

# AN INTEGRATED CIRCUIT DESIGN FOR SILICON-NANOWIRE READ OUT CIRCUIT

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## ABSTRACT

A read out circuit for poly-silicon nanowire field-effect transistor (SiNW FET) is proposed. The circuit use current variance of nanowire as small signal output. In other words, the readout circuit is designed to find correlation between measurement solution concentration variance and nanowire current variance.

The circuit is able to regular the current of nanowire in a fixed value. This is referred to as constant current method in this article. With this method, the transconductance of nanowire is fixed. And the output current variance is correlate monotonically with solution concentration. Also, a problem known as disparity may be solved, which often happens by fabrication flaws or time degradation.

This article shows the design concept, circuit schematic, table of spec and some post-simulation results.

## 1. INTRODUCTION

Poly-silicon nanowire(SiNW) is an interesting one-dimensional nano-structures because it can be directly integrated with IC. Many research of fabrication and electrical properties have been conducted [1]. Since it was first introduced to the biosensor field in 2001[2], it has become a promising candidate for ultra-sensitive, real-time and label-free sensor device. Although there has been some great advances on element structure design [3], the work of systems-level engineering is still insufficient. Mainly because a proper way of signal acquiring is still indefinite.

In this work, a read-out circuit for ion sensing SiNW based on constant current idea is proposed with some post-simulation results. All the design are based on the experiments beforehand with nanowire elements from Yang's team (Fig. 1[4]). These experiments provide nanowire electrical properties and the design spec.

## 2. DESIGN DESCRIPTION

Conventionally, nanowire is treated as a simple resistor with resistance varies with ion concentration. Its read out circuits are targeted on current measurement [5] or resistance detecting [6]. However, these circuits give a non-monotonic output result. Because nanowire is more like a MOS-FET, and factors such as transconductance and short channel effect must

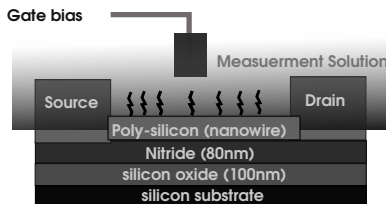


Fig. 1. Element Structure

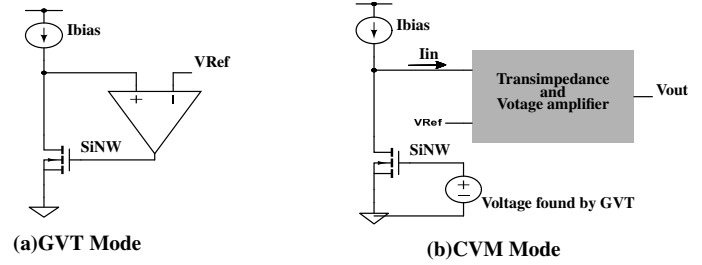


Fig. 2.

be considered. In this work, nanowire is treated as a complete field-effect transistor(FET). The read out circuit is designed for measuring the current variance. And its element transconductance, drain-source voltage and even gate-source voltage are fixed.

### 2.1. Constant Current

For a simple MOSFET, the transconductance(gm) is

$$\sqrt{2I_{DS}(\kappa\mu C_{ox} \frac{W}{L})} \quad (1)$$

in strong inversion region and

$$\frac{\kappa I_{DS}}{\phi_t} \quad (2)$$

in weak inversion region.  $\phi_t$  is the thermal voltage.  $\kappa$  is the gate coupling coefficient that is 1 in strong inversion and approximately between 0.4 to 0.7 in weak inversion. The transconductance of MOSFET of a fixed size can be roughly determined by a constant drain-to-source current( $I_{DS}$ ). Furthermore, a problem known as disparity which often caused by fabrication flaws or time degradation, may be solved because it is possible to force elements to operate in a same transconductance by giving different bias currents.

### 2.2. Architecture

The constant current structures such as source follower has been applied to several works of ion-sensitive field-effect transistor(ISFET) [7], which is a relative of SiNW. A similar structure is presented here. The structure can switch between two modes: Gate-Source Voltage Tracing Mode (GVT) (Fig. 2(a)) and Current Variance Measuring Mode (CVM) (Fig. 2(b)).

Operation in GVT is similar to Source follower. Except the negative feedback doesn't happen at source but gate through feedback loop circuits. This mode devotes to set up nanowire in the beginning when the reference ion solution is given.

CVM is used after suitable gate voltage is found in GVT. In this mode, the feedback loop is removed and the tested solution is then given. The ions in the solution are attached to the surface of nanowire(gate of the FET) and the electrical field are changed. A variance of current will then appear and be converted to voltage output by a transimpedance.

## 3. CIRCUIT IMPLEMENTATION

Fig. 3 shows the circuit schematic. GVT and CVM shared a common transimpedance, which is resistor-based because linearity is necessary

for a wide input current range (from 10nA to 1uA). A controlling switch switches manually between integrated circuit and an external voltage source(Vb) that can memorize the voltage obtained by GVT.

At SiNW gate control terminal in the GVT block, the open loop OP with a narrow bandwidth ( $< 20\text{Hz}$ ) has a use for low pass filter. It introduces only DC or low frequency signal into the feedback loop. Besides, the low frequency dominant pole it creates can keeps the feedback loop stable for sometimes the large transconductance of nanowire increases total loop gain a lot.

For the output of CMS, an OP, 2 capacitor and a resistor compose a bandpass amplifier with two amplification rate, 100 and 10 respectively. The pass band starts from point far below 1Hz and continue till about 1.4kHz. It is capacitor-based for diminishing the offset voltage, which has a maximal value of 0.2v. The resistor Rx is used for preventing a floating point on positive end of OP.

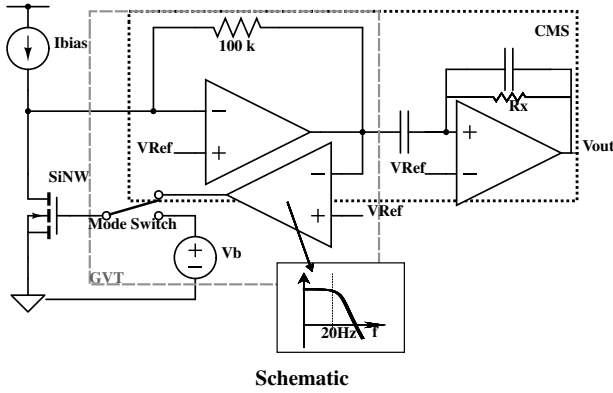


Fig. 3.

#### 4. SIMULATION RESULTS AND CONCLUSION

Fig 4 a-d shows the post-simulation results for circuit operated under CVM mode. A simple MOS with proper transconductance(gm) are substituted for nanowire(By experiment beforehand, gm should range from 200n to 20u). And a voltage signal is input to the gate of the MOS. 20mV is used to emulate the ion effect when measurement solution is added.

Fig. 4a shows the total amplification rate is 6.45db(2.1) for gm: 200n. This rate increases with the gm in the same degree. The fastest signal that can be detected without attenuation is about 1.4k(Hz). Fig. 4b and 4c are the input-referred and output referred noise response. Largest input referred noise should happen at gm 200n while the total gain is smallest. The noise is small enough since its value is ten times smaller than the input signal(20mV).

Fig. 4d gives transient response with an input signal rises in 1ms. It is to be observed the output signal has a long settling time about 1s. This is caused by the resistor Rx in Fig. 3. Its resistance (about 10G ohm in this work) makes trade-off between low speed signal detection and fast responding time. The resistance will be decided with more specific purpose in the future works.

In summary, the design meets the spec propped by experiment beforehand and is designed to give expected results with confidence. Two things are suggested working on in the future. One is to make mode deciding automatic. This can be achieved by a output analysing circuit with digital clock assistance. The other one is how to find bias current for individual element, also in an automatic way This is mentioned in the end of

Maximal Signal Detection Speed(Hz)	1.4k
Maximal Input Referred Noise(mV)	2.0
Power Consumption(mW)	0.25
SiNW transconductance Range	200n ~ 50u
SiNW Bias Current Range	100n ~ 10u

Table 1. Spec Summary

the section 2.1 and can be achieved if a transconductance detection way for individual nanowire is found.

#### 5. REFERENCES

- [1] Neil P. Dasgupta, Jianwei Sun, Chong Liu, and et al, "25th anniversary article: Semiconductor nanowires synthesis, characterization, and applications," *ADVANCED MATERIALS*, vol. 26, no. 14, pp. 2137–2184, Apr. 2014.
- [2] Yi Cui, Qingqiao Wei, Hongkun Park, and Charles M. Lieber, "Nanowire nanosensors for highly sensitive and selective detection of biological and chemical species," *SCIENCE*, vol. 293, no. 5533, pp. 1289–1292, Aug. 2001.
- [3] Li BR, Chen CC, Kumar UR, and Chen YT, "Advances in nanowire transistors for biological analysis and cellular investigation," *ANALYST*, vol. 139, no. 7, pp. 1589–1608, 2014.
- [4] Lin CH, Hung CH, Hsiao CY, Lin HC, Ko FH, and Yang YS, "Poly-silicon nanowire field-effect transistor for ultrasensitive and label-free detection of pathogenic avian influenza dna," *BIOSENSORS & BIOELECTRONICS*, vol. 24, no. 10, pp. 3019–3024, JUN 2009.
- [5] Ferrari G, Gozzini F, Molari A, and Sampietro M, "Transimpedance amplifier for high sensitivity current measurements on nanodevices," *IEEE JOURNAL OF SOLID-STATE CIRCUITS*, vol. 44, no. 5, pp. 1609–1616, MAY 2009.
- [6] A. Bonanno, V. Cauda, M. Crepaldi, P. M. Ros, M. Morello, D. Demarchi, and P. Civera, "A low-power read-out circuit and low-cost assembly of nanosensors onto a 0.13um cmos micro-for-nano chip," in *Advances in Sensors and Interfaces (IWASI), 2013 5th IEEE International Workshop on*, June 2013, pp. 125–130.
- [7] N. Nikkhoo, P. G. Gulak, and K. Maxwell, "Rapid detection of e. coli bacteria using potassium-sensitive fets in cmos," *IEEE Transactions on Biomedical Circuits and Systems*, vol. 7, no. 5, pp. 621–630, Oct 2013.

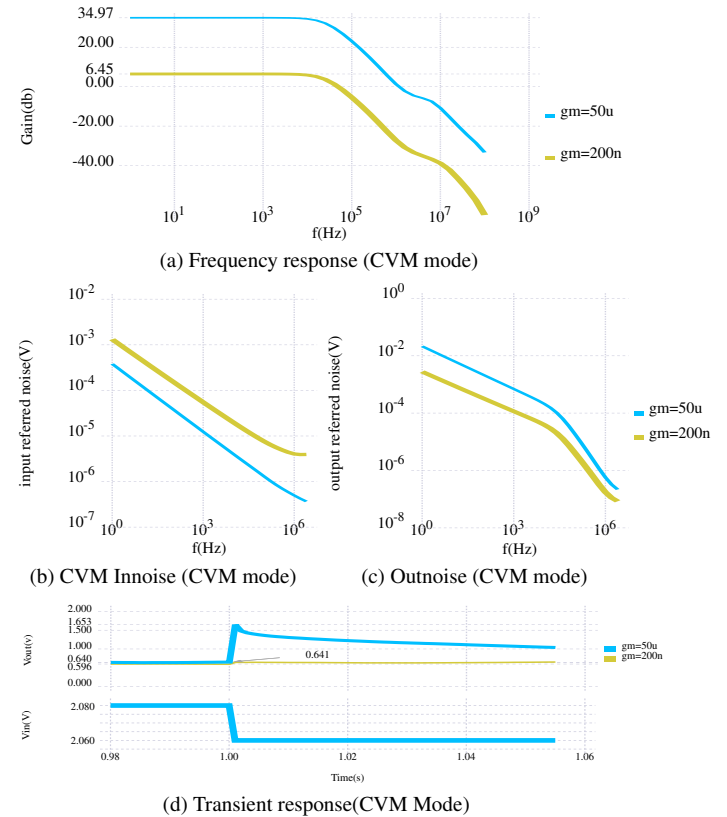


Fig. 4.