road segments **103** may be performed in order to prevent two adjacent vehicles from loading the same road segment **103**, which can produce opposite charges and reduce the overall electric output of the road segment **103**. The length of the individual road segments **103** may depend on a variety of factors, including the expected size of vehicles, the expected speed of vehicles, and potentially other factors. For example, vehicles moving at highway speeds tend to leave more space between each other for safety reasons than vehicles moving at low speeds on urban streets. Therefore, longer road segments **103** may be used on highways while shorter road segments may be used on urban or surface streets.

FIG. **2** depicts an example of an interconnection between outlet joints **116** to aggregate electric power for use by a power storage device **203**, such as a battery, capacitor, or similar device that store an electric charge. Each outlet joint **116** is connected to a full-wave rectifier **206**. A full-wave rectifier **206** may include a collection of diodes to smooth power from both positive and negative voltage outlet joints **116**. As an electric current is created from deformation of the piezoelectric-based asphalt layer **109** of individual road segments **103**, the current flows from the road segment **103** to the power storage device **203** as illustrated. Although FIG. **2** depicts the road segments **103** being connected in series, various embodiments of the present disclosure may connect the road segments in parallel as appropriate.

FIG. **3** depicts three different types of piezoelectric elements. These include a cylindrical piezoelectric element **303**, a spherical piezoelectric element **306**, and a concave piezoelectric element **309**. The cylindrical piezoelectric element **303** may be preferentially used to produce higher voltages when the piezoelectric-based asphalt layer **109** of a road segment **103** is thick and stiff. The spherical piezoelectric element **306** can be used to decrease the overall physical stress on the element and also generate more uniform electric current directions based on the geometric stability of the sphere. The concave piezoelectric element **309** can be used to translate a high vertical impact into bending strain inside the piezoelectric component to obtain a higher voltage.

FIG. **4** depicts a cross-section of road segment **103** according to various embodiments of the present disclosure. As shown, a road segment **103** can include two conductive asphalt layers **106** and a piezoelectric-based asphalt layer **109**. Optionally, the road segment **103** may also include a non-conductive surface asphalt layer **403** and a non-conductive base asphalt layer **406**. The surface asphalt layer **403** and base asphalt layer **406** may be used in order to increase the durability of the road segment **103** as vehicles drive over the road segment **103**. The surface asphalt layer **403** and base asphalt layer **406** may also provide some measure of weather-proofing for the road segment **103**, preventing moisture from reaching the conductive asphalt layers **106** and the piezoelectric-based asphalt layer **109** and creating a short-circuit between the two conductive asphalt layers **106**.

The piezoelectric-based asphalt layer **109** may be manufactured using a variety of approaches. For example, the piezoelectric-based asphalt layer **109** may include a number of piezoelectric elements, such as cylindrical piezoelectric elements **303** (FIG. **5**), spherical piezoelectric elements **306** (FIG. **6**), or concave piezoelectric elements **309** (FIG. **7**). To prevent the piezoelectric elements from being crushed or otherwise damaged, an insulating or non-conductive filler may be mixed with the piezoelectric elements to provide stiffness to the piezoelectric-based asphalt layer **109**. For example, regular asphalt or asphalt mixture may be used as a filler by mixing asphalt with the piezoelectric elements in order to create the piezoelectric-based asphalt layer **109**. However, other insulating or non-conductive fillers may be used as desired. Generally, a non-conductive filler will be used in order to prevent short-circuits from forming between the two conductive asphalt layers **106**.

In order to prevent moisture or water from entering the piezoelectric-based asphalt layer **109** and completing a circuit between the two conductive asphalt layers **106**, some embodiments may include a waterproof layer, membrane, or other moisture barrier between the two conductive asphalt layers **106**. For example, a waterproof or water resistant layer may be placed between the piezoelectric-based asphalt layer **109** and one of the conductive asphalt layers **106**.

Disjunctive language such as the phrase "at least one of X, Y, or Z," unless specifically stated otherwise, is otherwise understood with the context as used in general to present that an item, term, etc., may be either X, Y, or Z, or any combination thereof (e.g., X, Y, or Z). Thus, such disjunctive language is not generally intended to, and should not, imply that certain embodiments require at least one of X, at least one of Y, or at least one of Z to each be present.

It should be emphasized that the above-described embodiments of the present disclosure are merely possible examples of implementations set forth for a clear understanding of the principles of the disclosure. Many variations and modifications may be made to the above-described embodiments without departing substantially from the spirit and principles of the disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure and protected by the following claims.

Therefore, the following is claimed:

1. An energy harvesting roadway, comprising:
- a plurality of road segments, each of the plurality of road segments comprising:
  - a surface asphalt layer;
  - a first conductive asphalt layer located under the surface asphalt layer;
  - a piezoelectric-based asphalt layer located between the first conductive layer and a second conductive layer, the piezoelectric-based asphalt layer comprising:
    - a plurality of rigid piezoelectric elements; and
    - an insulating filler;
  - a second conductive asphalt layer located above a base asphalt layer; and
  - the base asphalt layer; and
- a power storage device electrically coupled to the plurality of road segments.

2. The energy harvesting roadway of claim **1**, further comprising a plurality of full-wave rectifiers, each full-wave rectifier electrically connected between a respective one of the plurality of road segments and the power storage device.

3. The energy harvesting roadway of claim **1**, wherein the power storage device is a capacitor.

4. The energy harvesting roadway of claim **1**, wherein the power storage device is a rechargeable battery.

5. The energy harvesting roadway of claim **1**, wherein the plurality of road segments are electrically coupled to the power storage device in parallel.

6. The energy harvesting roadway of claim **1**, wherein the plurality of road segments are electrically coupled to the power storage device in series.

7. The energy harvesting roadway of claim **1**, each of the plurality of road segments further comprises a waterproof layer between the first and second conductive asphalt layers.

8. The energy harvesting roadway of claim **1**, wherein the plurality of rigid piezoelectric elements comprise a plurality of cylindrically shaped rigid piezoelectric elements.

9. The energy harvesting roadway of claim **1**, wherein the plurality of rigid piezoelectric elements comprise a plurality of spherically shaped rigid piezoelectric elements.

10. The energy harvesting roadway of claim **1**, wherein the plurality of rigid piezoelectric elements comprise a plurality of concave rigid piezoelectric elements.

11. The energy harvesting roadway of claim **1**, wherein the insulating filler has a stiffness of three (3) MPa or less.

12. The energy harvesting roadway of claim **1**, wherein the insulating filler has a stiffness of less than thirty (30) MPa.

* * * * *