

CURRENT MEASURING METHOD, CURRENT SENSOR AND IC TESTING APPARATUS USING THE CURRENT SENSOR

TECHNICAL FIELD

5 The present invention relates to a current measuring method capable of providing a wide measuring range through the use of an optical modulator, a current sensor constructed by utilizing the current measuring method, and an IC (Integrated Circuit) testing apparatus that utilizes the current sensor. More
10 particularly, the present invention pertains to an IC testing apparatus that quickly measures a minute or very small current flowing through a power supply terminal of an IC under test constructed as a CMOS IC during its quiescent time and determines the quality of the IC (whether the IC is a defective
15 article or not) depending on whether the measured current value falls within a normal range or not.

BACKGROUND ART

20 There has heretofore been provided an IC testing method that measures a current flowing through an IC under test and determines whether the IC is a conforming or good article (pass article) or the IC is a non-conforming or bad article (failure article) depending on whether or not the current flowing through the power supply terminal of the IC under test falls within a
25 prescribed range.

Fig. 15 shows an example of the conventional testing method. A predetermined power supply voltage V_{DD} from a DC power supply 12 is supplied via a current measuring means 13 to

a power supply terminal T_{VDD} of an IC under test 11. The current measuring means 13 is constituted by a shunt resistor SR for converting a current to a voltage, a differential amplifier DF for having a potential difference produced across the shunt resistor SR as a voltage value inputted thereto, and limiter diodes D connected in parallel between input terminals of the differential amplifier DF.

The voltage signal outputted from the differential amplifier DF is sampled and held at a predetermined timing in a sample-and-hold circuit 14. The sampled and held voltage is converted into digital form by an A/D converter 15, and the digital output from the sample-and-hold circuit 14 is provided as a result of the measured current to an arithmetic and logic unit or operation processor 16 which determines whether the value of the measured current falls within a predetermined range.

In general, the IC under test 11 is constructed as a CMOS type circuit. As is well known, the CMOS type circuit is formed by an n-channel FET and a p-channel FET complementarily connected with each other, which alternately turn on and off respectively, thereby to transmit signals therethrough. For this reason, when the complementarily connected FETs change their states respectively, that is, one from on state to off state and the other from off state to on state, a relatively large current flows therethrough, and when they go to stable states, the current rapidly drops to a minute value (there may be a case that this current is called leakage current). That is, the current flows just like a pulse as shown in Fig. 16 by dotted lines.

The peak value of a large-current pulse I_{PL} flowing in the

form of a pulse is as large as several amperes in the case of a large-scale IC and a leakage current I_s that flows in the quiescent state is about several microamperes. A decision as to whether the IC under test 11 is defectless or defective is

5 rendered by measuring a leakage current I_s flowing in the stable state of the FETs and checking whether the leakage current I_s falls within a normal range or not. Accordingly, it is required to measure the leakage current I_s with high accuracy.

To meet such requirement, it is conventional to connect
10 the limiter diodes D to the input side of the differential amplifier DF. Since the limiter diodes D bypass the large-current pulse I_{PL} flowing through the shunt resistor SR, the current flow therethrough is limited and hence the amplitude of a voltage signal inputted to the differential amplifier DF is also limited to
15 operate the differential amplifier DF in its unsaturated region, thereby to measure the leakage current I_s .

Consequently, in the example shown in Fig. 16, the large current pulse I_{PL} flowing when the IC under test 11 changes its operation state is bypassed by the limiter diodes D, and during
20 the leakage current I_s is flowing, the limiter diodes D are held in the off state. As a result, a voltage induced across the shunt resistor SR when the leakage current I_s is flowing through the shunt resistor SR is taken out through the differential amplifier DF, the voltage thus taken out being fed to the arithmetic and
25 logic unit (hereinafter referred to as ALU) 16 after it is converted into a digital signal in the sample-and-hold circuit 14 and the A/D converter 15. The ALU 16 determines whether the IC under test is defective (failure) or not defective (pass).

Incidentally, such connection of the limiter diodes D to the input side of the differential amplifier DF results in a new disadvantage as will be described. That is, in case that the limiter diodes D are connected as in the above circuit

5 configuration, the current immediately after the large-current pulse I_{PL} does not rapidly reduce to the leakage current value due to the stored carriers and the junction capacitance inherent in the diode, which results in a phenomenon that the current comes to its stable state at a target leakage current value after a
10 certain time duration T_S has elapsed from a timing T_0 corresponding to the trailing edge of the large-current pulse I_{PL} as shown in Fig. 16 (this phenomenon will hereinafter be referred to as settling). Owing to the occurrence of this settling, a measuring point PT cannot be set until at least the time
15 duration T_S (this time duration T_S will be referred to as settling time, hereinafter) elapses from the timing T_0 corresponding to the trailing edge of the large-current pulse I_{PL} . In other words, no correct and accurate current value can be measured during the settling time T_S .

20 Furthermore, such conventional testing method measures the current I_S flowing into the power supply terminal T_{VDD} of the IC under test 11 when it is in its quiescent state. That is, such conventional testing method measures a leakage current of a large value that cannot flow inherently through the IC under test
25 and determines whether the IC under test is defective or not by checking the presence of the leakage current of a large value. Therefore, whether a failure part in the IC under test is reflected on the leakage of the power supply current or not relies on the

logical state of the failure part. As a result, it is necessary to change the combination of the logical states in the IC under test and measure the power supply current each time the combination of the logical states in the IC under test is changed. In order to
5 change the combination of the logical states, it is required to cause the IC under test 11 to be actuated inversely. Since the actuation of the IC under test 11 inevitably results in flow of the large-current pulse I_{PL} , to measure the leakage current I_S after the combination of the logical states has been changed will be
10 carried out after the settling time T_S has passed.

Thus, the measurement period T_{ES} during which the change of the combination of the logical states and the measurement of the leakage current I_S are repeated is affected by the length of the settling time T_S . That is, when the settling
15 time T_S is long, the period for changing the logical states in the IC under test 11 cannot be reduced, and consequently, the measurement period T_{ES} for the leakage current I_S also becomes long, resulting in a disadvantage that much time is needed to test every state of the IC under test 11. Since ICs show the tendency
20 to increase in their scale more and more, there is a drawback that the time needed to test such ICs becomes longer.

In addition, in the prior art, the DC power supply 12 and the current measuring means 13 are placed near the IC under test 11, that is, placed in a part called a test head, and the output
25 signal from the differential amplifier DF is transmitted via a cable or the like to the measuring instrument proper spaced apart from the test head, and in the measuring instrument proper the output signal is sampled and held, and then is converted into a

digital signal to compare and determine in the ALU 16 as to whether the IC under test is defective or not. With such configuration, when the distance between the test head and the measuring instrument proper is long, the output signal
5 transmitting therebetween is susceptible to the influences of an electrostatic capacity, a parasitic inductance and externally induced noises of the signal transmission path, which results in a shortcoming that the measuring accuracy is deteriorated.

A first object of the present invention is to provide a
10 current measuring method which is capable of widening a current measuring range, that is, widening a dynamic range to prevent the above-mentioned settling from occurring, and hence measuring a quiescent current in an IC under test within a very short time period immediately subsequent to the large-current
15 pulse, a current sensor using this current measuring method, and an IC testing apparatus utilizing this current sensor.

A second object of the present invention is to provide a current measuring method which is free from any adverse effects due to the signal transmission path and hence hardly suffers a
20 deterioration in the measuring accuracy even if the distance between the test head and the measuring instrument proper is long, and an IC testing apparatus utilizing this method.

DISCLOSURE OF THE INVENTION

25 The present invention provides a current measuring method comprising the steps of: converting a current to be measured in which a pulse-like large current of large amplitude and a minute current alternately appeared in time, into a voltage

signal; supplying the voltage signal to an electric field applying
electrode of an optical modulator to modulate light passing
through the optical modulator; causing the modulated light to
interfere with unmodulated light to obtain interference light; and
5 converting the intensity of the interference light into an electric
signal by a photodetector to be taken out as an electric signal
corresponding to the value of the current to be measured.

With the current measuring method according to the
present invention, the optical modulator does not saturate even if
10 an electric field of great amplitude is applied to the optical
modulator, and no settling occurs even immediately after a
pulse-like voltage signal of great amplitude has been applied to
the optical modulator.

Accordingly, even if the ratio between the large-current
15 pulse I_{PL} and the leakage current I_S flowing through the IC under
test in the quiescent state thereof is large and even immediately
after the large-current pulse I_{PL} has flowed, the leakage current
 I_S can be measured without being affected by the settling.

Moreover, the present invention provides an IC testing
20 apparatus utilizing the above-mentioned current measuring
method. The IC testing apparatus according to the present
invention, which measures the leakage current flowing through a
CMOS IC under test in its quiescent state of each state when the
CMOS IC has inverted in its state of operation, and renders a
25 decision that the IC under test is defective or not defective
depending upon whether the measured leakage current in the
quiescent state of the IC under test is larger or smaller than a
prescribed value, is capable of measuring the leakage current

without any influence of the settling even just after the operation state of the IC under test has been changed, and hence quickly inverting the operation state of the IC under test to measure the leakage current in each inverted operation state.

5 Accordingly, the IC testing apparatus according to the present invention has an advantage that the time duration needed for testing ICs can be reduced even if they are large scale integrated circuits.

10 Further, according to the present invention, it is possible to use an optical waveguide for connecting between the test head with the IC under test mounted thereon and the measuring instrument proper which performs processings of comparison operation of current values and so forth. There is no possibility that the optical waveguide is adversely affected by an
15 electrostatic capacity, a parasitic inductance, externally induced noises or the like. As a result, there is obtained an advantage that the accuracy of measurement can be maintained high even if the distance between the test head and the measuring instrument proper becomes long.

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BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a plan view for explaining a current measuring method according to the present invention and a current sensor using this current measuring method;

25 Fig. 2 is a plan view for explaining the operation of an optical modulator for use in the current measuring method and the current sensor according to the present invention;

Fig. 3 is a waveform diagram for explaining the operation

of the optical modulator depicted in Fig. 2;

Fig. 4 is a waveform diagram for explaining the operation of the embodiment shown in Fig. 1;

Fig. 5 is a plan view illustrating a modified embodiment
5 of the current sensor shown in Fig. 1;

Fig. 6 is a plan view for explaining another example of the current measuring method according to the present invention;

Fig. 7 is a perspective view illustrating an example of the specific structure of the optical modulator for use in the current
10 sensor according to the present invention;

Fig. 8 is a plan view for explaining an example of the IC testing apparatus using the current sensor according to the present invention;

Fig. 9 is a waveform diagram for explaining the operation
15 of the embodiment shown in Fig. 8;

Fig. 10 is a plan view for explaining a modified form of the embodiment shown in Fig. 8;

Fig. 11 is a waveform diagram for explaining the operation of the modified embodiment shown in Fig. 10;

Fig. 12 is a plan view for explaining a modified form of
20 the embodiment shown in Fig. 8;

Fig. 13 is a perspective view for explaining a still another modification of the embodiment shown in Fig. 8;

Fig. 14 is a plan view for explaining a modified
25 embodiment of the IC testing apparatus according to the present invention;

Fig. 15 is a schematic diagram for explaining an example of the prior art; and

Fig. 16 is a waveform diagram for explaining the operation of the prior art shown in Fig. 15.

BEST MODE FOR CARRYING OUT THE INVENTION

5 A description will be given, with reference to Fig. 1, of a current measuring method according to the present invention, the configuration and operation of a current sensor utilizing the current measuring method. In Fig. 1, reference numeral 10 denotes a circuit under measurement which outputs a current to
10 be measured I_M , and 20 denotes a current sensor for measuring the value of the current to be measured I_M by use of the current measuring method proposed by the present invention.

 The present invention provides the current measuring method which measures the current to be measured I_M by
15 applying it to a current-voltage converter 30, inputting a voltage signal VS generated therefrom into an optical modulator 40 to convert the voltage signal VS into interference light, and converting the intensity of the interference light into an electric signal.

20 Specifically, the current sensor 20 according to the present invention is constructed by a substrate 21, the current-voltage converter 30 mounted on the substrate 21, and the optical modulator 40 also mounted on the substrate 21 so that the current-voltage converter 30 generates the voltage VS
25 corresponding to the value of the current to be measured I_M , the voltage VS being applied to the optical modulator 40.

 As the optical modulator 40, a branched interferometric modulator shown in Fig. 2 may be used, for example. The

branched interferometric modulator 40 comprises an optical branching part 42 for branching an optical waveguide, an optical coupling part 43, two optical waveguides 44A and 44B formed between the optical branching part 42 and the optical coupling part 43, and electric field applying electrodes 45, 46 and 47
5 formed along both sides of each of the two optical waveguides 44A and 44B.

The optical branching part 42, the optical coupling part 43 and the optical waveguides 44A and 44B can be formed by
10 diffusing, for example, titanium or the like into a dielectric substrate 41 made of lithium niobate (LiNbQ_3) or the like, for instance. Optical waveguides such as optical fibers are optically coupled as an input optical waveguide 22 and an output optical waveguide 23 to a light receiving end 49A and a light emitting
15 end 49B formed and exposed on the end surfaces of the dielectric substrate 41, respectively, and a light source 51 such as a laser diode is coupled to the other end of the input optical waveguide 22 coupled to the light receiving end 49A, and a
20 photodetector 53 such as a photodiode is coupled to the other end of the output optical waveguide 23 coupled to the light emitting end 49B.

The light source 51 is driven to its lighting state by a light source driving circuit 52. This example shows that the light source 51 is driven by a DC power supply. Accordingly, the
25 light source 51 emits a fixed quantity of laser light into the input optical waveguide 22. To the photodetector 53 is connected a detecting circuit 54 which converts the intensity of light emitted from the output optical waveguide 23 into an electric signal to

be taken out.

The voltage VS generated from the current-voltage converter 30 is applied to one of pairs of the electric field applying electrodes 45, 46, and 47. The example shown in Fig. 1 shows the case that the voltage VS generated from the current-voltage converter 30 is applied between the electric field applying electrodes 45 and 46, and the electric field applying electrodes 45 and 47 of the other pair are connected in common and no electric field is formed therebetween.

By applying an electric field to the one optical waveguide 44A and no electric field to the other optical waveguide 44B as mentioned above, light passing through the optical waveguide 44A applied with the electric field is phase modulated therein and light passing through the optical waveguide 44B applied with no electric field is not modulated. Due to the phase modulation of light given in the optical waveguide 44B, interference of light occurs in the optical branching part 43, and the intensity of light emitted to the output optical waveguide 23 varies accordingly.

This manner will be described with reference to Figs. 2 and 3. Let the intensity of light incident to the input optical waveguide 22, the intensity of light outputted to the output optical waveguide 23 and the voltage applied to the electric field applying electrodes 45 and 46 be represented by P_{in} , P_{out} and VS, respectively. With a change of the applied voltage VS, the intensity P_{out} of light which is emitted to the output optical waveguide 23 varies along a cosine curve as depicted in Fig. 3A. That is, when the applied voltage VS is 0 ($VS=0$), P_{out} equals to

P_{in} ($P_{out} = P_{in}$), and when the voltage V_S is gradually varied in the positive (+) direction or negative (-) direction, the quantity of output light gradually decreases along the cosine curve and at a certain voltage the quantity of output light goes down to zero.

5 When the applied voltage V_S is further increased therefrom, the output light intensity P_{out} gradually increases along the cosine curve and when it is increase to a certain voltage, the output light intensity P_{out} goes to "1", namely, $P_{out} = P_{in}$. With the subsequent change in the voltage V_S , the output light intensity

10 P_{out} shows an optical modulation characteristic that it goes up and down between 1 and 0. Further, the optical modulation characteristic shown in Fig. 3A is one obtained from the case that the optical waveguides 44A and 44B have the same optical path length. When one of the optical waveguides 44A and 44B

15 has its optical path length longer than that of the other by a quarter of the wavelength of light propagating through the one optical waveguide, or when a bias electric field is applied to either one of the optical waveguides 44A and 44B, an optical modulation characteristic is obtained, as shown in Fig. 3B, that

20 the output light intensity varies along the sine curve with a change in the applied voltage V_S . That is, this optical modulation characteristic shows that the output light intensity sharply varies about the applied voltage $V_S = 0$. The following description will be given on the assumption that the optical

25 modulator 40 has the optical waveguides 44A and 44B the optical path length of one of which is longer than that of the other by a quarter of the wavelength of light passing through the one optical waveguide and hence it operates with the modulation

characteristic shown in Fig. 3B.

As is evident from the modulation characteristics of the optical modulator 40 described above, the intensity P_{out} of light outputted from the optical modulator 40 is expressed by a value
5 between the state $P_{out} = P_{in}$ and 0, that is, between $P_{out}/P_{in}=1$ and $P_{out}/P_{in}=0$, no matter what value an inputted electric field to the optical modulator may have, and therefore, the detecting circuit 54 shown in Fig. 1 needs only to measure a voltage between $P_{out}/P_{in}=1$ and $P_{out}/P_{in}=0$ to specify the value of the current to be
10 measured I_M .

In other words, when the value of the current to be measured I_M is large, the value thereof can be obtained by counting the number of times that the output light intensity P_{out} reaches, for example, 0 and by measuring the value between
15 $P_{out}/P_{in}=1$ and $P_{out}/P_{in}=0$ after it has finally reached 0. The value of the minute current I_S can also be obtained from a value between $P_{out}/P_{in}=1$ and $P_{out}/P_{in}=0$. Accordingly, the detecting circuit 54 is inputted with only a voltage between $P_{out}/P_{in}=1$ and $P_{out}/P_{in}=0$, no matter what value the input current to the current-voltage converter 30 may have. As a result, the detecting circuit
20 54 cannot saturate even without any limiter circuit, and can measure the voltage corresponding to the current value.

Consequently, no settling phenomenon occurs even immediately after the large-current pulse I_{PL} has appeared as shown in Fig. 4,
25 and hence the minute current I_S can be measured when a minute time interval has passed from the timing T_0 of the trailing edge of the large-current pulse I_{PL} . By applying this current sensor to the IC testing apparatus for measuring a leakage current which

flows through a CMOS IC under test in its quiescent state, thereby to determine whether the CMOS IC is defective or not defective, there is obtained an advantage that a high-speed testing can be carried out.

5 Further, since the detecting sensitivity of the current sensor 20 is proportional to the electrode lengths L of the electric field applying electrodes 45, 46 and 47 and inversely proportional to the spacing between adjacent electrodes, a desired sensitivity can be obtained by reducing the electrode
10 spacing and increasing the electrode lengths L. In addition, the detecting sensitivity of the current sensor 20 can also be enhanced by increasing the intensity of light emitted from the light source 51.

Moreover, it is possible to double the detecting sensitivity
15 of the current sensor by differentially applying the voltage VS to the two optical waveguides 44A and 44B as shown in Fig. 5.

Fig. 6 illustrates another embodiment of the current measuring method according to the present invention. In this embodiment an optical switch 55 is disposed at the light source
20 51 side, and switching pulses SWP are applied to the optical switch 55, thereby to input light incident to the optical modulator 40 thereinto as an optical pulse 56 in accord with a timing of the measurement, and the amount of the optical pulse 56 transmitted through the optical modulator 40 is detected by
25 the photodetector 53. Thus, the current value to be measured at the intended timing point can be measured with high accuracy.

That is, the timing point for measuring the current value is determined by the timing of the application of the optical pulse

56. Accordingly, the timing point for measuring the current value can be set with fine resolution by reducing the pulse duration or width of the optical pulse 56. Since the photodetector 53 needs only to measure the total quantity of light transmitted through the optical modulator, the value of the current I_M to be measured can be measured by measuring an integration voltage integrated in an integration circuit 57 provided at the output side of the detecting circuit 54. Therefore, no fast response is required at the photodetector 53 side. Thus, a measurement with fine resolution in measuring timing can be carried out by requiring only the optical switch 55 to operate at high-speed and without requiring fast operations for other elements and circuits.

Fig. 7 illustrates an example of the specific structure of the current sensor 20. The substrate 21 can be formed of an insulating material such as ceramic. The current-voltage converter 30 is constructed by depositing a resistance film 31 on one surface of the substrate 21 a resistance film 31 which constitutes the current-voltage converter 30, depositing electrodes 32 and 33 on opposite ends of the resistance film 31 respectively, and electrically connecting one ends of the electrodes 32 and 33 to current measuring terminals 34 and 35 respectively.

The substrate 21 can be made of a member having its size of approximately 10 mm by 10 mm. The current sensor 20 can be constructed by mounting a dielectric substrate 41 constituting the optical modulator 40 on the blank space on the surface of the substrate 21 on which the current-voltage converter 30 is formed.

Between the electrodes 32, 33 and the electric field applying electrodes 46, 45 constituting the optical modulator 40 can be electrically connected by, for example, bonding wires BF or the like. The current sensor 20 having a card-like shape as shown in
5 Fig. 7 is effective in its application to an IC testing apparatus described hereinafter.

Fig. 8 illustrates an example of the IC testing apparatus to which the current measuring method and the current sensor 20 according to the present invention are applied. This embodiment
10 shows the IC testing apparatus to which the current sensor 20 described above with reference to Figs. 1 through 6 is applied. A power supply voltage V_{DD} is given from a DC power supply 12 to a power supply terminal T_{VDD} of an IC under test 11 and a common terminal T_{VSS} thereof is connected to a common
15 potential point. The current-voltage converter 30 constituting the current sensor 20 according to the present invention is inserted in this power supply path in series therewith so that a current I_{DD} flowing to the power supply terminal T_{VDD} of the IC under test 11 is fed to the current-voltage converter 30, thereby
20 to generate therein the voltage V_S corresponding to the value of the current I_{DD} . The voltage V_S is applied between the electric field applying electrodes 45 and 46 to operate the optical modulator 40 to give to light an optical modulation corresponding to the value of the current flow to the power
25 supply terminal T_{VDD} of the IC under test 11.

The photodetector 53 converts the intensity of light outputted from the output optical waveguide 23 into an electric signal which is, in turn, outputted as a voltage signal from the

detecting circuit 54. The voltage signal outputted from the detecting circuit 54 is supplied to a sample-and-hold circuit 14 where it is sampled by a sampling pulse TGP and held therein, the sampling pulse being outputted from, for example, a pattern
5 generator 58 at the timing at which the IC under test 11 is in its quiescent state. The value of the sampled and held voltage is converted in an A/D converter means 15 to digital form, and the digital signal is inputted into an ALU 16 which in turn determines whether the value of the input digital signal falls
10 within a desired voltage range or not, thereby rendering a decision that the IC under test 11 is defective (failure) or not defective (pass).

The pattern generator 58 applies a driving signal to the IC under test 11 to change or invert its state step by step, and a test
15 is made to determine whether the value of the power supply current I_{DD} in the quiescent state of the IC under test at each step falls within a predetermined range or not.

The sample-and-hold circuit 14 is supplied with the sampling pulse TGP at a timing T_{ST} after a slight time interval
20 has passed from the trailing edge of the large-current pulse I_{PL} which flows through the IC under test 11, as shown in Fig. 9. As a result, the sample-and-hold circuit 14 measures the minute current I_S in each quiescent state of the IC under test 11 after the IC under test 11 has done its inverse operation step by step, and
25 the measured current value is compared with a preset value in the ALU 16 to determine whether the IC under test is defective or not defective.

As shown in Fig. 8, by using the current sensor 20

according to the present invention in the IC testing apparatus, it is possible to operate the current sensor 20 and the detecting circuit 54 without saturating them even if the IC under test 11 intermittently consumes the large-current pulse I_{PL} . Accordingly, the embodiment shown in Fig. 8 makes it possible that the sample-and-hold circuit 14 is activated at the timing T_{ST} immediately following the large-current pulse I_{PL} to sample and hold, the sampled signal is converted into a digital signal in the A/D converter 14, and the ALU 16 determines whether the IC under test 11 is defective or not defective on the basis of the digital signal. In this instance, the sample-and-hold circuit 14 can sample and hold the current signal at a timing point just after a slight time interval T_{ST} has passed from the falling edge of the large-current pulse I_{PL} , and it is possible to carry out the measurement in a short time period. Thus, the period T_{ES} that the IC under test 11 is inverted in its operation state can be reduced, and hence a practical benefit is obtained that the time duration needed to test an IC under test can be shortened even if the IC under test is tested in its every operation state. In addition, since the embodiment shown in Fig. 8 is insusceptible to external electromagnetic waves even if the input optical waveguide 22 and the output optical waveguide 23 are made long, the measuring accuracy does not deteriorate even in the case that the photodetector 53 is placed at a position greatly spaced apart from the IC under test 11. Accordingly, the accuracy of test does not deteriorate even if the IC testing apparatus proper has the photodetector 53 housed therein.

Fig. 10 illustrates another IC testing apparatus in which

an optical switch 55 is inserted in the input optical waveguide 22 coupling between the light source 51 and the optical modulator 40, and the optical switch 55 is turned on and off in synchronism with a timing for the measurement of current, 5 thereby to apply the optical pulse 56 (see Fig. 11B) to the optical modulator 40 in synchronism with the timing for the current measurement.

In this case, at the output side of the detecting circuit 54 is provided the integration circuit 57 which integrates the total 10 quantity of light received by the photodetector 53, the resulting integration voltage INTV (see Fig. 11C) is sampled in synchronism with the sampling pulse TGP (see Fig. 11D) and held in the sample-and-hold circuit 14, and the sampled voltage is converted to a digital signal in the A/D converter 15 to be 15 inputted into the ALU 16. The integration voltage INTV in the integration circuit 57 is reset by the reset pulse RSP shown in Fig. 11E upon each completion of sampling.

As described above, in the case of employing the configuration in which the optical pulse 56 is inputted into the 20 optical modulator 40, as already discussed with reference to Fig. 6, the measurement timing is determined by the timing of application of the optical pulse 56 to the optical modulator. Therefore, there is obtained an advantage that by reducing the pulse duration or width of the optical pulse 56, the resolution of 25 the measurement timing in the direction of time base can be made fine. Moreover, according to this embodiment, the photodetector 53, the detecting circuit 54 and the sample-and-hold circuit 14 need only to obtain the value corresponding to

the total quantity of light received by the photodetector 53, and hence they need not have fast-response characteristic. This also provides an advantage that the IC testing apparatus can be constructed by using elements which need not operate at high speed and hence are inexpensive.

Fig. 12 illustrates a still another embodiment of the IC testing apparatus used in testing an IC of the type having a plurality of power supply terminals T_{VDD} . In Fig. 12 there are not shown the pattern generator 58, the driving circuit for the light source 51, and the internal configuration of the current sensor 20.

In this embodiment, there are provided a plurality of current sensors 20 the number of which is equal to that of the power supply terminals T_{VDD} of the IC under test 11. Specifically, in this embodiment, four current sensors 20 are provided, and one end of the current-voltage converter 30 in each of the four current sensors 20 is connected to the positive voltage terminal of the DC power supply 12, and the other end of each current-voltage converter 30 is connected to an associated power supply terminal T_{VDD} . Furthermore, the input and output optical waveguides 22 and 23 to be connected to each of the optical modulators 40 are connected in series, and the light source 51 is optically coupled to one end of the series-connected optical waveguides and the photodetector 53 is optically coupled to the other end thereof.

With such arrangement, the quantity of light received by the photodetector 53 corresponds to the sum total of amounts of optical modulations that are given to light by the four current

sensors 20 respectively when the light has passed therethrough, and also that quantity of light corresponds to the sum total of the values of currents each flowing to the associated power supply terminal T_{VDD} . Accordingly, an adding means is constituted by the optical system, and the sum of the values of currents flowing through the plurality of power supply terminals T_{VDD} can be measured by one light source 51, one photodetector 53 and one detecting circuit 54. Consequently, it is possible to determine whether the sum of the values of currents flowing through the respective power supply terminals T_{VDD} falls within the range of normal values or not.

Fig. 13 illustrates a modified form of the embodiment shown in Fig. 12. This modified embodiment shows the case that probes 63 are brought into contact with electrode portions of IC chips 62 formed on a wafer 61 thereby directly testing the ICs under their chip state.

Conventionally, the probes 63 are supported by a ring-shaped probe card 64 so as to extend toward the center thereof, and the tip of each probe 63 is brought into contact with the electrode portion of each chip formed on the wafer 61. A power supply current and a driving signal are supplied through each probe 63, and the measurement of the power supply current is performed at the side of the power supply 12.

In contrast to the above, according to the present invention, the current sensor 20 is inserted in each probe 63 at the intermediate way thereof, and an optical signal optically modulated by the current sensor 20 is transmitted through the optical waveguide 23 and is received by the photodetector 53.

In this case, too, no disturbance is caused by external electromagnetic waves and the like even if the length of the optical waveguide 23 is extended. Therefore, it is possible to test ICs in chip form without being affected by external
5 electromagnetic waves and the like even if the probe card 64, the light source 51, the photodetector 53, the detecting circuit 54, the sample-and-hold circuit 14 and the like are housed in the measuring instrument proper disposed at a position spaced apart from the position (test head) where the IC under test 11 is
10 disposed.

Fig. 14 shows a modification of the current measuring method. This modified embodiment is intended, for example, to exclude the influence due to a drift of the quantity of light emitted from the light source 51 and to eliminate an offset
15 voltage of the photodetector 53.

In this embodiment, an optical coupler 65 is connected to the input optical waveguide 22 at the side of the light source 51. The optical coupler 65 branches an input light into two parts one of which is inputted into the optical modulator 40, and the other
20 of which is inputted into a correcting optical waveguide 66 formed adjacent to the optical modulator 40. The output light from the correcting optical waveguide 66 is received by a second photodetector 53B, and a voltage signal corresponding to the quantity of light received by the second photodetector 53B is fed
25 back to the driving circuit 52 for the light source 51, thereby to control the intensity of light emitted from the light source 51 to be stabilized. The voltage signals corresponding to the quantities of light received by the photodetectors 53A and 53B

respectively are supplied to a subtracting circuit 67 where one is subtracted from the other. With such arrangement, offset voltages produced in the photodetector 53A and the detecting circuit 54A can be removed.

5 Accordingly, the voltage signal from which the offset voltages have been removed in the subtracting circuit 67 is inputted via the sample-and-hold circuit 14 and the A/D converter 15 into the ALU 16, and hence it is possible to obtain the measured value from which the offset voltages have been
10 removed. Furthermore, since this embodiment is configured such that light branched by the optical coupler 65 passes through the correcting optical waveguide 66 formed adjacent to the optical modulator 40, the light passing through the correcting optical waveguide 66 is subject to the same influence in
15 temperature as that of the light passing through the optical modulator 40. Therefore, an additional advantage is obtained that there is eliminated variations in the optical modulation characteristic of the optical modulator 40 due to temperature variations of the dielectric substrate 41.

20

INDUSTRIAL APPLICABILITY

As described above, according to the current measuring method according to the present invention, since an electric signal which is detected in relation to a current flow of excess
25 amplitude results in that the ratio between the intensity P_{in} of light emitted from the light source 51 and the intensity P_{out} of light received by the photodetector 53 goes up and down only between the state of $P_{out}/P_{in}=1$ and the state of $P_{out}/P_{in}=0$, no

limiter circuit is needed at the detecting circuit side.

Accordingly, even if a current value returns to 0 immediately after an excess amount of current has flowed, there occurs no settling phenomenon, and hence the current immediately reaches
5 a target value and is stabilized at that value. Consequently, even if the phenomenon that the large-current pulse I_{PL} and the minute current I_s alternately flow is repeated at high speed, the minute current I_s can be measured with high accuracy and in stable condition even just after the large-current pulse I_{PL} has flowed.

10 As a result, the current measuring method according to the present invention is suitable for use in measuring a leakage current that flows through a power supply terminal of an IC having CMOS structure, and the current measuring method is suitably applied to an IC testing apparatus of the type that
15 renders a decision that an IC under test is defective or not defective depending upon whether the leakage current is within a prescribed range or not.

Moreover, according to the present invention, the measured value of current detected by the current sensor 20 is
20 transmitted through the output optical waveguide 23, and hence it is free from the possibility of suffering a variety of electrical interferences in the output optical waveguide 23. Accordingly, there is obtained an advantage that the accuracy of measuring the minute current can be maintained high even if the test head
25 and the measuring instrument proper are greatly distanced from each other.

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WHAT IS CLAIMED IS:

1. A current measuring method comprising the steps of:
converting a current to be measured into a voltage signal
by a current-voltage converter;
phase modulating light being transmitted through an
optical modulator by the voltage signal;
causing the phase modulated light to interfere with light
that is not phase modulated to obtain interference light; and
converting the intensity of the interference light into an
electric signal to specify the value of the current to be measured.
2. The current measuring method as set forth in claim 1,
wherein light inputted into said optical modulator is an optical
pulse which is generated in synchronism with a measuring
timing, and the transmission quantity of the optical pulse is
integrated to obtain the value of the current to be measured.
3. A current sensor comprising:
a branched interferometric optical modulator comprising
an optical branching part, an optical coupling part, two optical
waveguides formed between said optical branching part and said
optical coupling part, and two pairs of electric field applying
electrodes one pair being formed at both sides of one of said two
optical waveguides to put it between these two electrodes, the
other pair being formed at both sides of the other of said two
optical waveguides to put it between these two electrodes, said
optical branching part, said optical coupling part, said two





optical waveguides, and said two pairs of electric field applying electrodes being formed on a dielectric substrate;

a current-voltage converter for converting a current to be measured to a voltage signal;

a substrate for supporting said optical modulator and said current-voltage converter;

an input optical waveguide for applying light into said optical modulator; and

an output optical waveguide for taking out interference light emitted from said optical modulator.

4. The current sensor as set forth in claim 3, wherein a correcting optical waveguide is provided on the dielectric substrate on which said optical modulator is formed adjacent to said optical modulator, and an electric signal derived from light transmitted through said correcting optical waveguide is used to compensate an electric signal derived from the light transmitted through said optical modulator.

5. An IC testing apparatus which measures a current flowing to a power supply terminal of an IC under test and renders a decision that the IC under test is defective or not defective depending upon whether the current flowing to the power supply terminal is larger than or smaller than a prescribed value, said IC testing apparatus being characterized in:

that the current flowing to the power supply terminal is supplied to the current-voltage converter of the current sensor defined by claim 3;





that the intensity of interference light emitted from the output optical waveguide of the current sensor is converted into an electric signal by a photodetector; and

that the electric signal is compared with a preset value to determine whether the electric signal is larger than or smaller than the preset value, thereby to render a decision that the IC under test is defective or not defective.

6. An IC testing apparatus which measures a current flowing to a power supply terminal of an IC under test and renders a decision that the IC under test is defective or not defective depending upon whether the current flowing to the power supply terminal is larger than or smaller than a prescribed value, said IC testing apparatus being characterized in:

that the current flowing to the power supply terminal is supplied to the current-voltage converter of the current sensor defined by claim 4;

that the intensity of interference light emitted from the output optical waveguide of the current sensor is converted into a first electric signal by a first photodetector, and the intensity of light transmitted through the correcting optical waveguide of the current sensor is converted into a second electric signal by a second photodetector;

that said first and second electric signals are processed by operation thereof to compensate the first electric signal; and

that the first electric signal is compared with a preset value to determine whether the first electric signal is larger than or smaller than the preset value, thereby to render a decision that





the IC under test is defective or not defective.

7. The IC testing apparatus as set forth in claim 5 or 6, wherein the IC under test repeats at high speed the state of consuming a large current and the state of consuming a minute current, and in the measurement of current, the minute current is mainly measured.

8. The IC testing apparatus as set forth in claim 5 or 6, wherein when the IC under test has a plurality of power supply terminals, the current sensor is provided for each of the power supply terminals of the IC under test, and a current is measured for each power supply terminal.

9. The IC testing apparatus as set forth in claim 5 or 6, wherein when the IC under test has a plurality of power supply terminals, the current sensor is provided for each of the power supply terminals of the IC under test and the optical waveguides of the current sensors are optically connected in series, and the sum total of currents flowing to the plurality of power supply terminals respectively is found from the quantity of optical modulation for light.

10. The IC testing apparatus as set forth in claim 5 or 6, wherein an optical pulse is applied to the optical modulator at each measuring timing, and the quantity of optical modulation for each optical pulse is detected by a photodetector, thereby to measure the current value at each measuring timing.





11. The IC testing apparatus as set forth in claim 5 or 6, wherein the current sensor is mounted on a measuring probe supported by and protruding from a probe card, and the tip of said measuring probe is brought into contact with a terminal portion of an IC chip formed on a semiconductor wafer, thereby to test the IC chip.

12. The IC testing apparatus as set forth in claim 6, wherein the electric signal, derived from the light transmitted through the correcting optical waveguide provided adjacent to the optical modulator, is applied to a light source driving circuit to stabilize the intensity of light emitted from a light source, thereby to measure a current flowing through the IC under test.

This Sheet Has Been Replaced

