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低电压电泳芯片非接触电导检测电路设计

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摘要：根据低电压集成电泳芯片柱端非接触高频电导器的结构和非接触高频电导检测的基本原理，设计了非接触电导检测电路。该电路包括 AC 激励信号发生器、*I-V* 转换器、乘法运算器、低通滤波器和差分放大器。运用较少的元器件和较简单的电路形式实现了检测功能，解决了低电压电泳芯片微弱的非接触电导信号检测困难的问题。通过调节电路参数分别得到了频率为 450 kHz 和 1 MHz，幅值为 10 V 的正弦信号。在此激励信号下，在集成低电压电泳芯片上对一系列不同浓度的 K^+ 溶液进行了非接触电导响应信号的测试。实验结果表明，电路能分辨的离子浓度的下限为 10^{-9}；离子浓度为 10^{-9}～10^{-5} 时，电路响应具有很高的线性度和分辨率。该电路亦可用于其它微弱电导信号检测领域。

关　键　词：电泳芯片；非接触电导；检测电路；*I-V* 转换；乘法运算；低通滤波
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Design of contactless conductivity detecting circuit for electrophoresis chip

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Abstract: On the basis of the structure of a pole conductivity detector for an integrated low voltage electrophoresis chip, a contactless conductivity detecting circuit is designed according to the working principle of high frequency contactless conductivity detecting, which consists of an AC inspiriting signal generator, a *I-V* convertor, a multiplicator, a low-pass filter and a differential amplifier. By using less devices and simple structures to realize powerful detecting, the circuit resolves the problem difficult to detect the very weak signals of low voltage electrophoresis chips. Finally, a test is applied to a electrophoresis chip to detect the contactless conductance signals of different concentrations of K^+ by using the detecting circuit with an AC inspiriting signal of 10 V and the inspiriting frequencies of 450 kHz and 1 MHz. The experimental results show that the circuit can distinguish the lowest concentra-

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tion of 10^{-9}, and can reach the high linearity and resolution power in the ranges of 10^{-9}-10^{-5}. For its detecting functions, this circuit is able to used in other conductivity detecting fields.

Key words: electrophoresis chip; contactless conductivity; detecting circuit; *I-V* conversion; multiplication; low-pass filtering

1 Introduction

Contactless conductivity called as high frequency conductivity has many merits compared with the contact conductivity such as the electrode's insulation from the liquid, which can avoid the bubble emission and electrode pollution and also can isolate the effect of the separating electric field. The respond signal can weaken the background signal of electrophoresis chip and the detecting limit of the liquid. The contactless electrode is easy to minimize and integrate. For the contactless conductivity detecting has been successful and widely used in the conductivity detecting of chip electrophoresis[1].

2 Structure and working principle of detecting

The contactless conductivity detecting circuit is also called high frequency conductivity detecting[2]. Fig. 1 is the electrophoresis chip block diagram.

There are two integrated electrodes on the end of the separating channel in the uprightness direction, one is the inspiriting electrode that provides a high frequency AC signal, and the other is the receives electrode that receives a conductive signal of the liquid[3]. From the basic principle of electrochemistry, we know that if the inspiriting electrode is provided with the high frequency AC signal, the liquid ion will generate the conductive current because the liquid ion moves in the fixed direction. So the conductive current is in direct proportion to the conductance of the liquid when the frequency is below 1 MHz. The conductivity of the liquid is in direct ratio to the section area of the electrode and the sum of all ions, and in inverse ratio to the distance of electrode. It is shown as the Eq. (1).

$$G = (A/L_c) \times \sum c_i \lambda_i. \tag{1}$$

where, A is the area of electrode, L_c is the distance between the two electrodes, and $\sum c_i \lambda_i$ is the sum of all ions.

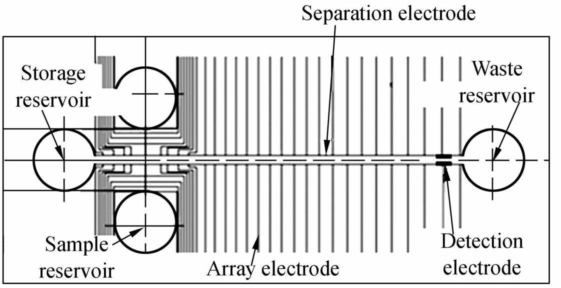

Fig. 1　Top view of integrated electrophoresis chip

3 Structure of detecting circuit

According to the working principle of con-

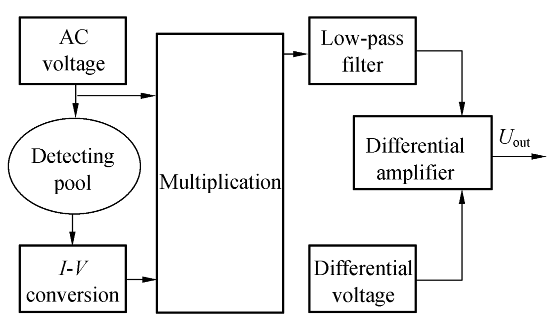

Fig. 2　Structure of detecting circuit

tactless conductive detection, the detecting circuit is designed[4] as shown in Fig. 2. It mainly consists of a cell of AC inspiriting signal generator, an *I-V* convertor, a multiplicator, a low-pass filter, and a differential amplifier.

3.1 AC inspiriting signal generator

The MAX038 is a high-frequency, precision function generator which can produce accurate, high-frequency triangle, saw-tooth, sine, square, and pulse waveforms with a minimal external components. The output frequency can be controlled over the ranges of 0.1 Hz to 20 MHz with an internal 2.5 V band gap voltage reference and an external resistor and a capacitor. Because the output signal of all waveforms is a $2V_{P-P}$, which is too small to drive inspiriting the liquid, the basic amplifying circuit is applied to amplify the output signal to make it get to 10 V peak value. The inspiriting signal use sine wave other than other types, because the sine wave has less high power, which can reduce the noise[5]. The circuit is shown in Fig. 3.

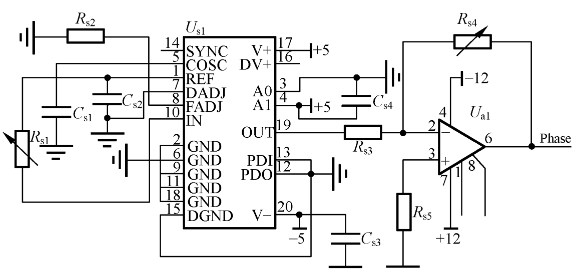

Fig. 3 AC inspiriting signal generator circuit

3.2 *I-V* conversion

The conductivity current of the electrophoresis chip is very small and difficult to detect, so we need to change the current into the voltage, and the circuits must also have large enough gain factor and wide bandwidth to ensure the conversed respond voltage is large under a high frequency exciting voltage. The amplifying IC OPA686 is chosen, which has a very high gain bandwidth of 1 600 MHz and good signal performances of very low input voltage noise of 1.3 $nV/\sqrt{Hz}$ and a low supply current of 12 mA. T-style feedback network shown in Fig. 4 can use smaller resistance to attain higher input resistance and larger gain, and it can achieve high-precision *I/V* conversion.

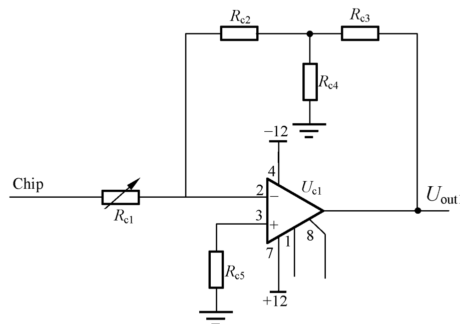

Fig. 4 *I-V* conversion circuit

3.3 Multiplication

Because there are many random noises with the conductivity signal, and the noises maybe lager than the conductivity, we cannot get the useful signal if we directly detect the output signal[6]. Multiplication fulfills correlation operation of two signals, which is the phase moved inspiriting signal (i.e. reference signal), and the other is the changed conductive voltage signal[7]. If the reference signal is $U_s(t)$ and the conductive voltage signal is $U_r(t)$ which are shown in the equation (2) and (3), the output signal of multiplication is U_o, as shown in the equation (4).

$$U_s = E_s \sin(\omega t + \phi_1), \tag{2}$$

$$U_r = E_r \sin(\omega t + \phi_2), \tag{3}$$

$$U_o = U_s U_r = \frac{E_s E_r}{2}\{\cos(\phi_1 - \phi_2) - \cos[2\omega t + (\phi_1 - \phi_2)]\}. \tag{4}$$

Because the noise doesn't correlated to the conductivity signal, the noise signals of amplification and the environment have no refection to the out signal. So the signal can get rid of most noises by correlation operation[8]. AD630 is chosen to realize the multiplication. AD630 is a high precision balanced modulator which combines a flexible commutating architecture with the accuracy and temperature stability afforded by laser wafer trimmed thin-film resistors. The circuit is shown in Fig. 5.

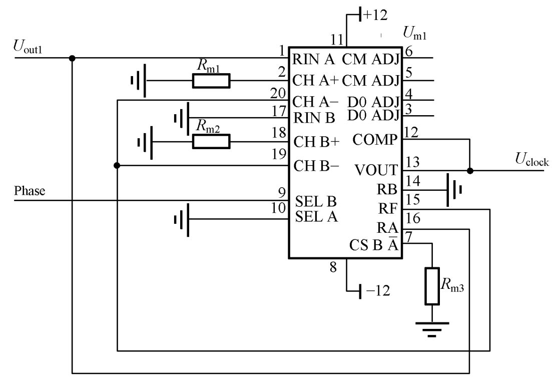

Fig. 5　Multiplication circuit

3.4　Low-pass filter

The signal of multiplication consists of two parts, one is a low frequency and the other is 2-order frequency of the inspiriting signal. The low-pass filter shown in Fig. 6 can get rid of the 2-order frequency of the result and export the DC signal. Furthermore, the filter is designed by using an infinite gain multiply feedback low-pass filter, which has less devices and a low output resister, so the circuit is stable. OP27 realizes an operational amplifier, and it has outstanding noise performance, excellent precision and high-speed specifications. The wideband noise is only 3 nV/$\sqrt{\text{Hz}}$ with the $1/f$ noise corner at 2.7 Hz, and the low noise is maintained in all low-frequency applications.

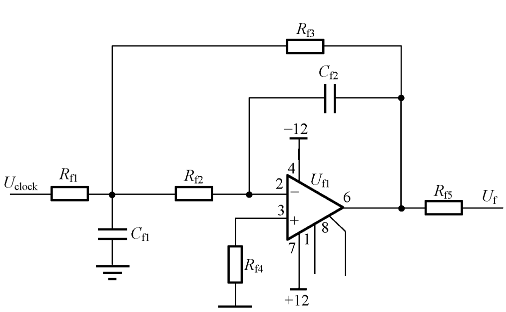

Fig. 6　Low-pass filter circuit

3.5　Differential amplifier

This cell can not only get rid of the large DC conductivity offset when there is only buffer liquid, but also amplify the conductivity respond signal passing through the filter. Differential amplification cell circuit can ensure the out signal is relatively small when there is only buffer liquid, and also provide large gain factor when the detected conductivity signal is much weak. The circuit is shown in Fig. 7. AD620 realizes a amplifier. AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gain from 1 to 1 000. Furthermore, the AD620 is smaller than discrete designs, and offers lower power (only 1.3 mA max supply current).

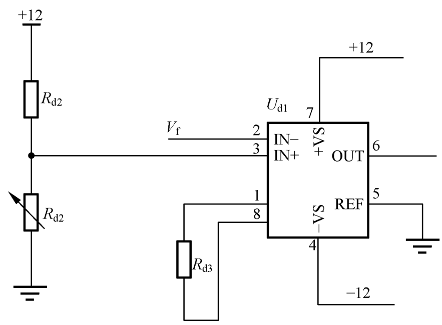

Fig. 7　Differential amplifier circuit

4　Experiments and testing of circuit

The detecting circuit is applied to the elec-

Tab. 1　Output voltage of conductance response of K^+

Concentration	U_{out} (V) at different frequencies	
	450 kHz	1 MHz
distilled water	1.141 2	0.814 2
1×10^{-9}	1.240 2	0.214 5
1×10^{-8}	1.373 6	0.301 1
1×10^{-7}	1.413 1	0.402 7
1×10^{-6}	1.535 8	0.476 6
1×10^{-5}	1.859 4	0.581 9

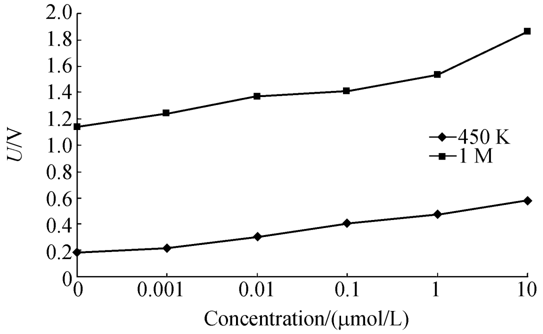

Fig. 8 Conductance response curves of K^+ concentration at 450 kHz and 1 MHz

trophoresis chip to detect the contactless conductivity signal of series concentration of K^+[9]. Through adjusting the resister of the MAX038 inspiriting signal generator, different frequencies can be obtained. The peak of inspiriting signal reaches 10 V, and inspiriting frequency is 450 kHz and 1 MHz, which are shown in Tab. 1. According to the table we draw the Fig. 8 which indicates conductance response of series K^+ concentration at 450 kHz and 1 MHz.

5 Conclusions

From the Tab. 1 and Fig. 8, we can draw a conclusion that the detecting circuit has very high resolving power, it can devolve the 10^{-9} K^+ from the distilled water, and has good linearity between 10^{-9} and 10^{-6}. It has more resolving power than those of all similar circuits before used. There are two DC supply voltages of 5 V and 15 V in the circuit, but a circuit with only one DC voltage will be studied in future.

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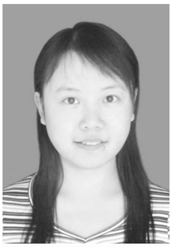

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● **下期预告**

高精度光学表面磁流变修形

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系统研究了确定性磁流变抛光高精度光学表面的关键技术及应用。采用自研的 KDMRF－1000 磁流变抛光机床和 KDMRW-1 水基磁流变抛光液对直径 80 mm 的 K4 材料平面反射镜和直径 145 mm 的 K9 材料球面反射镜进行修形实验。样件一面形收敛到 PV 值 55.3 nm，RMS 值 5.5 nm；样件二面形收敛到 PV 值 40.5 nm，RMS 值 5 nm。样件的表面粗糙度均有显著改善。磁流变修形技术具有高精度、高效率、高表面质量的特点，可广泛应用于高精度光学表面加工中。