The lambda diode: a versatile negative-resistance device

Two-terminal unit with bistable switching characteristic can easily be integrated on same chip with other devices; potential applications include protection, switching, oscillator, and digital memory circuits

by Gota Kano, Hitoo Iwasa, Hiromitsu Takagi, and Iwao Teramoto, *Matsushita Electronics Corp., Takatsuki, Osaka, Japan*

☐ Applications for negative-resistance devices like the unijunction transistor and silicon-controlled rectifier have in the past been limited to pulse and switching circuits. However, a new monolithic negative-resistance device, the lambda diode, demonstrates a remarkable range of versatility in new applications and also simplifies the design of many conventional circuits.

Despite its exotic name, the lambda diode is actually a simple two-terminal device, consisting of a pair of complementary depletion-mode junction-field-effect transistors. A valuable feature of the diode, which can be fabricated more easily than conventional negative-resistance devices, is that it can be integrated on a single chip or with bipolar and MOS devices on the same chip. What's more, unlike tunnel diodes, which are limited to a narrow negative-resistance range, lambda diodes can be produced with a wide range of characteristics.

The lambda device permits switching, memory, oscillator, and amplifier circuits to be fabricated in fairly simple forms. Four versions of the diode, the series MEL 4880 device, packed in a hermetic TO-18 metal can, are available at $1.75 each in single quantities. Since the diode has a bistable switching characteristic that exhibits a virtual off state at fairly high voltages, it has many potential applications as an electronic fuse.

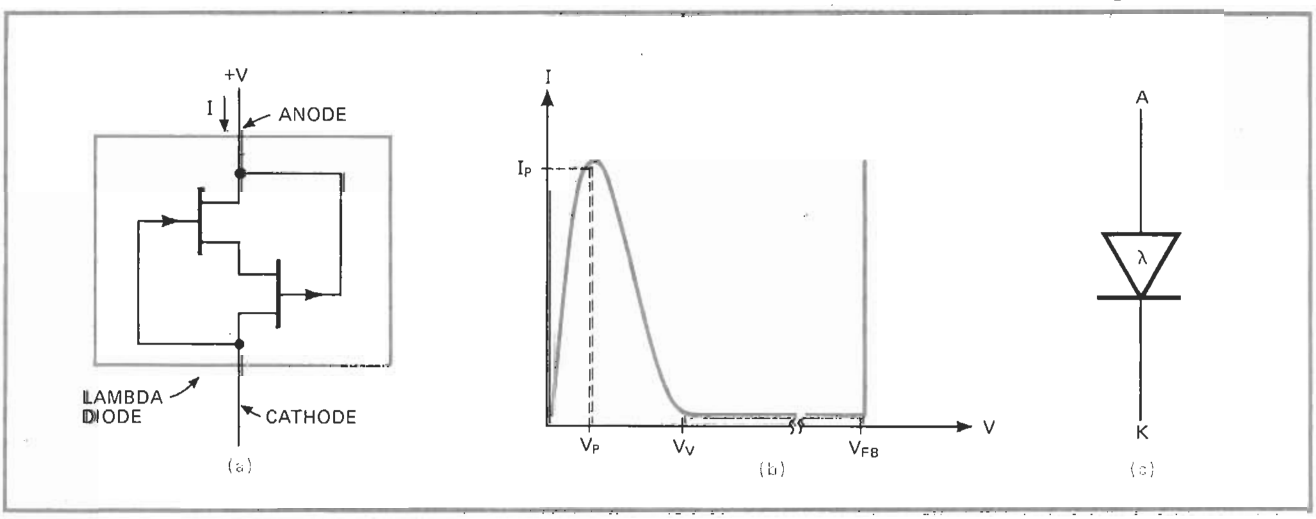
And because the device requires negligible standby power in its off state, it can be an automatic battery-voltage monitor in such products as cameras, tape recorders, portable television receivers, and automobiles. For battery-checking circuits, a special device, the MEL 4881S, is supplied in an axial-lead plastic package at about 35 cents each in production quantities.

Two other possible applications are in oscillator circuits and dc-to-ac power-conversion circuits. For these uses, the lambda diode provides high efficiency and good temperature stability, as well as a high-level constant-amplitude output. Because a lambda diode corresponds to a single flip-flop circuit, a sine-wave oscillator can be obtained merely by connecting an LC tank circuit to the device.

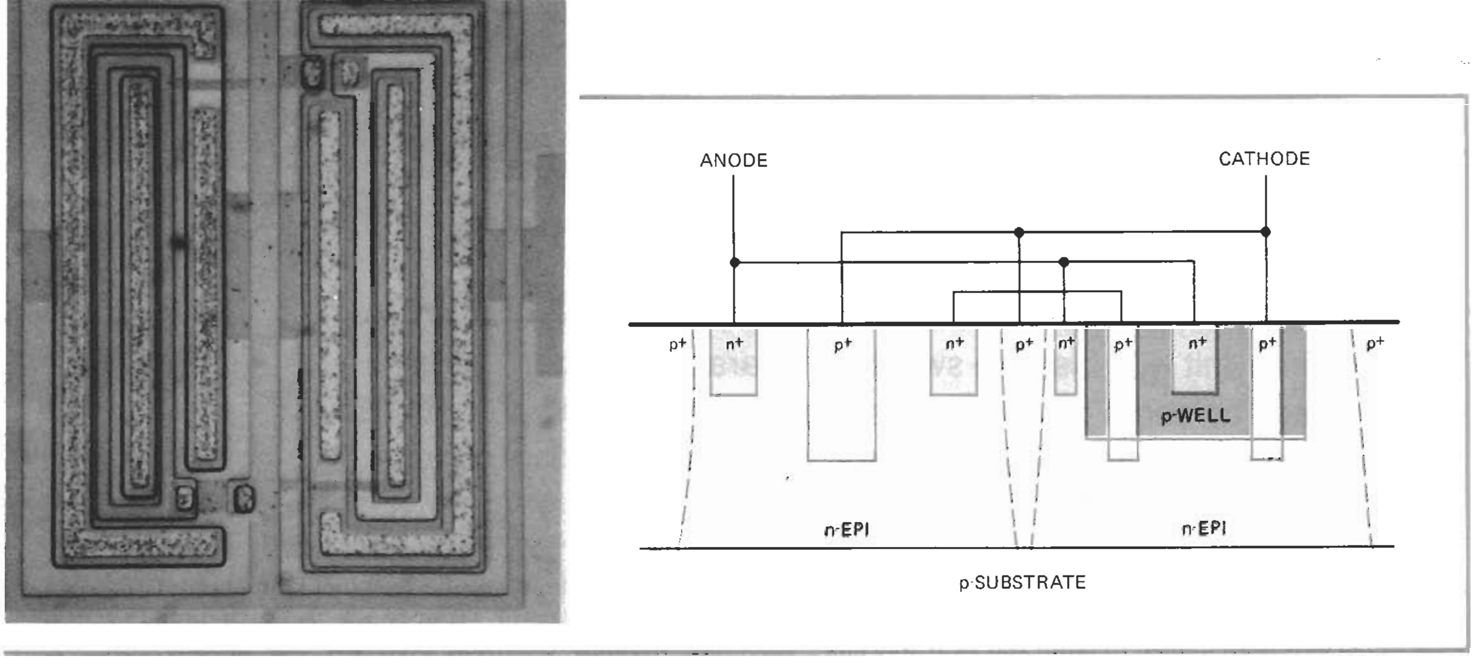
But of all the potential applications for the lambda diode, digital integrated circuits may well offer the most promising future. Not only can lambda devices be configured in diode arrays, but they can also become part of the unit-cell structure in a static MOS memory.

Examining the lambda diode

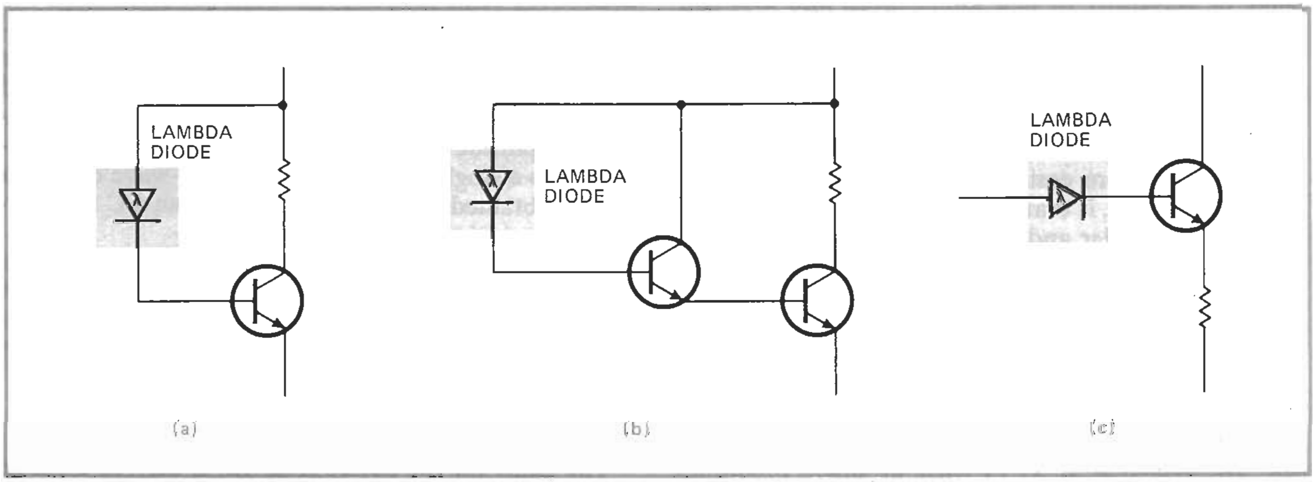
The name for the device (Fig. 1a) is derived from its lambda-shaped I-V characteristic curve (Fig. 1b), and the symbol for graphic representation is indicated in Fig. 1(c). When a positive voltage is applied to the anode of the diode, the current through the device in-



1. Introducing the lambda diode. Complementary JFETs are integrated on the same substrate and interconnected as shown in (a), forming a new monolithic device, called a lambda diode because of its lambda-shaped characteristic (b). Its graphic symbol is shown in (c).



2. Substrate structure. Since the lambda diode is fabricated essentially with only three diffusion steps, its structure is simple, enabling it to be easily integrated with other devices on the same substrate. In the photo, the n-channel JFET is on the left, the p-channel JFET on the right.



3. As a fuse. The lambda diode is an ideal protection device, because it exhibits a virtual off state at voltage levels on the order of 20 V. In (a), an overvoltage or overcurrent condition causes the diode to cut off, reducing transistor current practically to zero. The diode can even be operated well above its rated current or voltage levels, as indicated in (b) and (c), respectively.

creases until the applied voltage nearly equals the pinchoff voltage of either of the JFETs. The diode's current is now at its peak value, I_P, and the corresponding voltage level is called the peak voltage, V_P. If the applied voltage is increased further, the current will decrease until the applied voltage equals the sum of the pinchoff voltages of the two JFETs. At this valley voltage, V_V, both of the JFETs are in cutoff, so that the diode is in its off state, and leakage current is only in the nanoampere range. No matter how much more voltage is applied, the diode will remain off until the gate of either JFET breaks down. This ultimate voltage level is the forward breakdown voltage, V_{FB}.

Since the operating principle of the lambda diode is based on a functional integration of two complementary JFETs, rather than exotic physics, the device can be fabricated more easily than conventional negative-resistance devices. Figure 2 shows the basic structure of the lambda diode, which is fabricated in two epitaxial n-type isolation regions in p-type material. The n-channel JFET is obtained with two diffusions—the p^+ diffusion for the gate and the n^+ diffusion for the source and drain. The same p^+ diffusion forms the source and drain of the p-channel JFET, while the n^+ diffusion forms the gate.

Between these two diffusion steps, there is a p diffusion to form the p-type well of the p-channel JFET. The sources of the two transistors are joined together, and each transistor's gate is tied to the drain of the other transistor by an aluminum interconnection. A photograph of a chip surface is also shown in Fig. 2. The left-hand transistor is the n-channel JFET, the right-hand transistor is the p-channel JFET.

Because of its structure, the lambda diode is particularly suitable for integration with bipolar circuits. For instance, an npn or a pnp transistor, or both, can easily be fabricated on the same chip without any extra diffusion steps. With the structure of Fig. 2, an extra vertical pnp transistor can be obtained by putting an n-channel JFET on a different island.

Similarly, a p-channel JFET on a different island produces an extra vertical npn transistor. The only additional process required, other than the standard bipolar-type diffusions, is the formation of the p-type well layer for the p-channel JFET. This diffusion must be as low as 2×10^{16} atoms per cubic centimeter in impurity concentration and as thin as 0.8 micrometer in layer thickness to obtain a practical pinchoff voltage for the p-channel JFET.

In the four versions of the series MEL 4880 lambda diode available commercially, forward breakdown voltage is either 15 or 20 V maximum, depending on the model, while reverse voltage is 2 V maximum for all the units. The different versions (A, B, C, and D) are obtained by controlling the diffusion depth for the gate region of the p-channel JFET.

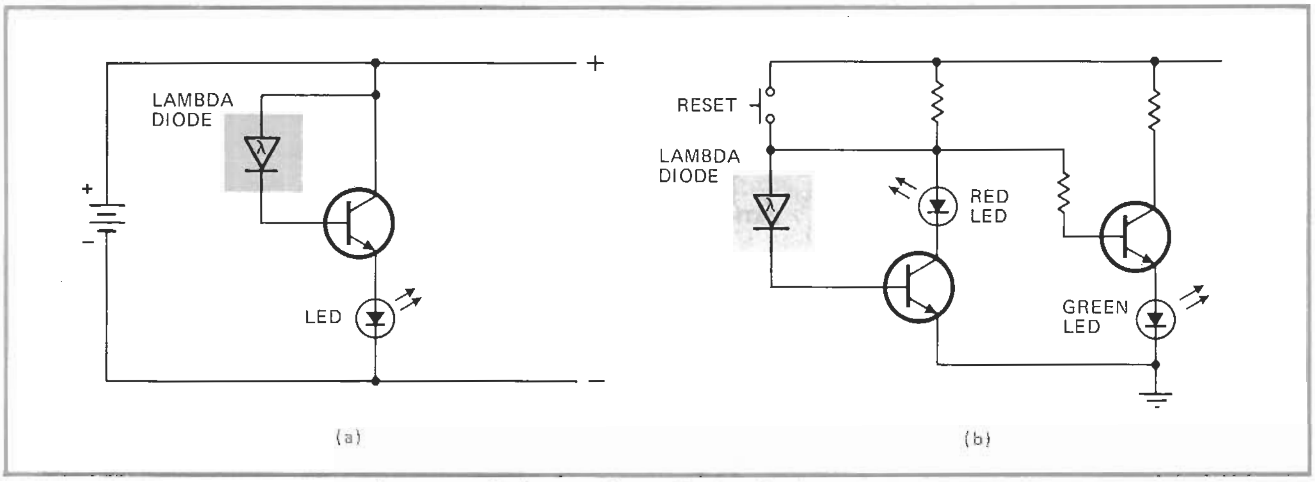
Typically, the peak current ranges from 0.06 to 0.7 milliampere, while valley or leakage current is in the order of a few nanoamperes. The result is that the peak-to-valley current ratio is around 10^5 or so. Values for the peak voltage range from 0.5 to 4 V, and for the valley voltage from 2.5 to 12 V.

Many potential applications are suggested for the lambda diode because it maintains a virtual off state at a fairly high voltage. For example, it can serve as a two-terminal voltage-controlled electronic fuse that blocks current effectively. Compared to its counterpart, the thermal fuse, the lambda diode offers the attractive features of nondestructive operation, fast switching, and low-current protection.

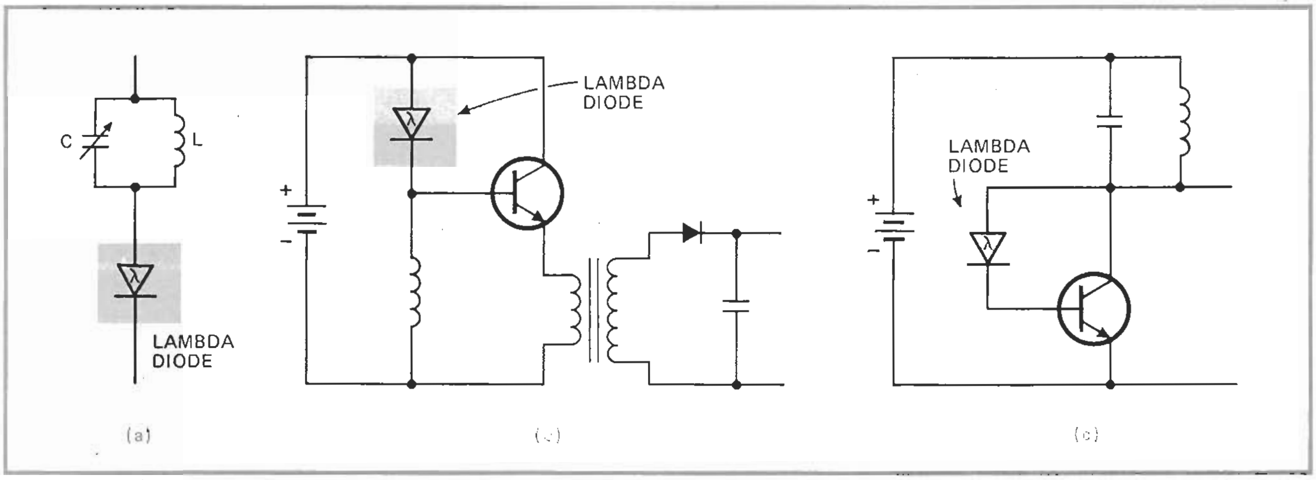
Using the lambda diode

Three-basic fuse-type applications are illustrated in Fig. 3. When the diode is connected as indicated in Fig. 3(a), an overload current will cause voltage across the device to increase until its cutoff state is reached, reducing the main line current through the power transistor practically to zero. Overvoltages in the main line will also produce the same result. Darlington configurations (Fig. 3b) enable the diode to work at currents of at least an ampere or so. To operate at voltages higher than the forward breakdown of the device, its anode terminal can be used as a sensing electrode (Fig. 3c).

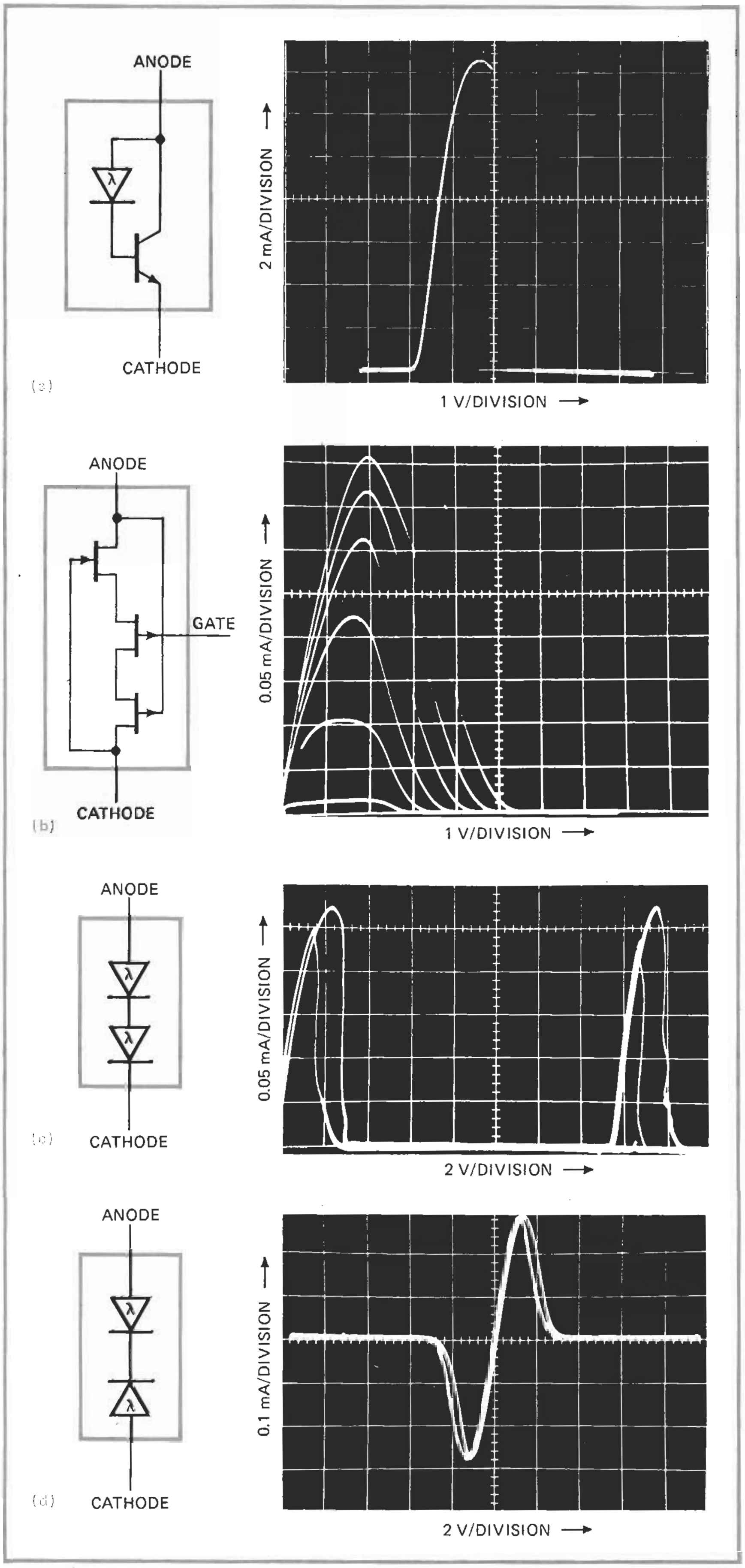
The diode also provides a bistable switching function with almost zero standby power, enabling it to check voltage automatically. In Fig. 4(a), for instance, the device is the heart of an automatic battery monitor. When the battery voltage drops below the desired level, the



4. As a monitor. Automatic voltage and power-monitoring are also applications for the lambda diode, which offers a bistable characteristic and requires negligible standby power. Here, the device is the key component in a battery checker (a) and a power-failure indicator (b).



5. As an oscillator. Building a sine-wave oscillator (a) is easy with the lambda diode—it is merely connected in series with an LC tank circuit. Similarly, the device can be used for a voltage-step-up circuit (b) or for a blocking oscillator (c).



6. Other possibilities. Different circuit functions can be obtained by combining the lambda diode with a conventional integrated device on the same chip. An npn transistor (a) will amplify the diode's peak current. With a third JFET (b), low peak currents can be controlled more precisely. Two series-connected diodes will provide two current peaks, either separated (c) when polarity orientation is the same, or symmetrical (d) when polarity orientation is opposing.