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Miyaki et al.

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(54) **SEMICONDUCTOR DEVICE AND MOTOR CONTROL UNIT**

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H01L 25/07 (2006.01)
H02M 3/158 (2006.01)
H03K 17/0812 (2006.01)

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CPC ***H02M 3/158*** (2013.01); ***H03K 17/08122*** (2013.01); *H03K 2217/0054* (2013.01)

(58) **Field of Classification Search**
CPC H01L 29/16; H01L 29/517
See application file for complete search history.

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(57) **ABSTRACT**

A semiconductor device includes a first switching element, a pre-driver, a coil, a second switching element and a capacitor. The first switching element is connected between a power and a load driving circuit and includes a parasitic diode having cathode adjacent to the load driving circuit. The pre-driver drives the first switching element. The coil is connected between the power and the first switching element. The second switching element includes an output terminal connected to a first connection point between the power and the coil, an input terminal connected to a second connection point between the first switching element and the pre-driver, and a control terminal connected to ground. The capacitor has one end connected to a point between the first switching element and the load driving circuit and another end connected to ground. Even when power supply voltage decreases, the semiconductor device can restrict breakage of switching element.

3 Claims, 6 Drawing Sheets

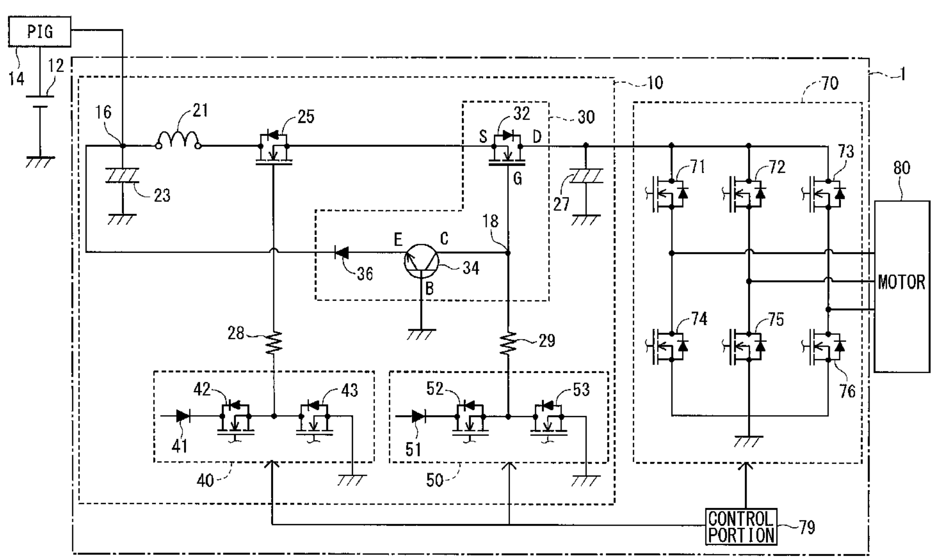


FIG. 1

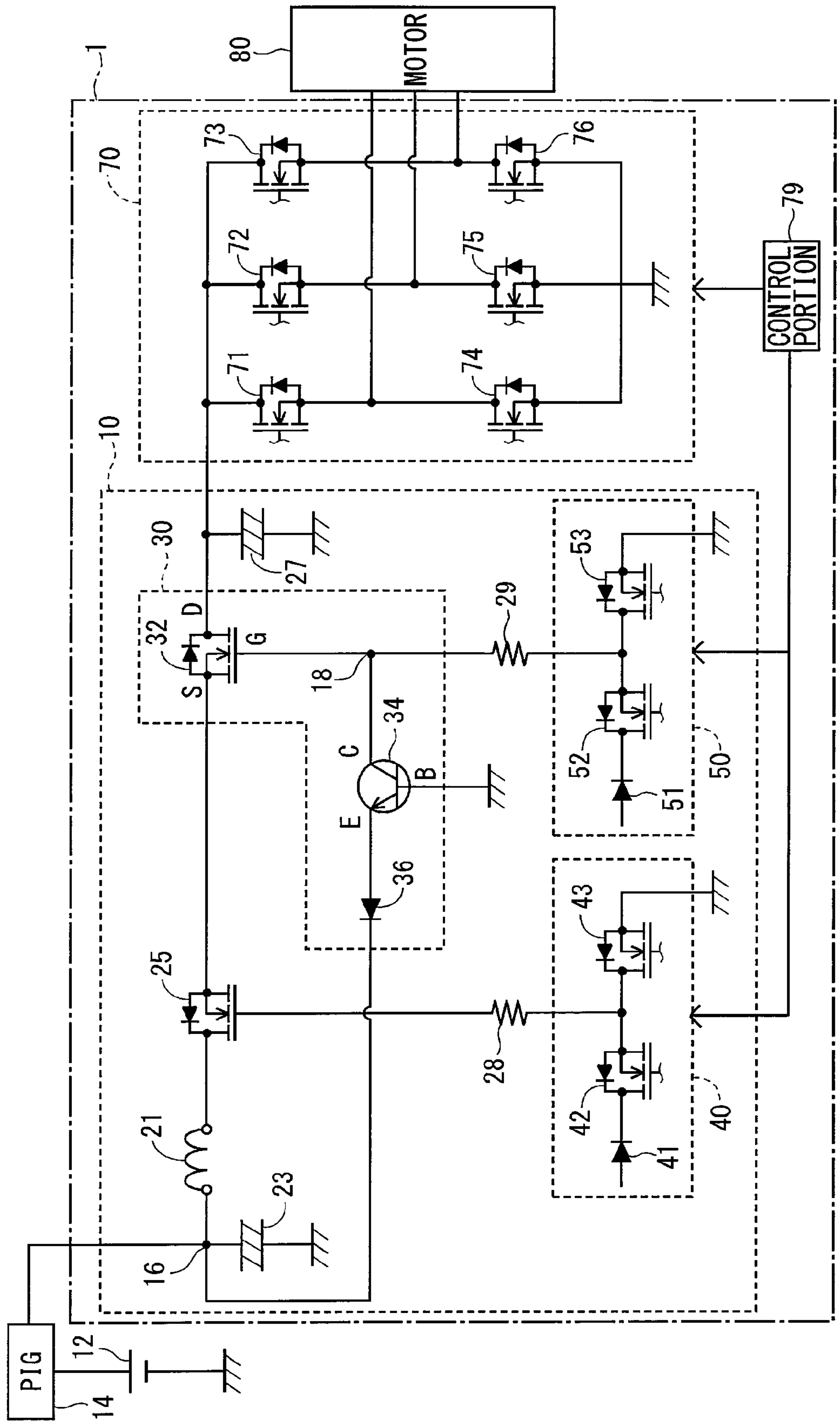

MOTOR
80
1
70
71
72
73
74
75
76
79
CONTROL PORTION
10
30
32
D
G
S
18
34
C
B
E
36
27
29
53
52
51
50
25
28
43
42
41
40
21
23
16
PIG
12
14

FIG. 2A

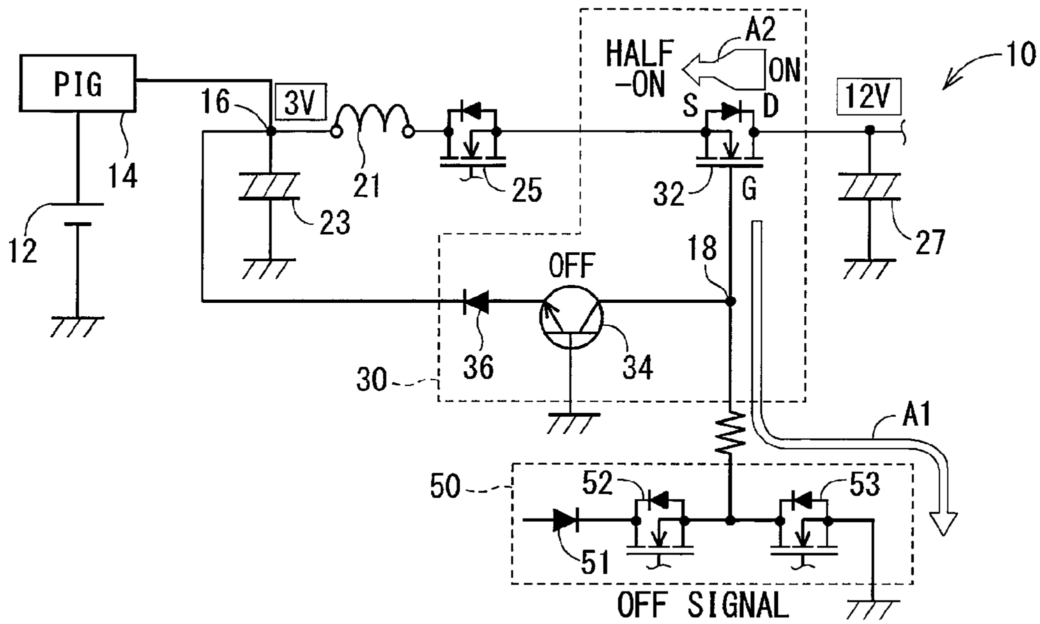

PIG
16
3V
HALF
-ON
A2
ON
S
D
12V
10
14
21
25
32
G
12
23
27
18
OFF
36
34
30
A1
50
52
53
51
OFF SIGNAL

FIG. 2B

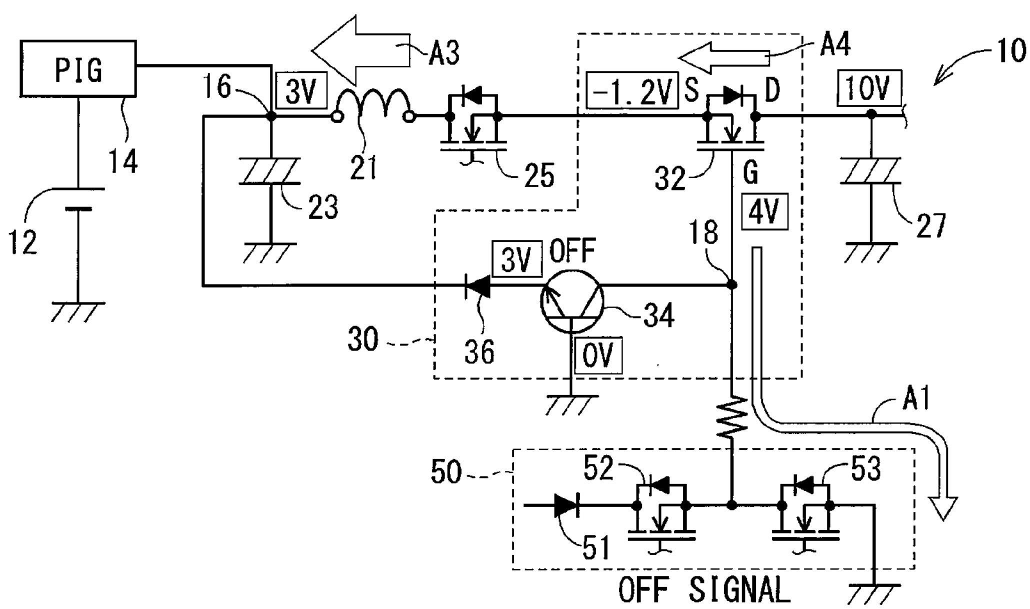

PIG
A3
A4
10
16
3V
-1.2V
S
D
10V
14
21
25
32
G
4V
12
23
27
18
3V
OFF
34
30
36
0V
A1
50
52
53
51
OFF SIGNAL

FIG. 2C

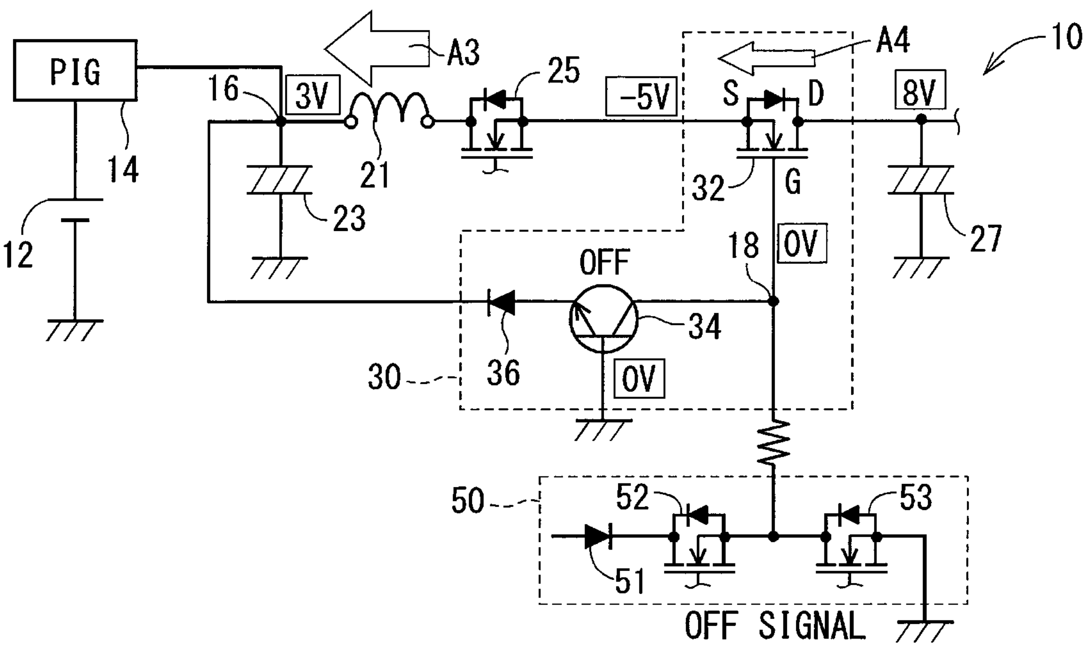

PIG
A3
25
16
3V
-5V
S
D
A4
8V
10
14
21
32
G
12
23
18
0V
27
OFF
34
36
30
0V
50
52
53
51
OFF SIGNAL

FIG. 3

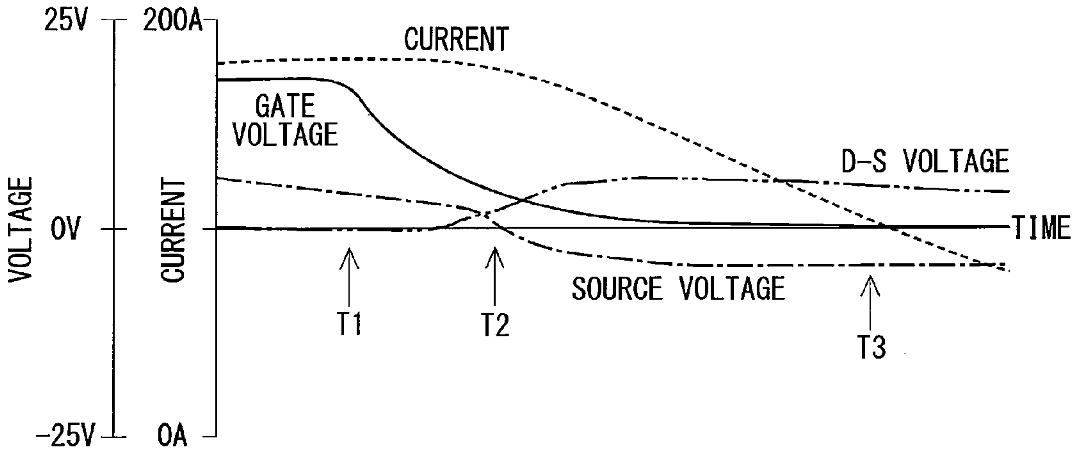

25V
200A
CURRENT
GATE VOLTAGE
D-S VOLTAGE
VOLTAGE
0V
CURRENT
TIME
SOURCE VOLTAGE
T1
T2
T3
-25V
0A

FIG. 4

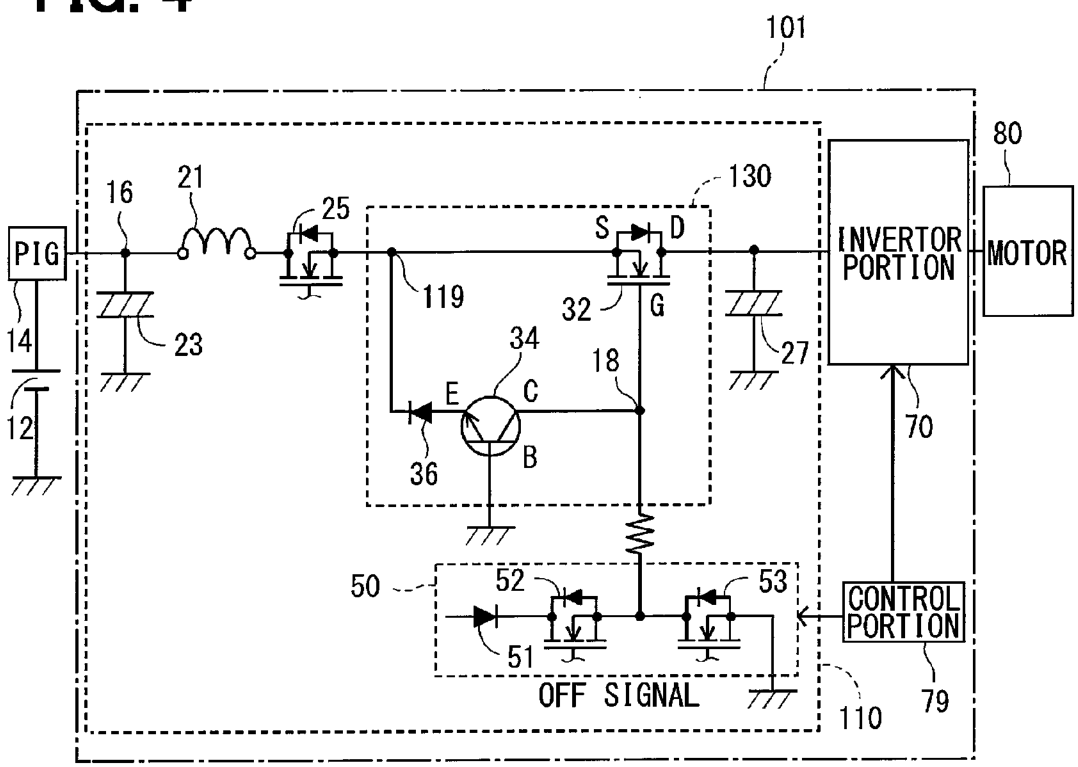

101
80
16
21
25
130
PIG
S
D
INVERTOR PORTION
MOTOR
119
32
G
14
23
34
27
18
E
C
12
70
36
B
50
52
53
CONTROL PORTION
51
OFF SIGNAL
110
79

FIG. 5A

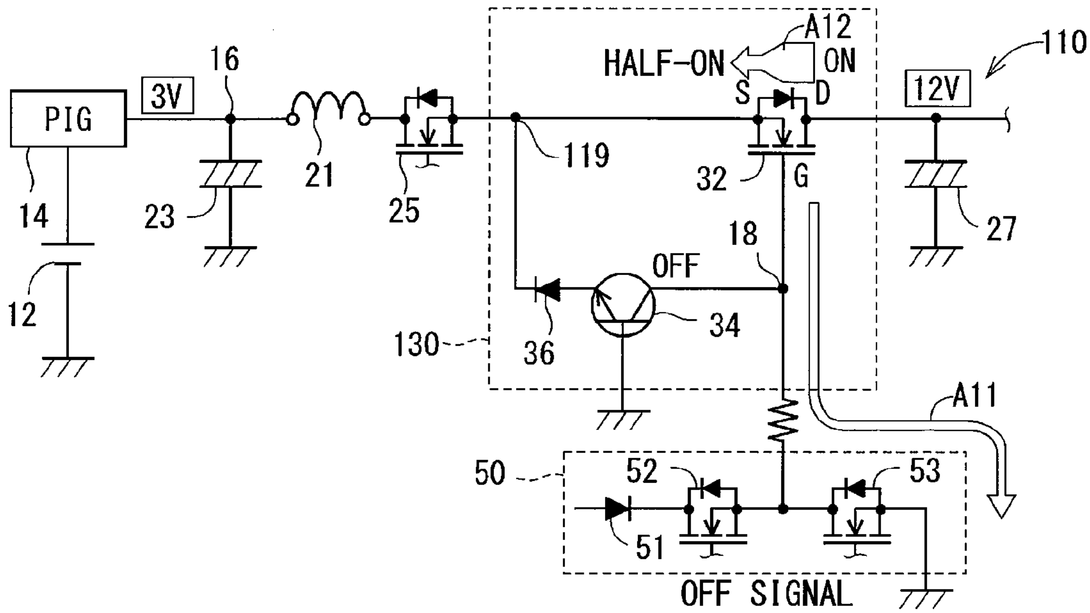

A12
HALF-ON
ON
S
D
110
12V
3V
16
PIG
21
25
119
32
G
14
23
27
18
OFF
12
34
130
36
A11
50
52
53
51
OFF SIGNAL

FIG. 5B

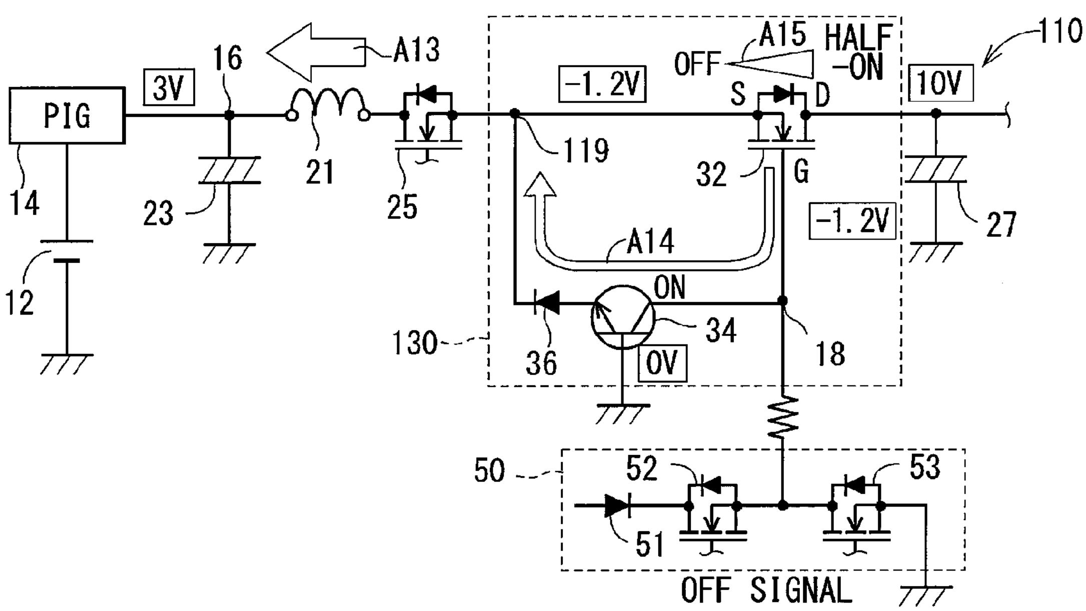
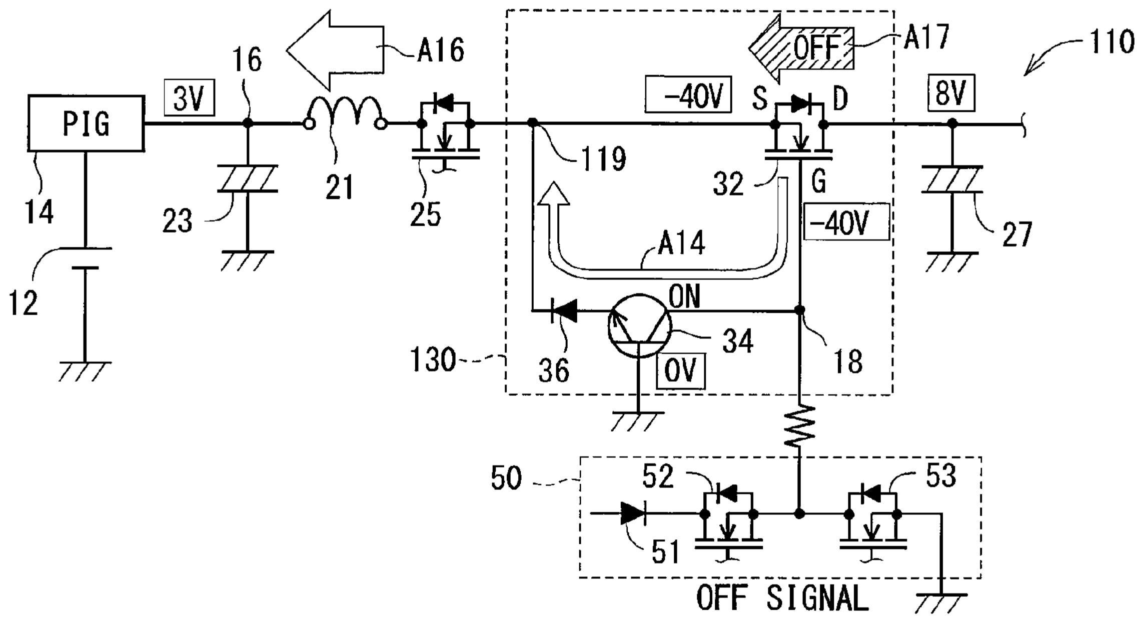
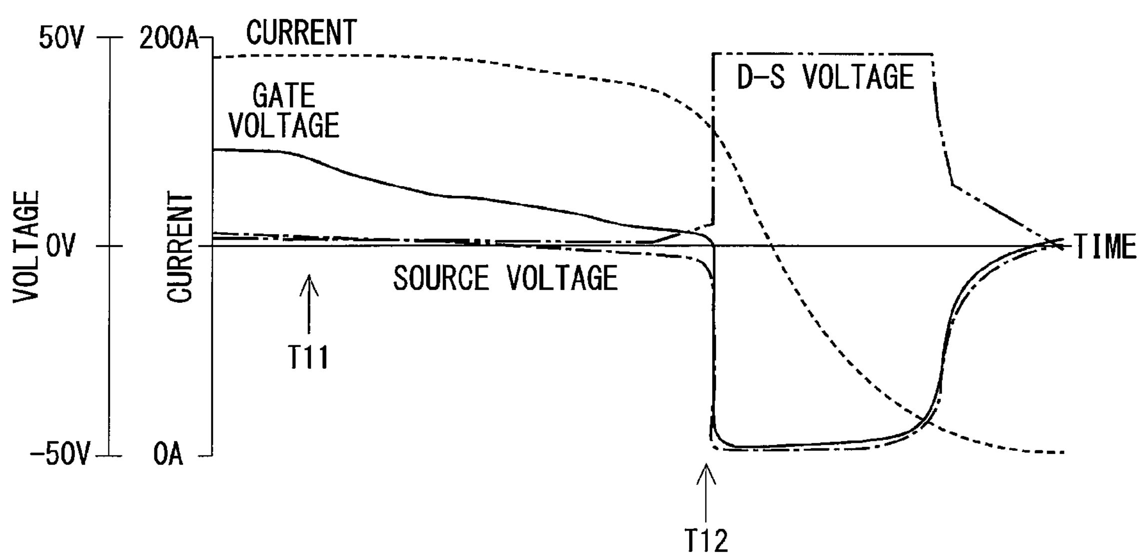

A13
16
A15
HALF
-ON
OFF
110
3V
-1.2V
S
D
10V
PIG
21
25
119
32
G
14
23
-1.2V
27
A14
12
ON
34
130
36
0V
18
50
52
53
51
OFF SIGNAL

FIG. 5C



A16
A17
OFF
110
16
3V
PIG
-40V
S
D
8V
14
21
25
119
32
G
23
27
-40V
A14
12
ON
34
130
36
0V
18
50
52
53
51
OFF SIGNAL

FIG. 6



50V
200A
CURRENT
D-S VOLTAGE
GATE
VOLTAGE
VOLTAGE
0V
CURRENT
TIME
SOURCE VOLTAGE
T11
-50V
0A
T12

SEMICONDUCTOR DEVICE AND MOTOR CONTROL UNIT

CROSS REFERENCE TO RELATED APPLICATION

This application is based on Japanese Patent Application No. 2015-45768 filed on Mar. 9, 2015, the disclosure of which is incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates to a semiconductor device and a motor control unit having the semiconductor device.

BACKGROUND

In a load driving circuit that drives a load using a direct current (DC) power source, for example, a metal-oxide-semiconductor field-effect transistor (MOSFET) that controls a current conduction has been conventionally used. In such a load driving circuit, when the DC power source is reverse-connected, that is, connected in reverse direction, there is a possibility that an unexpected current flows to the load through a parasitic diode of the MOSFET, and the MOSFET and the load are thermally destroyed. In JP 2014-50032 A, a load driving circuit is connected to a reverse-connection protecting circuit that can interrupt a current when a DC power source is reverse-connected.

SUMMARY

Generally, in a motor control unit used for an electronic power steering device or the like, a semiconductor device including the reverse-connection protecting circuit as described above is connected to an input terminal of a motor driving portion as the load driving circuit. The semiconductor device further includes a coil and a capacitor. The coil decreases a change of a current provided from the DC power source and absorbs a noise. The capacitor assists a power supplying to the motor driving portion.

When the DC power source is reverse-connected, a first switching element of the reverse-connection protecting circuit is turned off and a current flowing in a direction from the motor driving portion to the DC power source is interrupted. In order to turn off the first switching element, the semiconductor device is formed so that extra resistance such as a coil is not connected between a control terminal and an input terminal of the first switching element.

In such a semiconductor device, however, there is a possibility that the first switching element is destroyed (avalanche breakdown) due to an inductance of the coil and charge stored in the capacitor when a power supply voltage decreases.

It is an object of the present disclosure to provide a semiconductor device capable of restricting a breakage of a switching element even when a power supply voltage decreases, and to provide a motor control unit having the semiconductor device.

According to an aspect of the present disclosure, a semiconductor that is to be connected between a DC power source and a load driving circuit includes a first switching element, a pre-driver, a coil, a second switching element and a capacitor.

The first switching element is connected between the DC power source and the load driving circuit, and includes a control terminal and a parasitic diode having a cathode adjacent to the load driving circuit.

The pre-driver is connected to the control terminal of the first switching element and outputs a signal for switching on and off of the first switching element.

The coil is connected between the DC power source and the first switching element.

The second switching element includes an output terminal, an input terminal and a control terminal. The output terminal is connected to a first connection point between the DC power source and the coil. The input terminal is connected to a second connection point between the control terminal of the first switching element and the pre-driver. The control terminal is connected to a ground

The capacitor has one end connected to a point between the first switching element and the load driving circuit and another end connected to a ground.

In the above structure, the first switching element and the second switching element provide a reverse-connection protecting circuit that interrupts a current flowing from the load driving circuit to the DC power source when the DC power source is reverse-connected to the load driving circuit.

Specifically, when the DC power source is reverse-connected, the second switching element is forward-biased and turned on. Charge is released from the control terminal of the first switching element through the second switching element, and a voltage between the control terminal and the input terminal of the first switching element can be decreased to be lower than an on-threshold. In such a case, when the pre-driver outputs an off signal to the first switching element, the first switching element can be completely turned off. As such, the current flowing from the motor driving portion to the DC power source can be interrupted, and a breakage of the motor driving portion can be restricted.

In the above structure, the output terminal of the second switching element is connected to a point between the DC power source and the coil. In other words, the second switching element and the coil are connected to a wiring between the control terminal and the input terminal of the first switching element. As a result, the breakage of the first switching element does not occur when the DC power source is forward-connected.

Specifically, when the power supply voltage decreases, a current flows in a reverse direction from the capacitor to the DC power source due to charge stored in the capacitor. In such a case, when the pre-driver outputs an off signal to the first switching element, a state of the first switching element is changed to a half-on state and a regenerative current is generated in the coil.

In the present disclosure, however, even when the regenerative current is generated in the coil, the second switching element is not affected by the regenerative current and is kept in the off state. Therefore, the first switching element is kept in the half-on state and is not completely turned off. Hence, the avalanche breakdown does not occur in the first switching element.

Accordingly, the semiconductor device according to the aspect of the present disclosure can restrict the first switching element from being destroyed even when the power supply voltage decreases.

Also, the semiconductor device according to the aspect of the present disclosure can be employed to a motor control unit that is driven by electricity outputted from a motor driving portion as the load driving circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present disclosure will become more apparent from the following detailed description made with reference to the accompanying drawings, in which like parts are designated by like reference numbers and in which:

FIG. **1** is a circuit diagram illustrating a motor control unit including a semiconductor device according to an embodiment of the present disclosure;

FIG. **2**A to FIG. **2**C are schematic diagrams explaining operations of the semiconductor device of FIG. **1**;

FIG. **3** is a graph illustrating changes of a current and a voltage of a first switching element of the semiconductor device of FIG. **1**;

FIG. **4** is a circuit diagram illustrating a circuit structure of a motor control unit including a semiconductor device according to a comparative example;

FIG. **5**A to FIG. **5**C are schematic diagrams explaining operations of the semiconductor device of FIG. **4**; and

FIG. **6** is a graph illustrating changes of a current and a voltage of a first switching element of the semiconductor device of FIG. **4**.

DETAILED DESCRIPTION

A semiconductor device according to an embodiment of the present disclosure and a motor control unit including the semiconductor device will be described hereinafter with reference to drawings.

The motor control unit according to an embodiment of the present disclosure is employed to, for example, an electric power steering device of a vehicle. The electric power steering device can assist a steering operation of a driver by transmitting a steering assisting torque to a column or a rack through a reduction gear, the steering assisting torque being outputted by a motor driven by the motor control unit.

(Structure of Driving Device)

An electrical structure of a motor control unit **1** of the present embodiment will be described with reference to FIG. **1**. As shown in FIG. **1**, the motor control unit **1** is connected to a battery **12** through a power ignition (PIG) terminal **14**. The battery **12** is an example of a direct current power source. When a control circuit, which is not illustrated, is turned on, the motor control unit **1** starts its operation and controls a motor **80**, which is a load. For example, the motor **80** is a three-phase brushless motor.

The motor control unit **1** includes the semiconductor device **10**, an inverter portion **70** and a control portion **79**. The inverter portion **70** is an example of a load driving circuit (motor driving portion).

First, the semiconductor device **10** will be described. The semiconductor device **10** includes a coil **21**, a capacitor **23**, a power relay **25**, a reverse-connection protecting circuit **30**, a capacitor **27** and pre-drivers **40**, **50**.

The coil **21** is, for example, a choke coil. The coil **21** has one end connected to the battery **12** and the other end connected to the power relay **25**. The capacitor **23** has one end connected to a first connection point **16** between the battery **12** and the coil **21** and the other end connected to the ground.

The coil **21** and the capacitor **23** provide a filter circuit. The filter circuit reduces a noise that is transmitted to the motor **80** from other devices connected to the common battery **12**, and a noise that is transmitted to the other devices connected to the common battery **12** from the motor **80**. The coil **21** can reduce a change of a current provided by the battery **12**.

The power relay **25** is disposed between the coil **21** and a first switching element **32** of the reverse-connection protecting circuit **30** and can interrupt a current flowing in a direction from the battery **12** to the inverter portion **70**. The power relay **25** is, for example, a MOSFET.

The reverse-connection protecting circuit **30** includes the first switching element **32**, a second switching element **34** and a diode **36**.

The first switching element **32** is, for example, an N-channel-type MOSFET. The first switching element **32** is hereinafter referred to as a MOS **32**. The MOS **32** has a source connected to the power relay **25**, a drain connected to the inverter portion **70**. The MOS **32** is arranged so that a parasitic diode of the MOS **32** has a cathode adjacent to the inverter portion **70**. That is, a direction of the parasitic diode of the MOS **32** is opposite to a direction of a parasitic diode of the power relay **25**.

The second switching element **34** is, for example, an NPN-type bipolar transistor. The second switching element **34** is hereinafter referred to as a transistor **34**. The transistor **34** has an emitter connected to the first connection point **16** between the battery **12** and the coil **21**, and a collector connected to a second connection point **18** between a gate of the MOS **32** and the pre-driver **50**. A base of the transistor **34** is connected to the ground.

The diode **36** is disposed between the transistor **34** and the first connection point **16**. The diode **36** has a cathode adjacent to the first connection point **16**. When the battery **12** is forward-connected, that is, a connection direction of the battery **12** is forward (normal), the diode **36** interrupts a current flowing from the battery **12** to the transistor **34** through the first connection point **16**.

The capacitor **27** has one end connected to a point between the MOS **32** and the inverter portion **70** and the other end connected to the ground. The capacitor **27** stores charge to assist the power supplying to the inverter portion **70**. The capacitor **27** is, for example, an aluminum electrolytic capacitor that has a large capacity.

The pre-driver **40** is connected to the gate of the power relay **25** through a resistor **28** disposed between the power relay **25** and the pre-driver **40**. The pre-driver **40** includes a diode **41** and two switching elements **42** and **43**. In the present embodiment, the switching elements **42**, **43** are MOSFETs. The pre-driver **40** is controlled by the control portion **79** to output a signal for controlling on/off of the power relay **25** to the power relay **25**.

The pre-driver **50** is connected to the gate of the MOS **32** through a resistor **29** disposed between the MOS **32** and the pre-driver **50**. The pre-driver **50** includes a diode **51** and two switching elements **52** and **53**. In the present embodiment, the switching elements **52**, **53** are MOSFETs. The pre-driver **50** is controlled by the control portion **79** to output a signal for controlling on/off of the MOS **32** to the MOS **32**.

The gate of the MOS **32** is connected to the ground through a parasitic diode of the switching element **53** of the pre-driver **50**. Therefore, in order to completely turn off the MOS **32** when the battery **12** is reverse-connected, that is, when the connection direction of the battery **12** is reverse, the pre-driver **50** needs to output an off signal and, additionally, charge needs to be released from the gate of the MOS **32** through the transistor **34**.

When the pre-driver **50** outputs the off signal and the transistor **34** is off, the MOS **32** is in a half-on state. The half-on state is a state where a potential exists between the drain and the gate.

In the present embodiment, the inverter portion **70** is a three-phase inverter. The inverter portion **70** includes six switching elements **71** to **76** that are connected in a bridge configuration. The switching elements **71** to **76** are, for example, MOSFETs. Connection points between the high-potential-side switching elements **71**, **72**, **73** and the low-potential-side switching elements **74**, **75**, **76** are connected to an end of a winding of the motor **80** through power lines. The switching elements **71** to **76** execute switching operations to convert electricity provided by the battery **12** and provided to the motor **80**. The control portion **79** controls an operation of the inverter portion **70** based on external signals transmitted from a rotation angle sensor of the motor **80** and the like. Also, the control portion **79** outputs control signals to the pre-drivers **40** and **50**.

(Basic Operation of Reverse-Connection Protecting Circuit **30**)

When the battery **12** is reverse-connected, a base-emitter junction of the transistor **34** is forward-biased and the transistor **34** is turned on. Charge of the gate of the MOS **32** is released through the transistor **34** and the diode **36**. In such a case, when the pre-driver **50** outputs the off signal to the MOS **32**, a gate-source voltage of the MOS **32** is exhausted and the MOS **32** is completely turned off. As a result, a current flowing in a direction (reverse direction) from the inverter portion **70** to the battery **12** is interrupted.

Accordingly, the reverse-connection protecting circuit **30** can prevent the current from flowing in the reverse direction when the battery **12** is reverse-connected, and can restrict the other elements of the motor control unit **1** from being destroyed.

Comparative Example

A motor control unit **101** including a semiconductor device **110** will be described as a comparative example with reference to FIG. **4** to FIG. **6**. In the motor control unit **101** shown in FIG. **4**, similar structures to the embodiment described hereinabove are designated by the same symbols as the embodiment. In FIG. **5**A to **5**C, a part of the structure shown in FIG. **4** is omitted.

As shown in FIG. **4**, the motor control unit **101** includes the semiconductor device **110** and an inverter portion **70**. The semiconductor device **110** has a similar structure to the semiconductor device **10** of the above embodiment other than a point that the emitter of the transistor **34** is connected to a connection point **119** between the power relay **25** and the MOS **32**.

A basic operation of the reverse-connection protecting circuit **130** of the comparative example is similar to the embodiment described hereinabove.

Specifically, when the battery **12** is reverse-connected, the base-emitter junction of the transistor **34** is forward-biased and the transistor **34** is turned on. The gate charge of the MOS **32** is released through the transistor **34** and the diode **36**. In such a case, when the pre-driver **50** outputs the off signal to the MOS **32**, the gate-source voltage of the MOS **32** is exhausted and the MOS **32** is completely turned off. As a result, the current flowing in the direction (reverse direction) from the inverter portion **70** to the battery **12** is interrupted.

In the comparative example, in order to exhaust the gate-source voltage of the MOS **32** by the basic operation of the reverse-connection protecting circuit **130**, a resistance other than the transistor **34** is not connected to a wiring from the gate to the source of the MOS **32**. Therefore, the emitter of the transistor **34** is connected to the connection point **119** between the power relay **25** and the MOS **32**.

In the comparative example, however, when the battery **12** is forward-connected, there is the following issue. The issue of the comparative example will be described with reference to FIG. **5**A to **5**C and FIG. **6**. FIG. **6** is a graph illustrating changes of a gate voltage, a source voltage and a current of the MOS **32** while the power supply voltage decreases.

There is a possibility that the power supply voltage of the battery **12** decreases due to, for example, cranking. In such a case, the control portion **79** controlling the pre-driver **50** is shut down or executes an initial check at the time of restarting, and allows the pre-driver **50** to output the off signal (time point T**11**). As a result, as shown in FIG. **5**A, the gate charge of the MOS **32** is gradually released through the pre-driver **50** (see an arrow A**11**). A state of the MOS **32** is changed from an on state to a half-on state.

When the power supply voltage of the battery **12** decreases, a current flows in a direction (reverse direction) from the capacitor **27** storing the charge to the battery **12**. When the state of the MOS **32** is changed from the on state to the half-on state while the current flows in the reverse direction, the current flowing in the reverse direction through the MOS **32** is reduced (see an arrow A**12**).

When the current flowing through the MOS **32** is reduced, as shown in FIG. **5**B, a regenerative current is generated in the coil **21** to keep the current flowing (see an arrow A**13**). When the regenerative current flowing in the reverse direction is generated in the coil **21**, a voltage of the connection point **119**, which is located closer to the capacitor **27** than the coil **21**, decreases to be lower than 0V (for example, −1.2 V). In this case, the transistor **34** has an emitter voltage lower than 0V, and a base voltage equal to 0V. Since the base-emitter junction of the transistor **34** is forward-biased, the transistor **34** is tuned on.

When the transistor **34** is turned on, the gate charge of the MOS **32** is instantly released through the transistor **34** and the diode **36** (see an arrow A**14**), and the gate-source voltage of the MOS **32** is exhausted. In this case, the state of the MOS **32** is changed from the half-on state to the off state (time point T**12**). Also, the current flowing in the direction (reverse direction) from the capacitor **27** to the battery **12** is suddenly interrupted by the MOS **32** (see an arrow A**15**).

When the MOS **32** is turned off, as shown in FIG. **5**C, a larger regenerative current is generated in the coil **21** (see an arrow A**16**). In this case, the voltage of the connection point **119**, which is located closer to the capacitor **27** than the coil **21**, suddenly decreases. The MOS **32** has the gate voltage and the source voltage equal to or lower than, for example, −40V.

When the MOS **32** is turned off (time point T**12**), the charge of the capacitor **27** decreases, but still remains. Therefore, the drain voltage of the MOS **32** is larger than 0V (for example, about 8V).

Accordingly, the MOS **32**, which is turned off, has a voltage larger than a rated voltage that the MOS **32** can resist (for example, about 50V) between the drain and the source. As a result, an avalanche breakdown is occurred in the MOS **32**.

(Effects)

(1) As described above, the semiconductor device **10** of the present embodiment includes the MOS **32** as the first switching element, the pre-driver **50**, the coil **21**, the transistor **34** as the second switching element, and the capacitor **27**.

In the present embodiment, differently from the comparative example, the emitter of the transistor **34** is connected to the first connection point **16** between the battery **12** and the coil **21**. That is, the transistor **34** and the coil **21** are disposed on a wiring from the gate to the source of the MOS **32**. Also in this structure, the reverse-connection protecting circuit **30** can normally execute the basic operation when the battery **12** is reverse-connected.

According to the present embodiment, the issue occurring in the comparative example when the battery **12** is forward-connected, that is, the avalanche breakdown of the MOS **32** can be restricted. Effects of the present embodiment will be described with reference to FIG. **2**A to **2**C and FIG. **3**. FIG. **3** is a graph illustrating changes of the gate voltage, the source voltage and the current of the MOS **32** while the power supply voltage decreases. In FIG. **2**A to **2**C, a part of the structure shown in FIG. **1** is omitted.

When the power supply voltage of the battery **12** decreases due to, for example, cranking, the pre-driver **50** outputs an off signal (time point T**1**). As shown in FIG. **2**A, the gate charge of the MOS **32** is gradually released through the pre-driver **50** (see an arrow A**1**). A state of the MOS **32** is changed from an on state to a half-on state.

When the power supply voltage of the battery **12** decreases, a current flows in a direction (reverse direction) from the capacitor **27** storing the charge to the battery **12**. When the state of the MOS **32** is changed from the on state to the half-on state while the current flows from the capacitor **27** in the reverse direction, the current flowing through the MOS **32** in the reverse direction is reduced (see an arrow A**2**).

When the current flowing through the MOS **32** in the reverse direction is reduced, as shown in FIG. **2**B, a regenerative current is generated in the coil **21** to keep the current flowing (see an arrow A**3**).

When the regenerative current in the reverse direction is generated in the coil **21**, a voltage of a region closer to the capacitor **27** than the coil **21**, decreases to be lower than 0V (for example, −1.2 V). On the other hand, a voltage of the first connection point **16**, which is located closer to the battery **12** than the coil **21**, is substantially equal to the power supply voltage and larger than 0V (for example, 3V). In this case, the transistor **34** has the emitter voltage larger than 0V (for example, 3V) and the base voltage equal to 0V. Therefore, the base-emitter of the transistor **34** is reverse-biased, and the transistor **34** is kept in the off state. As a result, the gate charge of the MOS **32** is not instantly released through the transistor **34**, but gradually released through the pre-driver **50** (see an arrow A**1**).

Namely, right after the regenerative current is generated (time point T**2**), the gate voltage of the MOS **32** is kept larger than 0V (for example, around 4V) and the source voltage of the MOS **32** decreases to be lower than 0V (for example, −1.2V). Therefore, since the MOS **32** has the gate-source voltage (about 5V), the MOS **32** is kept in the half-on state and the current continues to flow through the MOS **32** in the reverse direction (see an arrow A**4**).

When the source voltage of the MOS **32** further decreases due to an effect of the regenerative current, the gate-source voltage of the MOS **32** relatively increases and the state of the MOS **32** approaches to the on state from the half-on state. In such a case, a reduction of the current in the reverse direction by the MOS **32** is weakened and the source voltage of the MOS **32** slightly increases. As a result, the state of the MOS **32** returns to the half-on state. The operation described above is repeated so that the MOS **32** is kept in the half-on state.

When entirety of the gate charge of the MOS **32** is released through the pre-driver **50** and the gate voltage of the MOS **32** decreases to be equal to 0V (time point T**3**), the source voltage of the MOS **32** further decreases (for example, −5V). That is, as shown in FIG. **2**C, the MOS **32** has the gate-source voltage (about 5V) and is kept in the half-on state.

As described above, while the power supply voltage decreases, the MOS **32** can be kept in the half-on state until the charge of the capacitor **27** is exhausted. As a result, in the MOS **32** of the present embodiment, the avalanche breakdown as described in the comparative example does not occur.

It is assumed the worst case scenario in which the power supply voltage decreases to 0V due to the cranking in the semiconductor device **10** including a wiring with a high inductance and the coil **21** with a low inductance. In such a case, there is a possibility that the voltage of the first connection point **16** is lower than 0V (for example, −3V). Since the base-emitter of the transistor **34** is forward-biased, the transistor **34** is turned on.

In the above structure, however, when the transistor **34** is turned on, the gate voltage of the MOS **32** is equal to the voltage of the first connection point **16**. On the other hand, the source voltage of the MOS **32** decreases to be lower than the voltage of the first connection point **16** due to a counter electromotive force generated in the coil **21**. Therefore, the MOS **32** has the gate-source voltage and can be kept in the half-on state. That is, the avalanche breakdown does not occur in the worst case scenario described above.

Accordingly, the semiconductor device **10** of the present embodiment can restrict the MOS **32** from being destroyed even when the power supply voltage decreases.

(2) In the present embodiment, the first switching element **32** is the MOSFET and the second switching element **34** is a bipolar transistor. The semiconductor device **10** can be suitably constituted by these switching elements.

(3) The semiconductor device **10** of the present embodiment can be employed to the motor control unit **1** including the inverter portion **70** as a concrete example of the load driving circuit. The motor control unit **1** includes the coil **21** and the capacitor **27** in order to drive the motor **80** stably. The coil **21** reduces the change of the current provided from the battery **12** and absorbs the noise. The capacitor **27** assists the power supplying to the inverter portion **70**. Therefore, the semiconductor device **10** of the present embodiment can be suitably employed to manage the issue caused by the inductance of the coil **21** and the charge stored in the capacitor **27**, that is, the avalanche breakdown of the first switching element **32**.

When the motor control unit **1** is employed to the electric power steering device, there is a possibility that the off signal is outputted to the MOS **32** when the power supply voltage decreases due to the cranking as described above. The semiconductor device **10** of the present embodiment can be especially effective in this case.

Other Embodiments

Although in the above embodiment, the first switching element **32** is the MOSFET and the second switching element **34** is the bipolar transistor, the first switching element **32** and the second switching element **34** are not limited to them and may be other switching elements.

In the above embodiment, an example is described in which the semiconductor device **10** is employed to the motor control unit **1** including the inverter portion **70** as the load driving circuit. However, the present disclosure is not limited to the above embodiment, and, for example, the load driving circuit may be other circuit such as an H bridge circuit.

Also, the load driving circuit may be a circuit driving a load other than the motor **80** such as the actuator.

The present disclosure is not limited to the embodiments and may be implemented in various other ways without departing from the gist of the present disclosure.

What is claimed is:

1. A semiconductor device connected between a direct current power source and a load driving circuit, the semiconductor device comprising:

a first switching element that is connected between the direct current power source and the load driving circuit and includes a control terminal and a parasitic diode having a cathode adjacent to the load driving circuit;

a pre-driver that is connected to the control terminal of the first switching element and outputs a signal for switching on and off of the first switching element;

a coil that is connected between the direct current power source and the first switching element;

a second switching element that includes an output terminal connected to a first connection point between the direct current power source and the coil so as to keep the second switching element in off state and restrict a charge of the first switching element being instantly released when a regenerative current is generated in the coil, an input terminal connected to a second connection point between the control terminal of the first switching element and the pre-driver, and a control terminal connected to a ground; and

a capacitor that has one end connected to a point between the first switching element and the load driving circuit and another end connected to a ground.

2. The semiconductor device according to claim **1**, wherein

the first switching element is a metal-oxide-semiconductor field-effect transistor, and

the second switching element is a bipolar transistor.

3. A motor control unit comprising:

the semiconductor device according to claim **1**;

a motor driving portion operating as the load driving circuit; and

a control portion controlling an operation of the motor driving portion, wherein

a motor is driven by an electricity outputted from the motor driving portion.

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