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Design of a High Precision Array Pulse Sensor in TCM

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Abstract: We designed a high-precision array pulse sensor for TCM (traditional Chinese medicine) that can directly transform pulse-pressure signal into electric current signal and is compatible with CMOS technology. We adopted a sacrifice-layer craft for the transistor gate. During testing, we found that the precision of the capacitor for the array sensor is 0.5fF/hPa when the pressure was changing within the range of 1.5kPa to 9.5kPa. More importantly, the output-current and the pressure of the sensor have a good linearity and exponential characteristics. According to the data from the experiment, we conclude that the characteristic of the response-current is related to the area of the MOS gate.

Key words: array senor; pulse senor; MOSFET gate; linearity
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1 Introduction

Pulse diagnosis in traditional Chinese medicine has a long history and abundant content. It is the most characteristic part of traditional medicine in our country. The veracity and sensitivity of the sensor directly affect the objective and scientific development of the sphygmology. The pressure sensor can reflect the change of the physical quantity under the measure quickly and sensibly. A high sensitivity sensor has great potential and advantage for application in clinical testing and pattern recognition systems[1]. The signal output of the sensor is the capacitance signal, temperature signal, chemistry quantity, and so on. When a small signal is read, precision and distinguishability are required. The signal processing circuit usually includes signal acquisition, signal multiplication, signal adjustment, signal conversion, and so on. Thus, the interface between the sensor and the processing circuit in back is always the bottleneck in the development of the system. The high precision pressure sensor designs the sensor capacitance in the dielectric gate of the MOSFET device. In this way, the pressure signal can be changed into the output of the electric current signal. Compared to a single-point pressure sensor, the array pressure sensor can collect and dispose the same signal at more points. This can improve the accuracy of the measurements and rating. Designing a high performance and high precision sensor according to the pulse signal needs to be solved in the design.

2 Sensor design

2.1 Pulse signal

The difference between people's pulse diastole and contractive pressure is about 40mmHg. According to the shape and trend of the artery tube, we can find the range of axial pressure of the blood when it was flowing in the artery tube, creating a mean value in the range 20mmHg to 41.64mmHg in the artery tube hem kinetic, obtaining the average:

$$30.82\text{mmHg} = (30.82/760) \times 1.013\text{Pa} \times 10^5 = 4108\text{Pa} \quad (1)$$

Water viscosity is 0.01Pa when the temperature is under 40℃, so the blood viscosity should be 0.013Pa because its viscosity is about 1.2 to 1.3 times of watery's. Combined with the artery radius and the distance from artery to heart (about 1000mm), we can approximate the flowing speed of the blood from the artery:

$$v = \frac{(p_1 - p_0) r^2}{8\eta l} = \frac{4108 \times 1 \times 1 \times 10}{8 \times 0.013 \times 1000} = 395(\text{mm/s}) \quad (2)$$

2.2 Design and manufacturing of the sensor

Figure 1 shows the sensor structure. The design uses the MOSFET gate as the movable component of sensor and creates sensor capacitance inside of the dielectric of the MOSFET device. The gate will move down under pressure, which changes the capacitance of the MOS-gate dielectric and the value of output current. In this way, the pressure-capacitance-current

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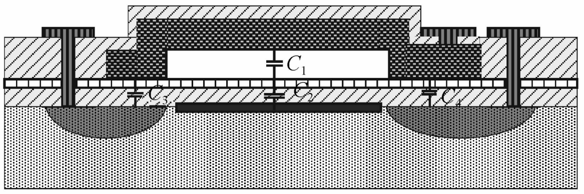

Fig. 1 Principal diagram of the pulse sensor

sensing device works. The main advantage is that it can transform the pressure signal into current signal directly.

The transistor grid includes a "sacrifice layer"[2], which usually include three steps: first, spatter the descendent silica sacrifice layer on the sacrifice layer and spatter the polysilicon structural sheet; second, sculpt the sacrifice layer in hydrofluoric acid; third, draw the device, rinse, and dry the hydrofluoric acid. The specific process flow is shown in Fig. 2.

(a) Threshold regulate adulterate infused: After the growth of silica film, which acts as a protective layer based on the p (100) wafer, the surface resistance of the infuse threshold regulate adulterate is 13.8Ω/□;

(b) Transistor source / drain junction: by way of ion-implantation

(c) Sacrificial layer deposition and patterning: A 0.2-μm-thick LPCVD sacrificial phosphosilicate glass (PSG) layer is deposited and patterned in two separate masking steps. The first is a timed etch to create "dimples" (mechanical standoffs). The second masking step etches through the PSG layer in windows, which allow the formation of the anchors of the polysilicon structure.

(d) Structural polysilicon deposition, doping, and

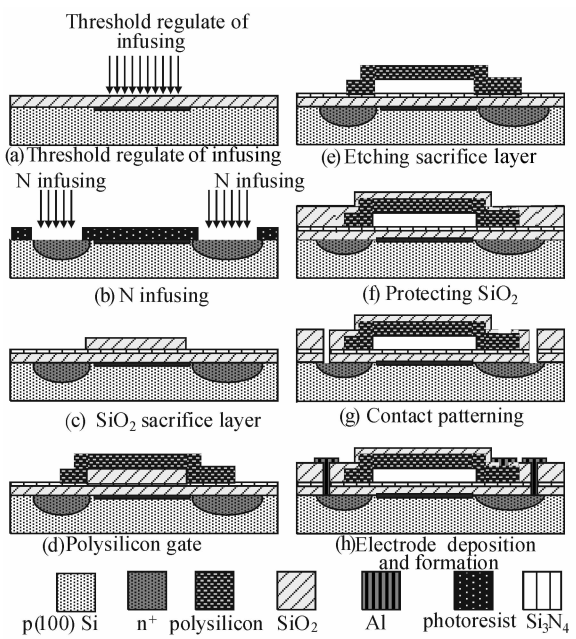

Fig. 2 Process steps of the sensor fabrication

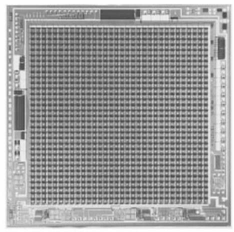

Fig. 3 256×256 array pressure sensor

stress anneal: The 0.2-μm-thick polysilicon structural layer is then deposited by LPCVD (undoped) at 610℃.

(e) Microstructure release, rinse, and dry. In the last step, the wafer is immersed in aqueous hydrofluoric acid (typically 10 : 1 diluted hydrofluoric acid (HF) or buffered HF) to dissolve the sacrificial PSG layer. The wafer is rinsed in deionized water and dried under an infrared lamp, or rinsed in deionized water, and then dried in a way to prevent its collapse and adhesion to the substrate—a phenomenon known as "stiction."

(f) Silicon dioxide insulation deposition: 0.1μm-thick.

(g) Photoengraving fairlead.

(h) Pole sputtertion.

2.3 Array configuration

The adult guan pulse can be collected using a 256×256 array pressure sensor, and the guan pulse image is displayed in Fig. 4. According to this figure, the attenuation of pulse vibration strength is exponential from center to outside. In order to reduce the number of sampling points while avoiding influencing the measurement accuracy, an 8×8 array pressure sensor is designed with large intermediate density and small marginal density (Fig. 5). First, we must design the standard transducer unit. Then, we get an 8×8 array structure by expanding the standard transducer unit with the interspace increasing in the exponent distribution law. The 8×8 units are interconnected and lead-out to the PAD. Every unit is assigned 2 pins. One wire is used to connect one of the two pins of all the units. In this way, the number of leading wires is decreased to 8×8+1=65. Because adult inch, shut,

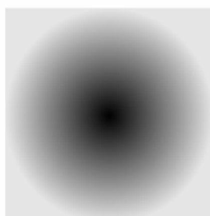

Fig. 4 The guan pulse image

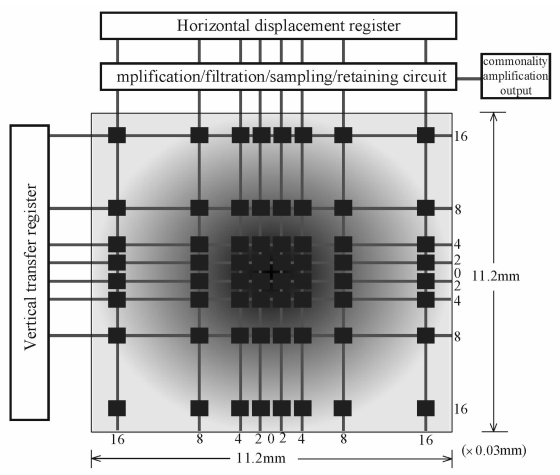

Fig. 5　Array of Pulse sensor

ruler pulse is about 4mm, finger area is about 1cm^2. The distance can be found though Eq. (3). For convenience, d takes 0.3mm and the whole physical dimension of the sensor is about 10.2mm ×10.2mm.

$$2d(1 + 2^1 + 2^2 + 2^3 + 2) \approx 10\text{mm}$$
$$d \approx 0.29412\text{mm} \qquad (3)$$

3　Sensor test

3.1　pressure capacitance test

According to Fig. 6, the transistor can be seen as a device with both ends, and transistor gate capacitance can be measured based on the different gate voltage. Pressure is applied on the surface of the gate, and then, the gate capacitance will be changed, correspondingly. Measurement of the capacitance has been made at different pressures.

The process is shown as: Starting from a negative gate voltage over 30V, gate negative potential attracts the substrate's cavity to the layer of the oxide interface, and MOSFET works in the "accumulation zone"[3]. Then, this device acts as a capacitance whose value is C per unit area; the interface cavity density decreases with the increase of V_{GS}, and the depletion layer under the layout of the oxide interface begins to form and the device come into the feebleness anti-configuration. Once V_{GS} is over V_{TH}, the channel will form with a capacitance per unit area also equal to C.

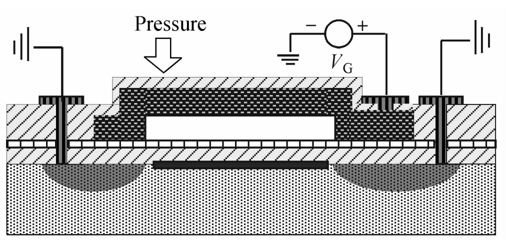

Fig. 6　Circuit of measure MOS gate capacitance

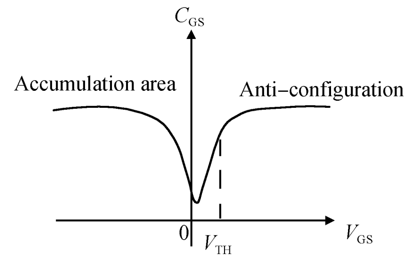

Fig. 7　Response curve of MOS gate capacitance with gate voltage

Fig. 7 shows this characteristic curve.

The capacitance-pressure response curve of the sensor device is shown in Fig. 8. In the dynamic range from 1.5kPa to 9.5kPa, the sensor sensitivity is about 0.5fF/hPa, and nonlinearity is about 3.6%. This Figure also shows the test results of the hysteretic. In the range from 4.5 kPa to 7.5kPa, the hysteresis reaches a maximum of about 2.4%. The sensor shows good linearity and hysteresis[4].

3.2　Current test

The most important advantage of the high precision array stress sensor for TCM is to transform the pressure of the sensor into a pulse signal output directly. At room temperature, it can simulate manikin pulse. The dynamic range of the stress is from 1.5kPa to 9.5kPa. It can measure the output current of the center and the edge of the array stress sensor, respectively. Figures 9 (a) and (b) are the output current response curve of the center and the edge of the array stress sensor. The nonlinearity is about 6.4%. Comparing Fig. 9 (a) with Fig. 9(b), the center part of the array stress sensor has better linearity. At the same time, Figure 9 compares the output current relationship between the center and the edge. It is a steady exponential hypotaxis. The sensor shows good linearity and exponential characteristics.

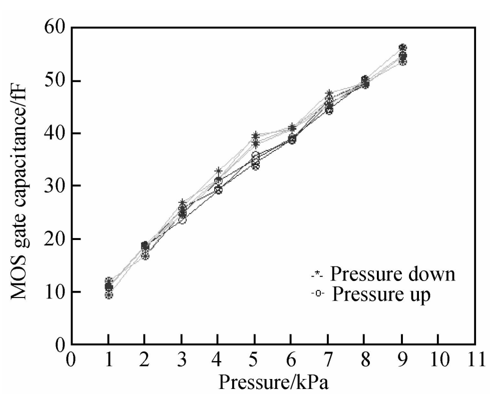

Fig. 8　Response curve of MOS gate capacitance with gate pressure

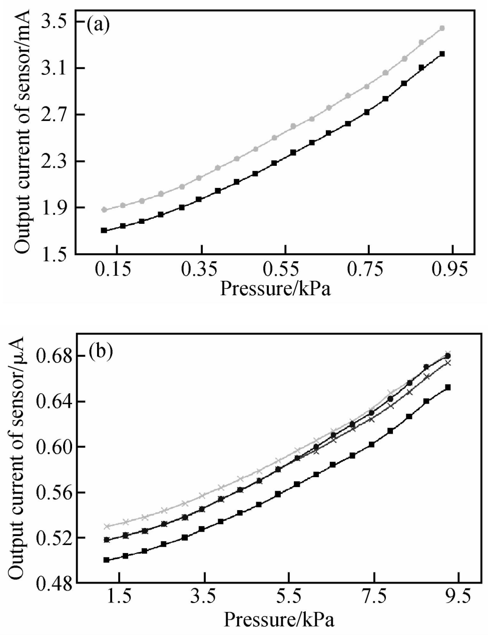

Fig. 9 Output current response curve of pressure (a) Center of sensor; (b) Edge of sensor

4 Analyses of results

Grid capacitance C_s is composed of four capacitances: C_1 and C_2 are in series and they are parallel with C_3 and C_4, as shown in Fig. 1. Thus, the grid capacitance is $C_s = C_{tal} + C_3 + C_4$.

There into: $C_1 = \frac{\varepsilon A}{d}$, $C_2 = \frac{6.9Ad}{5\times10^{-9}}$(fF), C is the capacitance per unit length of the channel and L is the effective channel length;

$$C_{tal} = \frac{C_1 C_2}{C_1 + C_2} = \frac{6.9\varepsilon A^2 d}{5\times10^{-9}\varepsilon A + 6.9Ad^2} = CL \quad (4)$$

When $V_{GS} \geqslant V_{TH}$, the gate charge is mirror imaged by the channel charge and they generate a symmetrical channel charge density with the value

$$Q_d = C_{tal}(V_{GS} - V_{TH}) \quad (5)$$

When the drain voltage is positive, the drain potential changes from zero to the voltage of V_D, the voltage of the gate and channel changes from V_G to $V_G - V_D$. Therefore, the charge density of channel point x can be expressed as:

$$Q_d(x) = C_{tal}(V_{GS} - V(x) - V_{TH}) \quad (6)$$

From $I = Q_d v$, we can get:

$$I_D = -C_{tal}[V_{GS} - V(x) - V_{TH}]v \quad (7)$$

I_D is negative because the carrier charge is negative; v is the drift speed of the channel electron. For the semiconductor, $v = \mu E$, in this formula, μ is the mobility rate of the carrier, E is the electric field, $E(x) = -dV/dx$, and electron mobility rate is expressed by μ_n. Thus, we find:

$$I_D = C_{tal}[V_{GS} - V(x) - V_{TH}]\mu_n \frac{dV(x)}{dx} \quad (8)$$

The corresponding boundary conditions are $V(0) = 0$ and $V(L) = V_{DS}$. The integral results of the two formulae are:

$$\int_{x=0}^{L} I_D dx = \int_{V=0}^{V_{DS}} C_{tal}\mu_n[V_{GS} - V(x) - V_{TH}]dV \quad (9)$$

$$I_D = \mu_n \frac{C_{tal}}{L}\left[(V_{GS} - V_{TH})V_{DS} - \frac{1}{2}V_{DS}^2\right] \quad (10)$$

when V_{DS} is fixed and I_D and C_{tal} have a linear relationship.

With the effect of pressure, the sensor membrane becomes flexural because of the stretch effect, which leads to the distance between gate and substrate becoming smaller. So, because the sensor capacitance C_{tal} increases the geometry deformation caused by external force, the relationship between I_D and C_{tal} is linear, which leads to the output current increasing. Table 1 shows the corresponding capacitance value and current value of the pressure sensor due to geometric deformation under different pressures. The computational processes are follows: building the entity mode of the pressure sensor in ANSYS, choosing the unit "Shell 181" as the model; The reseau-plot (50 × 50 divided), applying boundary conditions and load; determining the values of the different nodes with different pressure[5]; substituting Eqs. (4) and (10), and then finding the corresponding capacitance value and current value caused by geometric deformation.

With the effect of pressure, the sensor membrane becomes flexural[6]. The area of the sensor membrane changes because of the stretch effect. According to the measurement result in Fig. 9 and the computational results in Table 1 and Eq. (4), we can find the capacitance value caused by changing the area. Figure 10 is as follows, when the pressure changes from 0 to 9.5kPa, according to Eq. (4) the capacitance value changes, and the change in area causes the output current to increase, which will influence the press-current response line.

5 Conclusion

We designed a high-precision array pulse sensor,

Table 1 Capacitance and current value caused by geometric deformation with different pressures

p/kPa	0	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5
C/fF	0	10.81	18.13	24.39	30.04	35.19	40.09	45.13	50.21	54.89
I_D/μA	0	17.3	18.5	19.6	21.0	23.2	24.8	27.2	30.3	32.0

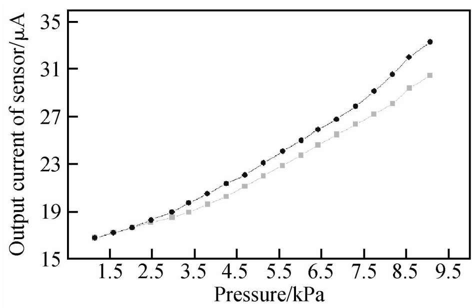

Fig.10 Influence of capacitance area to output current

which can directly transform pulse-pressure signal into electric current signal. The design uses the MOSFET gate as the movable component of the sensor and creates the sensor capacitance inside of the MOSFET device. The value of the output current changes with the change in the capacitance of the MOS-gate dielectric. The test shows that the MOS gate capacitance has better linearity and stagnant characteristics, and the output electric current has better linearity and exponential characteristics with the effect of the outside force. Compared with current capacitance pressure sensors, this device not only exports the current signal directly, but also solves the bottle-neck between the sensor and the back-end interface circuit. More importantly, the production of this sensor is simple and it has a better configuration. Moreover, the craftwork of the device narrow is in accordance with the normal CMOS process. Finally, work remains to solve the problem of the equalization mechanism for the gate's acreage caused by outside force.

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中医用高精度阵列脉搏传感器的设计

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摘要：提出了一种可以把脉搏压力信号直接转换为电流信号输出的高精度阵列脉搏传感器.采用牺牲层法加工晶体管的栅极与CMOS工艺具有良好的兼容性.对传感器栅电容和输出电流进行测试,在1.5～9.5kPa的动态范围,传感器电容的灵敏度约为0.5fF/hPa;传感器输出电流与压力呈现较好的线性和指数特性.分析结果表明MOS栅面积的改变对压力-电流响应曲线的线性度有一定影响.

关键词：阵列传感器；压力传感器；MOSFET 栅；线性度

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