Measuring and analysing low frequency noise in nano devices

Nicolas Clement (nicolas.clement@iemn.univ-lille.1.fr)
IEMN - CNRS, University of Lille, Avenue Poincaré, 59652 Villeneuve d'Ascq, France
Katsuhiko Nishiguchi
NTT Basic Research Laboratories, 3-1 Morinosato Wakamiyia, Atsugi-shi, 234-0198 Japan
Akira Fujiwara
NTT Basic Research Laboratories
Dominique Vuillaume
IEMN - CNRS, University of Lille, Avenue Poincaré, 59652 Villeneuve d'Ascq, France

---

Method Article

Keywords: Low-frequency noise, Random Telegraph Signal, automation software, Nano MOSFETs, nanowire, single electron, Coulomb repulsion

Posted Date: December 3rd, 2010

DOI: https://doi.org/10.1038/protex.2010.202

Abstract

Low frequency noise gives additional informations to DC current in nanodevices such as estimation of number/position of defects in nanotransistors \[1-14] and inelastic resonant energy levels in molecular devices \[15-16]. It provides also the charge sensitivity limit \[1,5] for sensors and memories. However, low frequency noise measurements remain marginal for device electrical characterization which is probably due to additional efforts required for non specialists to measure and analyse such signals. This is particularly true for nanodevices where current level is low and noise more difficult to measure. Here, we detail a protocol including experimental setup optimization, developed automation softwares and data analysis. An example of low frequency noise study of a silicon nanowire transistor is shown.

Equipment

1. A personal computer \(Macintosh, Unix/Linux or Windows operating system). 2. An electrical measurement station. 3. An ultra low noise DC power supply \(e.g. Shibasoku PA15A1) or batteries \(Fig.1) 4. RC filters \(Fig.1) 5. A current/voltage pre-amplifier \(e.g. DL instrument DL 1211 or Stanford Research SR 570)\(Fig.1) 6. A spectrum analyzer \(e.g. Agilent 35570 or 35665) \(Fig.1) 7. A php server \(since latest versions of php might be incompatible with our scripts, we recommand to "download version 1.7 from Easyphp":http://chalet-bay.com/downloads/easyphp1-7_setup.exe) 8. Our automated softwares for "web interface":http://chalet-bay.com/downloads/programs_php.zip and "OriginC programs":http://chalet-bay.com/downloads/programs_originC.zip 9. Origin plotting software \(From OriginLabs: minimum v.7 with OriginC Language updated)

Procedure

Experimental setup optimization: 1. Electrical connexions are shown in Figure 1. Each electrical measurement system has some noise, usually at the utility frequency 50-60 Hz, due to ground loops. For sensitive nanodevices that can potentially detect the elementary charge, this extrinsic noise can hide the target signal. Therefore, the noise contribution of each connected equipment to the electrical measurement system should be carrefully investigated. For example, vacuum pumps or temperature controllers may increase 50 Hz noise amplitude. We consider that 50 Hz noise amplitude is reasonable if \(SIxΔf)^0.5<0.1%xId, where SI is the power spectrum current peak noise, Δf~1.5 Hz is the 50 Hz peak bandwidth and Id the drain DC current. 2. Pre-amplifier parameters: The selection of preamplifier’s specifications are detailed in caption of Figure 1. If the rise time can be tuned, it should be used as a low pass filter to reduce the 50 Hz noise for very low frequency signals such as Random Telegraph Signal \[1] if the resonant frequency is much lower than 50 Hz. 3. Dynamic Signal Analyser \(DSA) parameters: We use the window _Hanning_ for Fast Fourier Transform analysis with the maximum number of sampling points that the DSA provides \(e.g. 1600). The input is set to _ground_ and the ground of the DSA linked physically to the _Faraday box_ of the electrical measurement system. For power specra acquisition, we select the _average mode_ with a typical average of 100 spectra \(meanwhile, it is possible to save curves in the time domain). Frequency axis is in log scale. 4. Data acquisition with the floppy disk: In order to use our automation softwares, spectra should be stored with the extension .DT and time domain datas with the extension .TP \(Figure 2a). In order to obtain a spectrum covering the frequency range from 0.1Hz to 100kHz, experimentally 2 to 5 spectra are taken \(depending on the number of samples per spectrum). No order \(in file naming) is required for measurements in the time domain, but should be successive for a given channel resistance. Measurements in the time domain are optional. **Automation software \(web interface):** 1- Download and install the php server and our developed softwares \(in the www folder) 2- Edit _racine.php_ file and replace _K:\\test_ by the emplacement where you want to store datas. Replace the next constant the path to reach _sdftoasc_ file. 3- Browse the local web and select exec>formdatatreatment 4- Fill in datas as shown in Figure 2c. 5- Press _treatment button_ for converting the datas. Text lines will appear in the browser as shown in Figure 2c. These lines should be copied and past in the _Labtalk window_ of origin \(see OriginC interface) 6- Folders with original and converted files are automatically created \(see Figure 2d). **Automation software \(OriginC interface):** 1- Download and install our developed OriginC code. All the procedure is detailed in the _Readme_ file. 2- Double click on the new empty origin file \(Figure 3a). 3- Paste the text lines copied from the web browser \(Figure 3b). 4- Power spectra as in Figure 3c and time domain datas will be automatically created. **Calibration procedure:** Measuring the power spectrum current noise of known resistors is a safe procedure to verify that the white noise of amplitude 4kT/R is measured where k is the Boltzman constant, T the temperature and R the resistance value. It also shows the maximum bandwidth of the preamplifier. Figure 4c shows such calibration procedure with 4 different resistors and Stanford research SR570 preamplifier. Frequency bandwidth is much smaller than for DL1211 preamplifier at low gains and we therefore use the latter one for noise measurement in silicon nanowires. **Power spectrum noise analysis:** An example of power spectrum current noise spectra SI at different gate voltages for a silicon nanowire transistor as in \[1] is shown in Figure 5a. Normalized noise makes the analyzis more direct. SI can be normalized by DC current I squared or transconductance gm squared \[1,5,13] \(see Figure 5b). The bell shape in figure 5b is due to a maximum noise at resonant energy level for a defect located close to the silicon nanowire. It can be fitted with equations detailed in \[1]. **Random telegraph signal analysis:** Random Telegraph Signal \(RTS) is a two levels fluctuation of current mostly related to the trapping/detrapping of an electron in a defect close to the transistor’s channel \[4]. Figure 5a is an example of RTS for a silicon nanowire as in \[1] and Figure 5c the histogram of drain current. To evaluate up and down time constants, RTS is first cleaned as a perfect two levels system by substracting an average value \(e.g. red line in Figure 5a) and getting the sign \(e.g. with the functionSIGN\() from Excel software). The modified signal is shown in Figure 5b and its histogram in Figure 5d. Finally, using the our web-based RTS function, we get from this point list each down and up times of our RTS \(Figure 5e). If the two levels signal is not clear enough, this should be done manually.

Timing

The complete measurement and analysis of a device at different biasing points takes one working day or more if many RTSs to treat.

References

\(1) N. Clement, K. Nishiguchi, A. Fujiwara & D. Vuillaume "One-by-one trap activation in Silicon nanowire transistors" Nat. Commun. 10.1038/ncomms1092 \(2) C.T.Rogers and R.A.Buhrman, Composition of 1/f noise in Metal-Insulator-Metal tunnel junctions. Phys.Rev.Lett. 53, 1272-1275 \(1984). \(3)L. Zhang, J. Zhuge, R. Wang, R. Huang, C. Liu, D. Wu, Z. Kang, D-W. Kim, D. Park and Y. Wang, New insights into oxide traps characterization in gate-all-around nanowire transistors with TiN metal gates based on combined Ig-Id RTS technique, VLSI Tech.Dig. 46-47 \(2009) \(4)F. Liu and K.L.Wang, Correlated random telegraph signal and low-frequency noise in carbon nanotube transistors. Nanolett. 8, 147-151 \(2008). \(5) N.Clement, H. Inokawa and Y.Ono., Studies on Metal-Oxide-Semiconductor field effect transistor low frequency noise for electrometer applications. Jpn.J.Appl.Phys. 45, 3606-3608 \(2006). \(6) J. Jeon, J. Lee, J. Kim, C.H. Park, H. Lee, H. Oh, H.-K. Kang, B.-G. Park and H. Shin The first observation of shot noise characteristics in 10-nm scale MOSFETs, VLSI Tech.Dig. 48-49 \(2009) \(7) N. Tega, H. Miki, F. Pagette, D.J. Frank, A. Ray, M.J. Rooks, W. Haensch and K. Torii Increasing threshold voltage variation due to random telegraph noise in FETs as gate lengths scale to 20 nm, VLSI Tech.Dig. 50-51 \(2009) \(8) K. Takeuchi, T. Nagumo, S. Yokogawa, K. Imai and Y. Hayashi Single-charge-based modeling of transistor characteristics fluctuations based on statistical measurement of RTN amplitude, VLSI Tech.Dig. 54-55 \(2009) \(9) M.Xiao, I.Martin, E.Yablonovitch and H.W.Jiang, Electrical detection of the spin resonance of a single electron in a silicon filed-effect transistor Nature 430, 435-439 \(2004). \(10) M.J. Uren, M.J. Kirton and S. Collins, Anomalous telegraph noise in small-area silicon metal-oxide-semiconductor field-effect transistors Phys.Rev.B. 37, 8346-8350 \(1988) \(11) J. Chan, B. Burke, K. Evans, K.A. Williams, S. Vasudevan, M. Liu, J. Campbell and A.W. Ghosh Reversal of current blockade in nanotube-based field effect transistors through multiple trap correlations Phys.Rev.B. 80, 033402 \(2009) \(12) M.J. Kirton and M.J. Uren, "Noise in solid state microstructures: a new perspective on individual defects, interface states an low-frequency \(1/f) noise Adv.Phys. 38, 367-468 \(1989) \(13) V. Singh, H. Inokawa, T. Endoh, and H. Satoh "Low Frequency Noise Characterization in Metal Oxide Semiconductor Field Effect Transistor Based Charge Transfer Device at Room and Low Temperatures" Jpn.J.Appl. 49, 034203 \(2010) \(14) N. Clement, D. Tonneau, H. Dallaporta, V. Bouchiat, D. Fraboulet, D. Mariole, J. Gautier and V. Safarov, "Electronic transport properties of single-crystal silicon nanowires fabricated using an atomic force microscope", Physica E 13, 999-1002 \(2002) \(15) N. Clement, S. Pleutin, O. Seitz, S. Lenfant and D. Vuillaume "1/f tunnel current noise through Si-bound alkyl monolayers" Phys.rev.B. 76, 205407 \(2007) \(16) Y. Kim, H. Song, D. Kim, T. Lee and H. Jeong, "Noise characteristics of charge tunneling via localized states in metal-molecule-metal junctions" ACSnano 4, 4426 \(2010)

Acknowledgements

The authors thank H. Inokawa for helpful advices for experimental setup optimization.

Figures

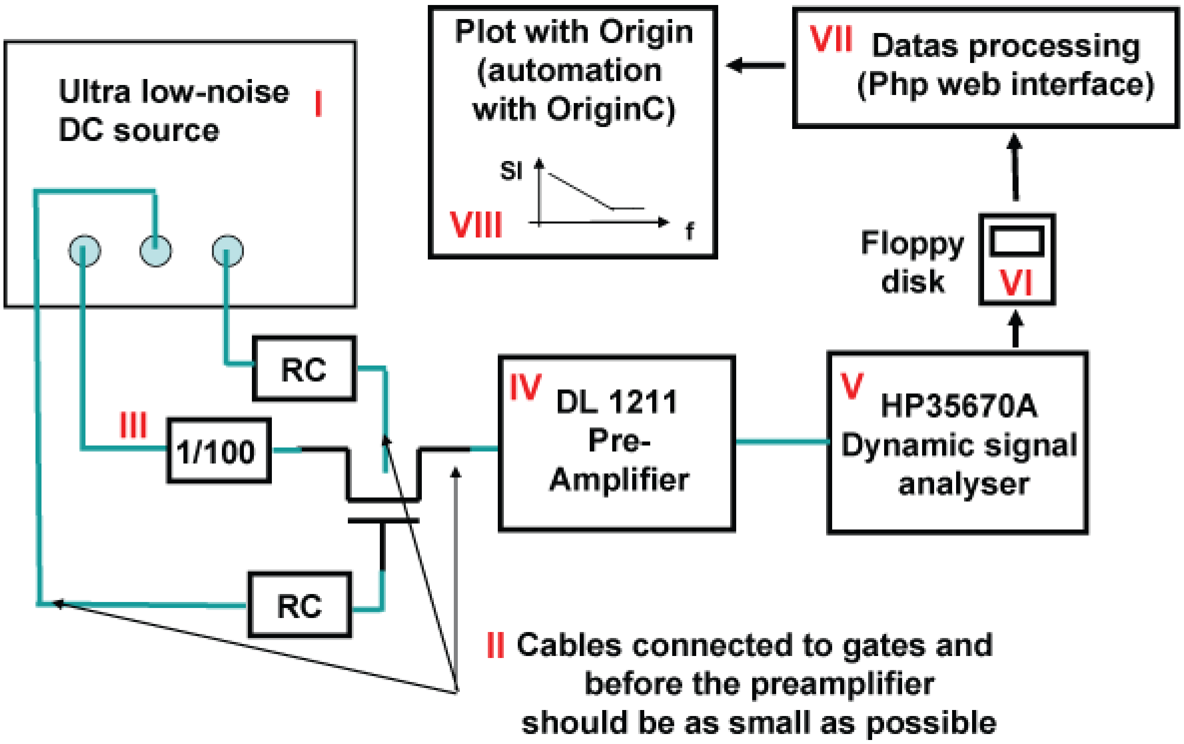

Figure 1

Schematic picture of the experimental setup. I An ultra-low noise DC source is a key point for ultra sensitive noise measurements. We use a Shibasoku PA15A1 DC power supply but batteries with divider bridges give also good results. II Coaxial cables connected to gates and before the preamplifier should be as small as possible. If not, one can observe increase of noise at high frequency due to parasitic capacitances. III Low-pass RC filters are used for connexion to gates (a 100 kΩ resistance in series with a 100 nF capacitor). This reduces 50 Hz noise to gates but cannot be used if the gates are leaking. A divider bridge may be used for low drain biases. IV Requirements for current voltage pre-amplifier for nanodevices are the following: powered by batteries, large gain (up to x10^11) and large bandwidth, no electrostatic discharge and perfect current match after gain change, possibility of rise time selection. V A dynamic signal analyser VI Since GPIB connexion adds some noise, we prefer use the floppy disk to store datas and use an automation software to treat datas (VII and VIII).

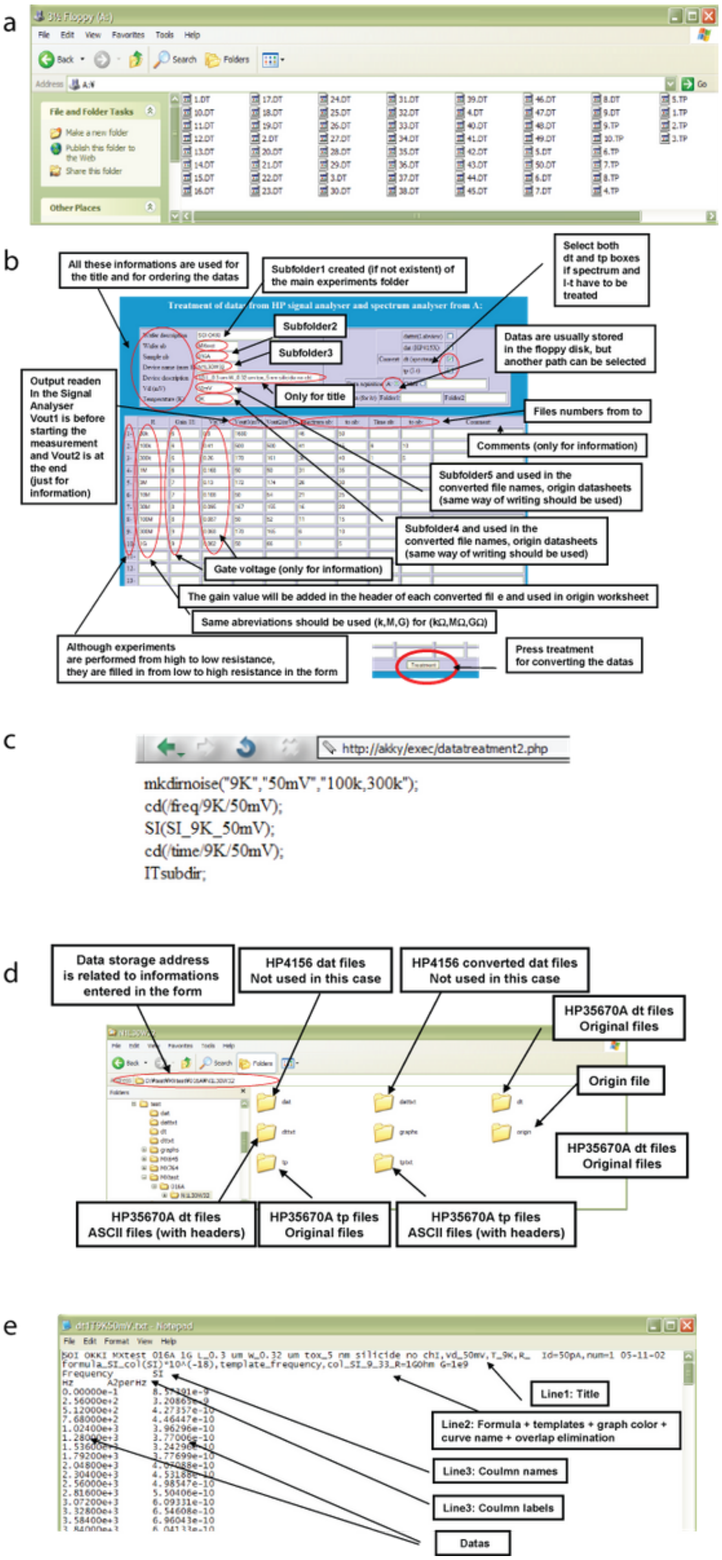

Figure 2

Data processing (Php web interface) a Floppy disk's explorer window b Web interface. c Lines shown by the web browser afetr data treatment. These should be copied and used for OriginC automation d Window explorer explaining the various folders created.

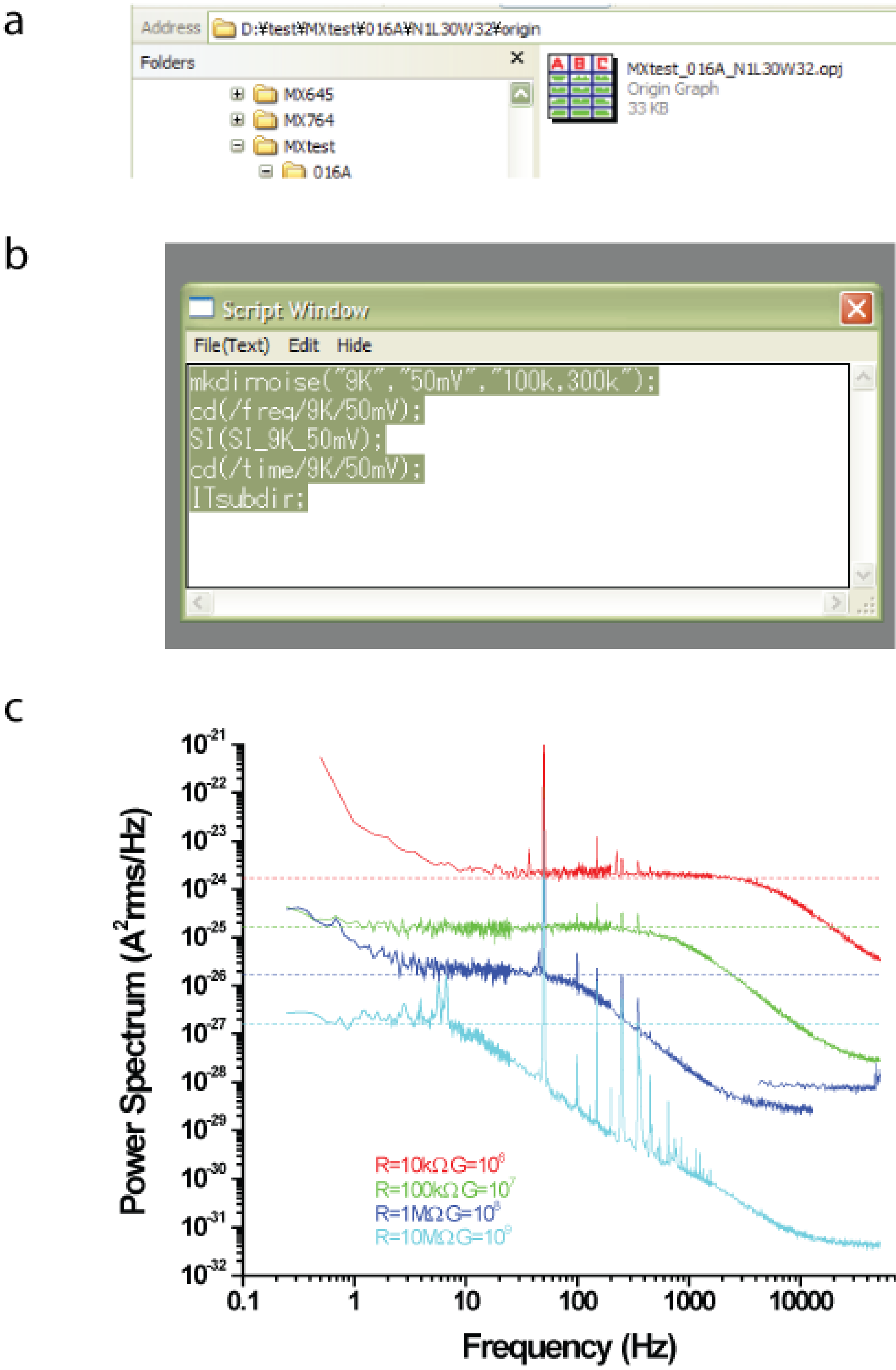

Figure 3

Data processing (originC interface) a Print screen of the window explorer showing the virgin origin file b Print screen of the Labtalk script window where the command lines should be posted. c Example of power spectrum current noise graph obtained after such procedure

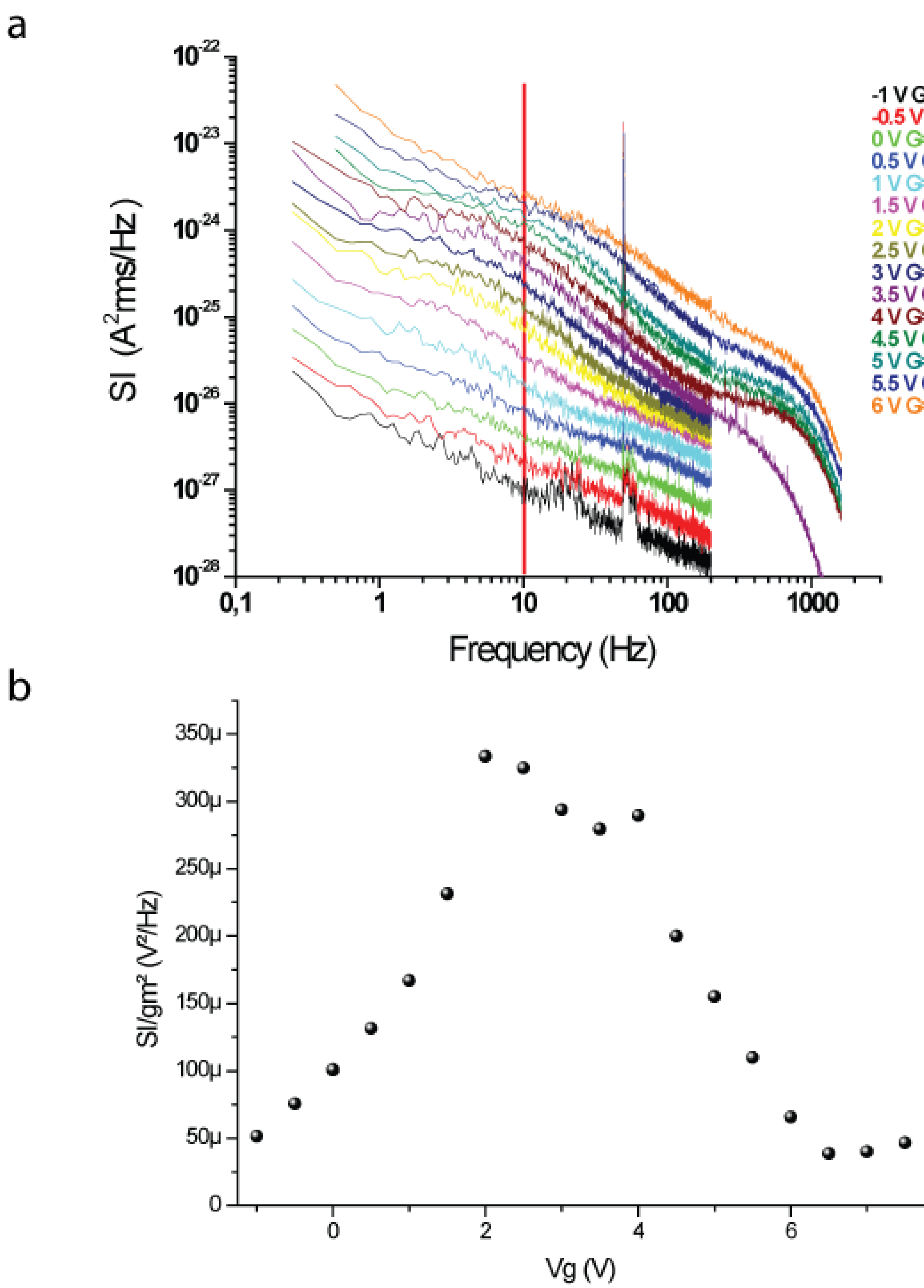

Figure 4

Power spectrum noise analyzis for a silicon nanowire transistor at room temperature a Power spectrum current noise at different gate voltages b Normalized noise by the transconductance gm²

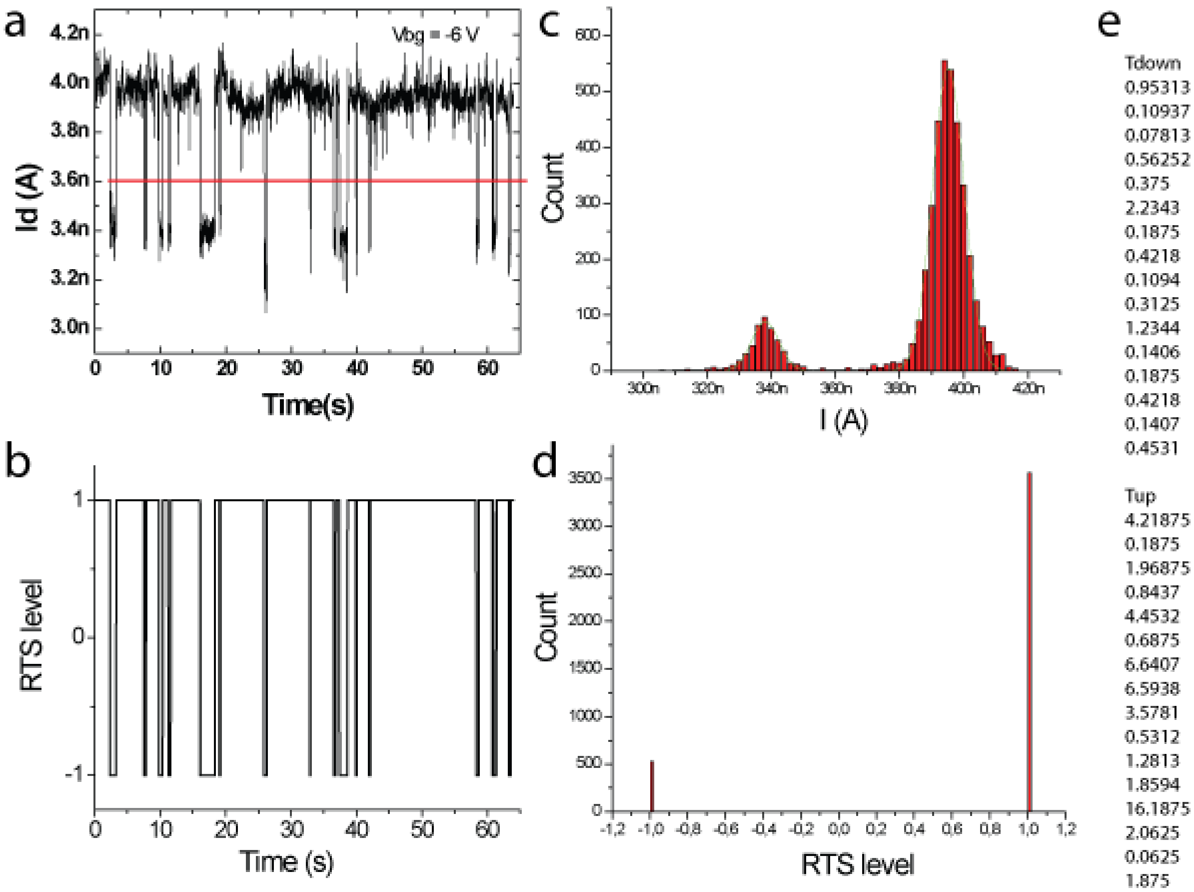

Figure 5

Random Telegraph Signal analyzis for a silicon nanowire transistor at room temperature a Experimental Random Telegraph Signal (RTS) b Cleaned RTS c Histogram of drain current for the experimental and d cleaned signal e Using automation RTS web software, we get up and down times of the RTS signal in a column