Title
Accurately measuring current-voltage characteristics of tunnel diodes

Journal
IEEE Transactions on Electron Devices, 53(10)

ISSN
0018-9383

Authors
Bao, Mingqiang
Wang, Kang L

Publication Date
2006-10-01

Accurately Measuring Current–Voltage Characteristics of Tunnel Diodes

Mingqiang Bao, *Member, IEEE*, and Kang L. Wang, *Fellow, IEEE*

***Abstract*—This paper provides an approach to monitor oscillation status in tunnel diode measurement circuits—by measuring the second derivative of the current–voltage (I–V) characteristic curve while doing I–V curve measurement. The method of using the second derivative to detect oscillations works even when the oscillation frequency is ultrahigh or the oscillation amplitude is very small, e.g., below 10 mV. In this paper, the experimental principle of the tunneling spectroscopy was extended to measurement circuits with the presence of internal oscillations, in contrast to the conventional tunneling spectroscopy, which normally does not deal with internal oscillation. The numerical relationships between the measured average values of transient derivatives and the derivatives of the average current are derived: The average values of the transient first and second derivatives are shown to equal the derivatives of the average current. These relationships serve as the foundation for the authors' experiments. The typical oscillation characteristics in the curves of the first and the second derivatives are used to detect the presence of oscillations and the bias voltage range of oscillation in the I–V curve. The monitor of oscillation status during measurements provides the tester the confidence in the measurement data and whether it is necessary to improve the test circuit further. Finally, benefited from free-of-oscillation, the indirect tunneling current contributions arising by 121-mV $(\mathrm{TO}+\mathrm{O})$ two-phonon combination, 144-mV $(\mathrm{TA}+\mathrm{O}+\mathrm{O})$ and 181-mV $(\mathrm{TO}+\mathrm{O}+\mathrm{O})$ three-phonon combinations at the negative differential resistance region are observed from a silicon Esaki tunnel diode at 4.2 K.**

***Index Terms*—Circuit stability, current measurement, second derivative, tunnel diodes, tunneling spectroscopy.**

I. INTRODUCTION

THE TUNNEL diode was fabricated for the first time in 1958 and the unique negative differential resistance (NDR) was demonstrated at forward bias [1]. To date, tunnel diodes have been widely studied, and over 3000 research papers have been published on various aspects of tunnel diodes. In order to characterize the diode property and extract the diode parameters correctly, it is necessary to obtain accurate current–voltage (I–V) characteristics. Since tunnel diode has NDR, it potentially has the oscillation issue during measurement. Oscillations will distort the measured I–V characteristics, causing the measured I–V curves to have "plateau" and "double-humped" structures in the NDR region [2]–[4]. Thus, the I–V characteristics of such structures are usually not correct but are of pseudo I–V type.

There have been several means to stabilize a tunnel diode in the measurement: To place a shunt capacitor to the terminals of the test diode [2], [3], [5], [6], or to place a resistor in parallel with the diode [7]–[10], or the diode is shunted by both a resistor and a capacitor [11], or to use a forward-biased diode in shunt to the test diode [12]. By using the above procedures, most of test circuits could be stabilized, but as stated in [10], some diodes could not be stabilized in any test circuits.

In order to extract the parameters of a test tunnel diode accurately, it is critical to be able to distinguish whether the I–V characteristic curve obtained is free-of-oscillation, and if oscillations are present, it is necessary to know its bias voltage range in which the oscillations occurred.

Our experiments showed that the shape of I–V curve could look naively smooth, as if there were no oscillations in the test circuits even when oscillations were in fact present. Thus, it is difficult to distinguish the correct I–V curve from the pseudo ones by simply inspecting the shapes of I–V curves. An oscilloscope could be used to monitor the oscillation status directly in the measurement, but sometimes the oscillation frequency of a tunnel diode could be very high (a hundred gigahertz and beyond) and the oscillation amplitude could be as small as 10 mV or less. It is difficult to monitor such oscillations by an oscilloscope.

This paper provides an alternative way to real-time monitor the oscillation status in tunnel diode measurement circuits—by measuring the second derivative of I–V curve while doing I–V curve measurement. The experimental principle of the tunneling spectroscopy is extended to the measurement circuits with the presence of internal oscillations. The I–V characteristics with and without oscillations are obtained and contrasted.

II. EXPERIMENTAL PRINCIPLES

The second derivative of an I–V curve has been used to detect weak nonlinear signals, such as phonon-assisted electron tunneling through a barrier [13]. Lambe and Jaklevic already showed that such tunneling had a peak on the second derivative curve with the linewidth at half-maximum of 5.4 kT (T is the temperature in Kelvin) and the constant product of the height and the linewidth of the peak [14]. This indicates that such phonon spectra could be observed by the second derivative of the I–V characteristic only at low temperature; however, at room temperature, no phonon spectra or defect vibration

---

Manuscript received January 16, 2006; revised May 11, 2006. This work was supported in part by the Microelectronics Advanced Research Corporation (MARCO) Focus Center on Functional Engineered Nano Architectonics (FENA) funded by Semiconductor Industry Association (SIA) and the U.S. Department of Defense (DARPA), monitored by Dr. S. Thomas and Dr. D. Radack. The review of this paper was arranged by Editor S. Kimura.

The authors are with the Department of Electrical Engineering, University of California Los Angeles, CA 90095 USA (e-mail: baoming@ee.ucla.edu).

Color versions of Figs. 1, 2, 4, and 5 are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TED.2006.882281

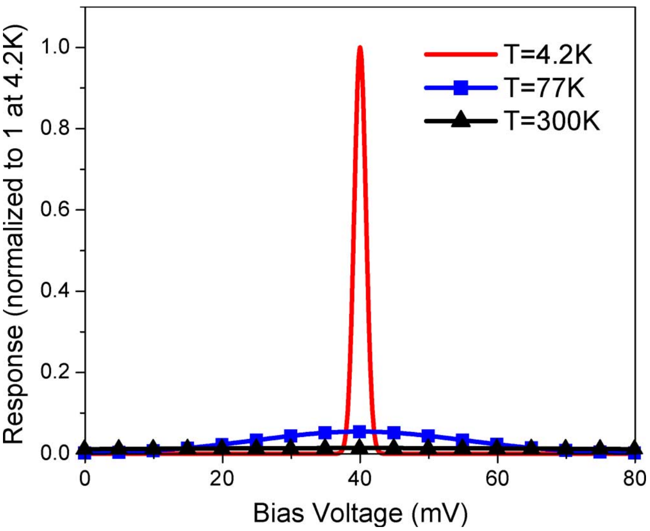

Fig. 1. Simulation results of second derivative of inelastic tunneling current between normal metals through a barrier at different temperatures. At $T = 300$ K, the peak height is 0.014 (normalized to 1 at 4.2 K) and the linewidth is 140 mV.

spectra can be seen. This fact is further illustrated in Fig. 1, which clearly shows a very small response at liquid nitrogen temperature and extremely small response at room temperature. Therefore, at room temperature, the second derivative of an I–V curve can be used to measure weak nonlinear performance from device itself, instead of phonon spectra or defect vibration spectra.

To measure the I–V characteristic of a tunnel diode, if it is biased at an unstable point in the NDR region, oscillations will normally occur in the measurement circuit. The current measured with oscillations is the average of the transient current. In brief, it can be expressed in following formula:

$$\overline{I}_{\mathrm{dc}} = \frac{1}{T_s} \int_0^{T_s} i(V_{\mathrm{dc}} + V_o \sin \omega_o t)\, dt \qquad (1)$$

where V_{dc} is the dc bias on the diode; $V_o \sin(\omega_o t)$ is the internal oscillation part with the oscillation amplitude of V_o (the oscillations could be much more complex; here, we only assumed the simple one with one frequency; $V_o = 0$ when the measurement circuit is free of oscillation); $i(V_{\mathrm{dc}} + V_o \sin(\omega_o t))$ is the transient current through the diode, which is the function of the transient voltage $V_{\mathrm{dc}} + V_o \sin(\omega_o t)$; and T_s is the integration time for the measurement or the sampling time[1].

When oscillations are present in the measurement circuit, there are two special points: point A, which is the first bias point in the I–V curve, beyond which the oscillation will be present, and point B, beyond which the oscillation will not happen, as illustrated in Fig. 2(a). It is worth noting that, here, point A is located at the positive differential resistance region prior to the peak point of I–V curve.

Beyond point A, the voltage across the diode has both dc bias and oscillation components. The oscillation makes the voltage swing along with the dc bias and causes the measured dc current to decrease due to the fact that the oscillation is more likely to occur at much steeper region in the NDR region of I–V curve. This fast decrease of the current at point A results in a valley in the first derivative of I–V curve, and therefore, the second derivative curve will show a sharp valley immediately followed by a sharp peak. The typical measured derivative curves with oscillations are shown in Fig. 2(b) and (c), respectively. At point B, as the NDR is smaller negative, oscillations are quenched. The quenching of oscillations results in a sharp decrease of the measured dc current since the average current would be larger at point B if the oscillations were present, at this time, the oscillations are more likely occurred at the lower voltage which caused the larger current. The same characteristic of a sharp valley immediately followed by a sharp peak will appear in the second derivative curve at point B. This pair of the oscillation characteristics in the second derivative curve can be used to monitor the oscillation status in the measurement circuit and determine the bias voltage range in which oscillations occur.

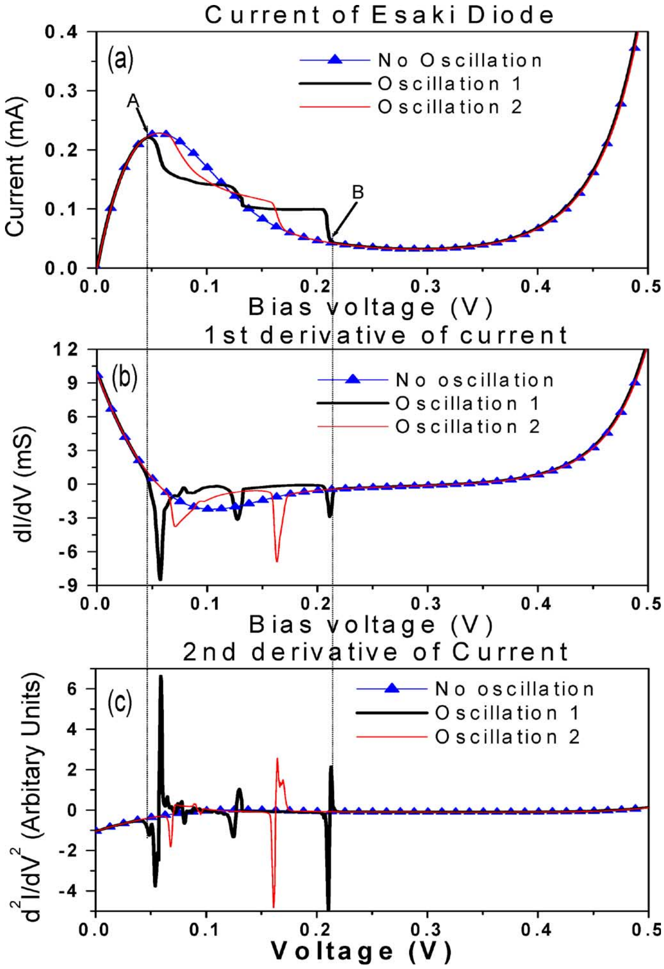

Fig. 2. I–V characteristics of an Esaki diode at room temperature at different conditions: without and with oscillations. (a) Measured I–V curves, (b) the first derivative of I–V curves, and (c) the second derivative of I–V curves.

In practice, the dc current, the first and the second derivatives are measured simultaneously by using a standard lock-in method. But when there are large oscillations present in the test

---

[1] In some cases, the measured current may be expressed as: $\bar{I}_{\mathrm{dc}} = ((1/T_s)\int_0^{T_s} i^2(V_{\mathrm{dc}} + V_o \sin \omega_o t)\, dt)^{1/2}$

circuit, whether the lock-in method can still be applied, needs to be reexamined. The following gives the detailed analysis showing that indeed this is the case.

When a small low frequency, for example 1 kHz, signal $V_e \cos(\omega_e t)$ (V_e is less than 1 mV) is superimposed onto the dc bias, while an internal oscillation $V_o \sin(\omega_o t)$ is present in the measurement circuit, the diode current may be expressed as a Taylor's expansion

$$\begin{aligned} I(t) &= i\left(V_{\mathrm{dc}} + V_o \sin(\omega_o t) + V_e \cos(\omega_e t)\right) \\ &\approx i\left(V_{\mathrm{dc}} + V_o \sin(\omega_o t)\right) + \left(\frac{di}{dV}\right)_{V=V_{\mathrm{dc}}+V_o \sin(\omega_o t)} \\ &\quad \times V_e \cos(\omega_e t) + \frac{1}{4}\left(\frac{d^2 i}{dV^2}\right)_{V=V_{\mathrm{dc}}+V_o \sin(\omega_o t)} \\ &\quad \times V_e^2 \cos(2\omega_e t). \end{aligned} \tag{2}$$

The measured dc current, and the measured first and second derivatives are the **average** current $\overline{I}_{\mathrm{dc}} = (1/T_s) \int_0^{T_s} i(V_{\mathrm{dc}} + V_o \sin(\omega_o t))\, dt$, the **average** first derivative $\overline{(di/dV)_{V=V_{\mathrm{dc}}+V_o \sin(\omega_o t)}}$, and the **average** second derivative $\overline{(d^2 i/dV^2)_{V=V_{\mathrm{dc}}+V_o \sin(\omega_o t)}}$, respectively, instead of the **transient** current, and the **transient** first and second derivatives, due to the fact that the oscillation frequency is much higher than the instrument response. The dc current, and the first and second derivatives were obtained simultaneously in our experiments. Furthermore, we show that

$$\begin{aligned} \left(\frac{d\overline{I_{\mathrm{dc}}}}{dV}\right)_{V=V_{\mathrm{dc}}} &= \left.\frac{d\left(\frac{1}{T_s}\int_0^{T_s} i\left(V + V_o \sin(\omega_o t)\right) dt\right)}{dV}\right|_{V=V_{\mathrm{dc}}} \\ &= \frac{1}{T_s}\int_0^{T_s} dt \left.\frac{di\left(V + V_o \sin(\omega_o t)\right)}{d\left(V + V_o \sin(\omega_o t)\right)}\right|_{V=V_{\mathrm{dc}}} \\ &= \overline{\left(\frac{di}{dV}\right)_{V=V_{\mathrm{dc}}+V_o \sin(\omega_o t)}} \end{aligned} \tag{3}$$

and similarly

$$\left(\frac{d^2\overline{I_{\mathrm{dc}}}}{dV^2}\right)_{V=V_{\mathrm{dc}}} = \overline{\left(\frac{d^2 i}{dV^2}\right)_{V=V_{\mathrm{dc}}+V_o \sin(\omega_o t)}}. \tag{4}$$

Thus, even as a large oscillation is present in the measurement circuit, the average value of the transient first derivative $\overline{(di/dV)_{V=V_{\mathrm{dc}}+V_o \sin(\omega_o t)}}$ and that of the second derivative $\overline{(d^2 i/dV^2)_{V=V_{\mathrm{dc}}+V_o \sin(\omega_o t)}}$ are still equal to the derivative of the average current $(d\overline{I_{\mathrm{dc}}}/dV)_{V=V_{\mathrm{dc}}}$ and the second derivative of the average current $(d^2\overline{I_{\mathrm{dc}}}/dV^2)_{V=V_{\mathrm{dc}}}$, respectively.

Equations (3) and (4) also imply that the measured derivatives are equal to the numerical derivatives of the measured dc current even when a large oscillation is presented, which serves as the foundation of our experiments.

In practice, the noises of the numerical derivatives are much higher than the measured derivative terms. In our measurement setup, two lock-in amplifiers were used to measure those derivatives for high signal-to-noise ratios.

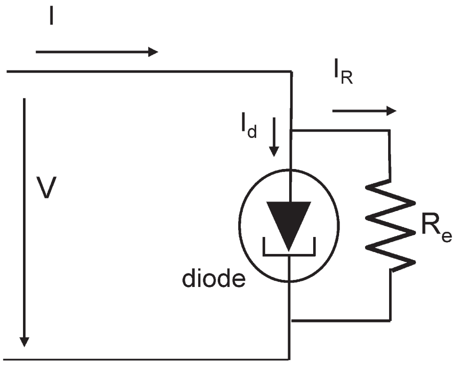

Fig. 3. Resistor with suitable resistance is shunt to the tunnel diode to eliminate oscillations in the measurement circuit.

III. EXPERIMENT PROCEDURES AND RESULTS

In order to model the diode accurately, it is necessary either to make the measurement circuit stable and obtain free-of-oscillation I–V characteristic if the test circuit can be stabilized or to know the exact voltage range of oscillation in the I–V characteristic curve if it is impossible or very difficult to obtain free-of-oscillation I–V curve by any treatment [10], [11]. It is the premise of accurate measurement.

In our experiments, first, the diode under test was directly connected to the tunneling spectroscopy system for measuring I–V curve and the first and the second derivatives without any treatment except keeping the connection cables as short as possible. If there are oscillation characteristics present in the second derivative curve, like Oscillation 1 curve in Fig. 2, it means the measurement circuit was unstable and oscillations were present between two bias voltages (points A and B of Fig. 2) in the measured I–V curve. In order to narrow oscillation range and obtain the free-of-oscillation range in the I–V curve as wide as possible, a resistor with a suitable resistance is shunted to the two terminals of the tunnel diode, since either too large or too small shunt resistance cannot suppress oscillations effectively [9]–[11]. The connection circuit is simply illustrated in Fig. 3.

The initial shunt resistance value R_e was estimated by the following procedures: From the oscillation characteristics in the second derivative of the I–V curve, the beginning point and the end point of oscillation range were obtained. Then, a smooth curve is drawn from the beginning point to the end point based on our observation that the area of $\int_A^B I\, dV$ is the same, and the error in all our experiments was less than 0.2% regardless of the presence of oscillations. After that, the estimated maximum value of $|dI/dV|$ at the NDR region, $|g|_{\max}$, was derived from this drawn I–V curve. Therefore, the initial shunt resistance R_e was derived by $R_e = 1/|g|_{\max} - \Delta$, where Δ used in our experiments is $0.05/|g|_{\max}$.

Again, the I–V curve, and the first and second derivatives curves are measured after the shunt resistance was placed to the terminals of the tunnel diode. The diode current can easily be obtained by

$$I_d = I - I_R = I - \frac{V}{R_e} \tag{5}$$

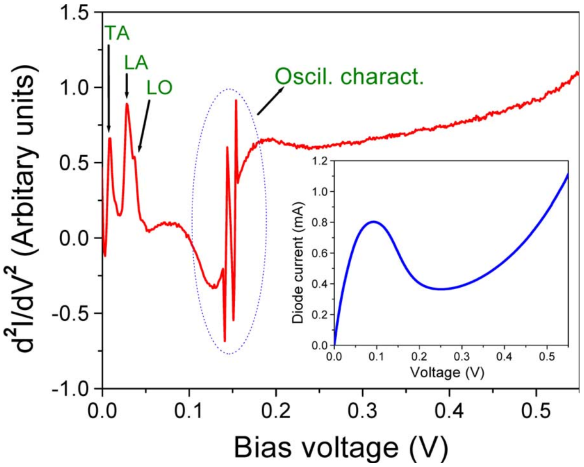

Fig. 4. Second derivative spectra of Esaki tunnel diode 1N4396 at 4.2 K. The inset is the measured current. From the shape of the measured I–V curve, it seems there was no oscillation present in the measurement circuit; however, its second derivative spectrum indicated oscillations were present in the measurement circuit in the bias range from 0.139 to 0.156 V.

where I_d is the diode current, I is the total measured system current, and I_R is the current through shunt resistor, V is applied dc bias, and R_e is the shunt resistance.

The first derivative of the diode current can be obtained by

$$\frac{dI_d}{dV} = \frac{d(I - V/R_e)}{dV} = \frac{dI}{dV} - \frac{1}{R_e}. \tag{6}$$

The second derivative of the diode current is the same as the measured second derivative of the total system current because the resistor shunted is a linear component, which is shown below

$$\frac{d^2I_d}{dV^2} = \frac{d}{dV}\frac{dI_d}{dV} = \frac{d}{dV}\left(\frac{dI}{dV} - \frac{1}{R_e}\right) = \frac{d^2I}{dV^2}. \tag{7}$$

The next step is to check whether there are oscillations still present in this test circuit. If no oscillation characteristic is seen from the measured second derivative curve $((\mathrm{d}^2I)/(\mathrm{d}V^2) \sim V)$, the test circuit is believed free of oscillation and the correct diode current can be obtained by (5). Otherwise, at this time, the kind of Oscillation 2 curve in Fig. 2 may be seen. Repeating the above procedures of deriving initial shunt resistance, a new improved shunt resistance would be derived. As this time, the oscillation range should be smaller than that without the shunt resistance, the new shunt resistance R_e could be refined to an improved value. By shunting this refined resistor to the diode, a free-of-oscillation I–V curve, and the first and the second derivatives curves should be obtained. Otherwise, one may repeat the above stated procedures to further refine the shunt resistance value until oscillations are stopped. Even if the oscillations could not completely be suppressed, the exact bias range of oscillation in the I–V curve could be obtained, and at out of the bias range of oscillation, the measured I–V characteristic is accurate.

Fig. 4 shows the measured I–V characteristics of tunnel diode 1N4396 from American Microsemiconductor at 4.2 K. Since the measured I–V curve is very smooth, it might be thought that there was no oscillation in the measurement system. However, the detailed experiment using our method revealed that oscillations actually occurred in the bias range from 0.139 to 0.156 V as the oscillation characteristic in the second derivative curve was seen. By simply shorting the cable length in the measurement circuit, this oscillation characteristic disappeared in the second derivative curve and a new I–V curve was obtained, even though the difference between the new one and the old one is small. (This diode 1N4396, although labeled as a silicon tunnel diode [15], is indeed a germanium tunnel diode based on the obvious germanium phonon peaks.)

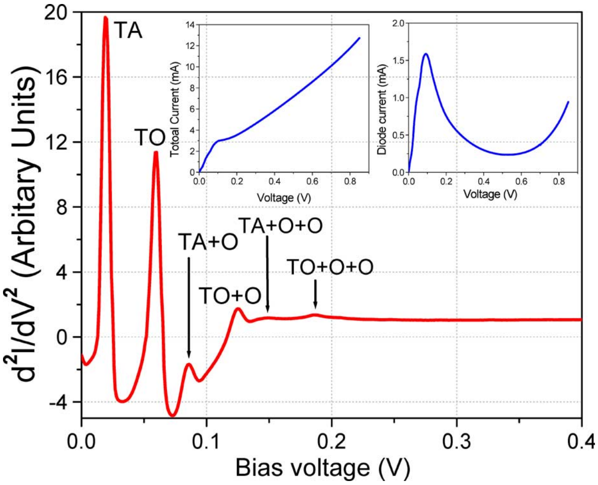

Fig. 5. Second derivative spectrum of silicon Esaki tunnel diode 1N4397 at 4.2 K. A 72-Ω shunt resistor is used to eliminate oscillations present in the measurement circuit. The left inset shows the total measured system current; no negative resistance is seen anymore. The right inset shows the extracted diode current from (5).

Fig. 5 shows the second derivative spectra of silicon Esaki tunnel diode 1N4397 also obtained from American Microsemiconductor at 4.2 K. A 72-Ω shunt resistor was connected in parallel with the tunnel diode to eliminate oscillation in the measurement circuit, and was determined at room temperature by the above stated procedures. The left inset of Fig. 5 is the total measured current, which is the sum of the diode current and the shunt-resistor current. The inset shows that no system NDR was observed in the entire measurement region. The right inset shows the diode current calculated from (5). The second derivative spectrum shows that indirect tunneling current contributions arising by the 18-mV transverse acoustical (TA) and the 58-mV transverse optic (TO) phonons are very strong. In addition, when the bias voltage is higher than 80 mV, indirect current contributions arising from the combinations of two phonons: 83-mV optical phonon of zero wavenumber (O) and TA phonon $(\mathrm{TA} + \mathrm{O})$ combination, and 121-mV $(\mathrm{TO} + \mathrm{O})$ combination, are also very clear. Furthermore, the combinations of three phonons, 144-mV peak of $(\mathrm{TA} + \mathrm{O} + \mathrm{O})$ and 181-mV $(\mathrm{TO} + \mathrm{O} + \mathrm{O})$ peak, can be seen from this figure even they are weak. It is worth noting that the bias voltages of 121-mV two-phonon $(\mathrm{TO} + \mathrm{O})$, and the three-phonon $(\mathrm{TA} + \mathrm{O} + \mathrm{O})$ and $(\mathrm{TO} + \mathrm{O} + \mathrm{O})$ combinations are in the diode NDR region. The extremely low noise background of the second derivative spectrum in the diode NDR region directly comes from the elimination of oscillation in the measurement system by using the 72-Ω shunt resistor.

IV. CONCLUSION

The tunneling spectroscopy has been shown to be able to apply to the measurement circuit with internal and external oscillations present in it. The measured first and the second derivatives were shown to equal the numerical derivatives of the measured dc current. A method to detect the oscillations in the measurement circuit containing NDR devices has been developed: by monitoring the oscillation characteristic in the first and the second derivatives of the current. This method can be conveniently implemented and can still work in detecting the oscillations even when the oscillation frequency is ultrahigh or when the amplitude is as small as 10 mV. The shunt-resistor method resulted in a very low noise level at the NDR region, and leaded to observe the indirect tunneling current contributions arising from 121-mV $(\mathrm{TO}+\mathrm{O})$ two-phonon, and 144-mV $(\mathrm{TA}+\mathrm{O}+\mathrm{O})$ and 181-mV $(\mathrm{TO}+\mathrm{O}+\mathrm{O})$ three-phonon contributions in the NDR region of a silicon tunnel diode. By monitoring of the circuit oscillation status, the tester has the confidence to assess if I–V curves are present of oscillations. In addition, this technique provides the additional information of the bias voltage range of oscillations in the I–V curve. This paper provides a way for measuring accurate I–V characteristics of general NDR devices.

ACKNOWLEDGMENT

The authors would like to thank the manuscript reviewers for good suggestions and providing references [9]–[11].

REFERENCES

[1] L. Esaki, "New phenomenon in narrow germanium p-n junctions," *Phys. Rev.*, vol. 109, no. 2, pp. 603–604, Jan. 1958.

[2] H. C. Liu, "Simulation of extrinsic bistability of resonant tunneling structures," *Appl. Phys. Lett.*, vol. 53, no. 6, pp. 485–486, Aug. 1988.

[3] J. F. Young, B. M. Wood, H. C. Liu, M. Buchanan, D. Landheer, A. J. SpringThorpe, and P. Mandeville, "Effect of circuit oscillations on the dc current–voltage characteristics of double barrier resonant tunneling structures," *Appl. Phys. Lett.*, vol. 52, no. 17, pp. 1398–1400, Apr. 1988.

[4] N. Jin, S. Y. Chung, R. Yu, S. J. Di Giacomo, P. R. Berger, and P. E. Thompson, "RF performance and modeling of Si/SiGe resonant interband tunneling diodes," *IEEE Trans. Electron Devices*, vol. 52, no. 10, pp. 2129–2135, Oct. 2005.

[5] M. E. Hines, "High frequency negative-resistance circuit principles for Esaki diode applications," *Bell Syst. Tech. J.*, vol. 39, no. 3, pp. 477–513, May 1960.

[6] C. Kidner, I. Mehdi, J. R. East, and G. I. Haddad, "Power and stability limitations of resonant tunneling diodes," *IEEE Trans. Microw. Theory Tech.*, vol. 38, no. 7, pp. 864–872, Jul. 1990.

[7] J. T. Wallmark, L. Varettoni, and H. Ur, "The tunnel resistor," *IEEE Trans. Electron Devices*, vol. 10, no. 6, pp. 359–363, Nov. 1963.

[8] A. Daire, "An improved method for differential conductance measurements," *Keithley White Paper*, 2005.

[9] W. H. Card, "Bridge measurement of tunnel-diode parameters," *IEEE Trans. Electron Devices*, vol. 8, no. 3, pp. 215–219, May 1961.

[10] "IEEE standard on definitions, symbols, and methods of test for semiconductor tunnel (Esaki) diodes and backward diodes," *Trans. Electron Devices*, vol. 12, no. 6, pp. 373–386, Jun. 1965.

[11] L. A. Davidson, "Optimum stability criterion for tunnel diodes shunted by resistance and capacitance," *Proc. IEEE*, vol. 51, no. 9, p. 1233, Sep. 1963.

[12] M. Reddy, R. Y. Yu, H. Kroemer, M. J. W. Rodwell, S. C. Martin, R. E. Muller, and R. P. Smith, "Bias stabilization for resonant tunnel diode oscillators," *IEEE Microw. Guided Wave Lett.*, vol. 5, no. 7, p. 219, Jul. 1995.

[13] A. G. Chynoweth, R. A. Logan, and D. E. Thomas, "Phonon-assisted tunneling in silicon and germanium Esaki junctions," *Phys. Rev.*, vol. 125, no. 3, pp. 877–881, Feb. 1962.

[14] J. Lambe and R. C. Jaklevic, "Molecular vibration spectra by inelastic electron tunneling," *Phys. Rev.*, vol. 165, no. 3, pp. 821–832, Jan. 1968.

[15] Online datasheet. Available: http://www.americanmicrosemi.com/information/spec/?ss_pn=1n4396

Mingqiang Bao (M'04) received the B.S. degree in physics from Nanjing University, Nanjing, China, in 1989 and the M.S.E.E. degree in physical electronics from the Chinese Academy of Sciences, Beijing, China, in 1994.

He is a Research Engineer in the Electrical Engineering Department, University of California, Los Angeles. He was previously with the Semiconductor Product Sector, Motorola (now Freescale Semiconductor), where he was responsible for developing high-frequency isolation models for passive components and developing high-voltage MOSFETs for color liquid crystal display (LCD) drivers. Prior to that, he was a Research Engineer in the Electrical Engineering Department, National University of Singapore (NUS), Singapore, where he conducted thermal management of high-power GaAs monolithic microwave integrated circuit. Before joining NUS, he was with Department of High-Power Microwave Device, Institute of Electronics, Chinese Academy of Sciences, Beijing, China, where he was a key player in designing and fabricating high-power microwave vacuum devices. His current research interests are RF weak signal detection, spin-wave bus implementation, and InAlGaN-based advanced transistor design.

Kang L. Wang (F'92) received the B.S.E.E. degree from National Cheng-Kung University, Tainan, Taiwan, R.O.C., in 1964, and the M.S. and Ph.D. degrees in electrical engineering from the Massachusetts Institute of Technology, Cambridge, in 1966 and 1970, respectively.

He has been with the Department of Electrical Engineering, University of California, Los Angeles, since 1979. He was Chair of the department from 1993 to 1996. From 2000 to 2002, he was the Dean of School of Engineering, Hong Kong University Science and Technology. He has been the Director of the Microelectronics Advanced Research Corporation (MARCO) Focus Center on Functional Engineered Nano Architectonics (FENA) since 2004 and has been the Director of the Western Institute of Nanoelectronics (WIN) since 2006. His research interests include nanoelectronics and optoelectronics, spintronics, MBE and superlattices, microwave and millimeter electronics/optoelectronics, and quantum computing.

Dr. Wang has received the Semiconductor Research Corporation Inventor Award, the 1996 Semiconductor Research Corporation Technical Excellency Award, and the Guggenheim Fellow Award for his outstanding works. He is a member of the American Physical Society and the Materials Research Society. He received the Honoris Causa from Politecnico University, Torino, Italy, in 2005.