

The research of device for measuring film thickness of intelligent coating machine

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Abstract. Ion beam sputtering machine uses computer to real time monitor the change of film thickness in the preparation process of soft X ray multilayer element fabrication. It solves the problems of uneven film thickness and too thick film thickness and so on, which exist in the original preparation process. The high-precision quartz crystal converts film thickness measurement into frequency measurement. The equal precision frequency meter based on FPGA measures the frequency. It can reduce the signal delay and interference signal of discrete components, accordingly improving the accuracy of measurement. Then it sends the count value to the host computer through the single chip microcomputer serial port. It calculates and displays the value by the GUI of LabVIEW. The experimental results show that, the relative measurement error can be decreased to 1/10, i.e., the measurement accuracy can be improved by more than ten times.

1 Introduction

Coating technology is widely applied in the industrial process. Sputtering coating technology is widely used in optical thin film, the large scale integrated circuit coating, building materials coating, decorative materials coating, super hard cutting tool coating industry, and so on. With the development of our national economy, the domestic need for sputtering coating equipment increases rapidly. At present, there are already some coating equipments introduced, and some units are also considering the introduction. In industrial production, it will obviously change the physical characteristics of the workpiece after coating. Ion beam sputtering machine uses computer to real time monitor the change of film thickness in the preparation process of soft X ray multilayer element fabrication. It solves the problems of uneven film thickness and too thick film thickness and so on, which exist in the original preparation process^[1].

It coats the workpiece using ion beam sputtering principle, meanwhile, it also coats the sideward quartz crystal oscillator probe^[2]. There is a linear relationship between the change of quartz crystal frequency changes and thickness, so it can achieve the control of film thickness by test the change of frequency. By a common control of FPGA, MCU and PC, it achieves design of intelligent control system, which reduces the signal delay and interference signal of discrete components, accordingly improving the accuracy of measurement.

In this paper, the main research includes: Study of the work principle of coating machine and film thickness control technology; Development of equal precision frequency meter based on FPGA; Implementation of

control program based on the virtual instrument software platform LabVIEW; Data sending and receiving by MCU serial port.

2 The principle of the film thickness control system of ion beam sputtering coating machine

2.1 The principle of ion beam sputtering coating

The ion beam sputtering coating machine uses Kaufman type ion gun. The working gas (Ar gas) getting into the ion gun has been ionized to produce ion flow Ar. Through the limiting plate, the ion flow will bombard the target material. The sputtering target material is deposited on the coating sample^[3]. The target material is deposited on the coating sample. At the same time, it is also deposited on the sideward quartz crystal oscillator probe. It takes advantage of the quartz crystal piezoelectric effect and the quality load effect to monitor the film thickness^[4].

The inherent frequency of the piezoelectric effect of AT cut type quartz crystal f:

$$f = \frac{n}{2d_q} \left(\frac{c}{\rho}\right)^{\frac{1}{2}} \quad (1)$$

n : the number of harmonics = 1,3,5,...;

d_q : the thickness of quartz crystal;

c : the elasticity coefficient of section 0;

ρ : the density of quartz crystal($2.56 \times 10^3 \text{ Kg} / \text{m}^3$).

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Obviously, there is a direct relationship between the resonant frequency f and d_Q, c, ρ . There are many external influence, such as crystal temperature, temperature gradient, and excitation field, to affect the resonant frequency. This is because the factors above may affect the parameters d_Q, c, ρ .

For the common fundamental (n=1), it can be:

$$f = \frac{N}{d_Q} \tag{2}$$

$$N = \frac{1}{2} \left(\frac{c}{\rho} \right)^2$$

In the equation: N is called the frequency

constant of the crystal. d_Q is the thickness of quartz crystal.

$$\Delta f = -\frac{N}{d_Q^2} \Delta d_Q$$

Both ends for differential: $\Delta f = -\frac{N}{d_Q^2} \Delta d_Q$. The physical meaning of the equation above is, if the quartz crystal thickness, which is d_Q , is increased Δd_Q , the vibration frequency of crystal changes $-\Delta f$. The minus sign in the equation represents that the crystal frequency will decrease with increasing film thickness. However, in the actual coating, the deposition is a variety of membrane material, and not quartz crystal material. So it needs to convert the quartz crystal thickness increment Δd_Q into the film thickness increment.

$$\Delta d_Q = \left(\frac{\rho_m}{\rho} \right) \times \Delta d_m$$

That is $\Delta d_Q = \left(\frac{\rho_m}{\rho} \right) \times \Delta d_m$, then,

$$\Delta f = -\frac{\rho_m}{\rho} \times \frac{N}{d_Q^2} \times \Delta d_m = -\frac{\rho_m}{\rho} \times \frac{f^2}{N} \times \Delta d_m$$

Making S : $S = -\frac{\rho_m}{\rho} \times \frac{f^2}{N}$, then, $\Delta f = S \times \Delta d_m$ or

$$\Delta d_m = \left(\frac{1}{S} \right) \times \Delta f$$

S is called transform sensitivity.

For a certain kind of coating material, ρ_m is a constant. When The film is not very thick, namely the deposited film quality is far less than the quartz plate quality, natural frequency changes will not be great. It can approximate to see S as constant, then there is a linear relation between the change of quartz crystal frequency Δf and the deposited film thickness Δd_m . So it can achieve the control of film thickness by detecting the change of the quartz crystal inherent frequency.

2.2 The measurement principle of equal precision frequency meter

The measurement precision of the frequency meter, which is based on traditional counting frequency measurement principle, will reduce with the measured signal frequency reducing. There is a big limitation in

practical application. The equal precision frequency meter not only has high measurement precision, but also to maintains a constant test accuracy in the whole frequency region. Therefore, the system uses the equal precision frequency meter based on FPGA as the frequency measurement unit. The equal precision measurement principle diagram is shown in Figure 1:

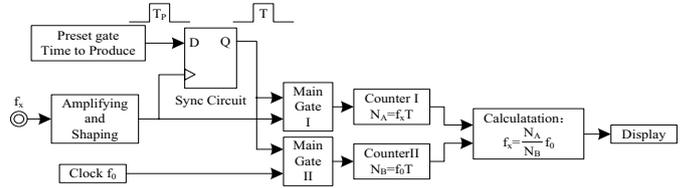


Figure 1. The equal precision measurement principle diagram

The measurement principle of equal precision frequency is: After the preset gated signal came, the Q end of D triggers generates high level along with D end while the rising edge of the measured signal triggers. Until the next trigger pulse's rising edge comes after the arrival of the preset signal's falling edge, the Q end becomes low. This will produce a gating signal to control the main door I and II. At the same time, the measured signal and standard signal respectively go through the main doors I and II, into the counting unit. Then it can get the count value $N_A = f_x \cdot T$ and $N_B = f_0 \cdot T$. With comparison of the two equation, it can get the calculation

$$f_x = \frac{N_A}{N_B} \cdot f_0$$

unit: $f_x = \frac{N_A}{N_B} \cdot f_0$. The measured signal frequency can be obtained thereby. That is, in effective level of the same gating signal, it counts the measured signal and the standard signal at the same time. Then it calculates and displays through the formula^[5].

3 The overall design of the film thickness control system of ion beam sputtering coating machine

According to the working principle of ion beam sputtering coating machine, the system consists of the measuring frequency part (complete frequency meter function), the stepping control part (switch target material) and the control host part.

The basic block diagram of the overall system design is shown in Figure 2:

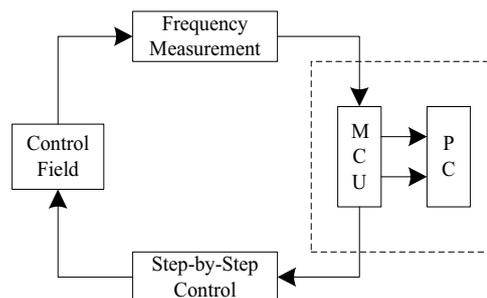


Figure 2. The basic block diagram of the overall system design

The measuring frequency part adopts the complex programmable logic device FPGA for frequency measuring, that can reduce the signal delay and interference signal of discrete components, accordingly improving the accuracy of measurement.

The host control part adopts currently mature two levels of management system which consist of single chip microcomputer and the host computer. The single chip microcomputer which is the central control unit, can fully guarantee the reliability of the whole system on the hardware. The host computer uses virtual instrument to calculate and display frequency, and manages the single chip microcomputer, which makes the whole design more intelligent and flexible.

FPGA interfaces to the single chip microcomputer. It can serve as a MCU peripheral to implement the function required by the MCU. It can reach flexibility of embedded application system. On the function, there is a strong complementarity between MCU and FPGA. MCU has the characteristics of high cost performance, functional flexibility, easy man-machine communication and good ability of data processing, etc. FPGA has the advantages of high reliability, high reliability, convenient development and specification, etc^[6].

The client computer communicates to the host computer by serial communication. MCU's serial port is TTL level, which is converted by RS232. It uses a low power consumption chip MAX232 with a single power supply. TXD of PC communication adapter board connects to the receiver RXD of MCU. TXD of MCU connects to the receiver RXD of PC. So it can PC can be realizes communication between PC and MCU.

4 The design of system hardware

In the unit of frequency measurement, the system uses equal precision frequency measurement circuit based on FPGA, which requires the accuracy up to 10^{-7} . In order to achieve the accuracy requirements, standard frequency signal must reach more than 10MHz. The stability of general LC oscillator frequency can reach $10^{-3} \sim 10^{-5}$ level, so the test circuit can adopt the quartz crystal oscillator of high frequency, high stability and high precision, which can be adjusted with constant temperature, as the standard frequency generating circuit. This system uses quartz crystal oscillator of 16MHz. The quartz crystal oscillator is of high accuracy and high stability.

4.1 The interface logic design of 89C51 and FPGA

FPGA is connected to MCU. It can be used as a peripheral of MCU to achieve the required functions. In function, MCU has strong complementarity with FPGA. MCU has the characteristics of high performance price ratio, flexible function, easy human-computer interaction, good ability of data processing etc. FPGA has the advantage of high speed, high reliability and convenient development, specification etc.

In the frequency measuring system, the task of 89C51 is to achieve equal precision frequency measurement through the signal line, to read the value of the standard

frequency counter and the measured signal counter in FPGA, to process the measurement results and to communicate with the host computer. The hardware connection of MCU and FPGA is shown in Figure 3.

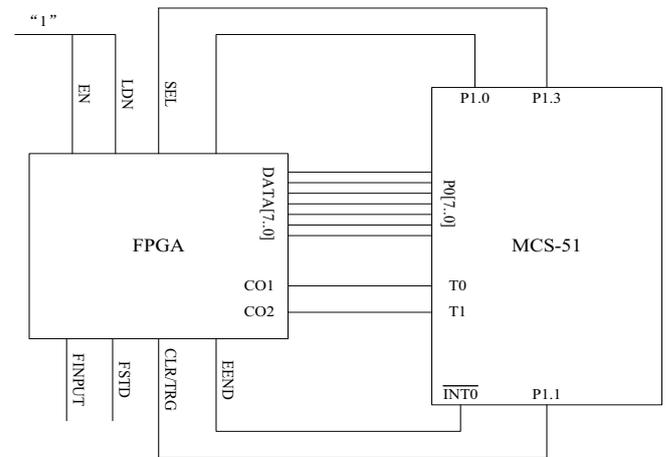


Figure 3. The hardware connection of MCU and FPGA

4.2 Design of serial communication interface between 89C51 and PC

The client computer communicates to the host computer by serial communication. MCU's serial port is TTL level, which is converted by RS232. It uses a low power consumption chip MAX232 with a single power supply. TXD of PC communication adapter board connects to the receiver RXD of MCU. TXD of MCU connects to the receiver RXD of PC. So it can PC can be realizes communication between PC and MCU^[7]. The communication interface of MCU and PC is shown in Figure 4.

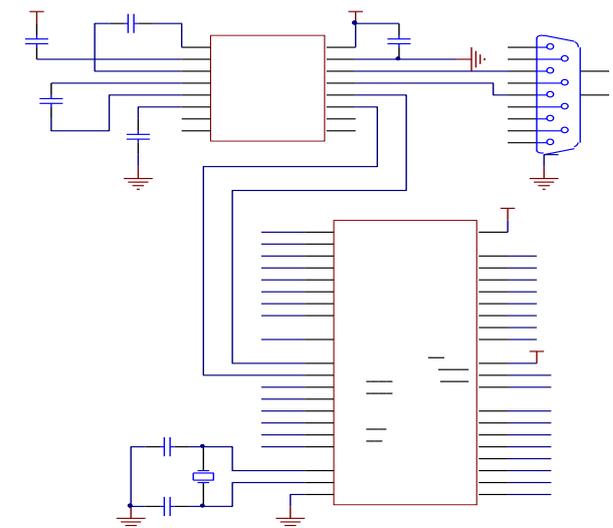


Figure 4. The communication interface of MCU and PC

5 The design of system software

5.1 The software implementation of FPGA in this system

With the continuous development of electronic technology, the chip design based on EDA technology is becoming the mainstream of electronic system design. Large-scale programmable logic device CPLD/FPGA is two most widely used kinds of programmable application-specific integrated circuit (ASIC). This system uses ALTERA company's software Quartus II to design and simulate CPLD/FPGA^[8].

The counts of two 24 bits counter, which are used to count the frequency of the measured signal and standard signal respectively, is realized by the very-high-speed integrated circuit hardware description language VHDL. It produces the following device by Quartus II:

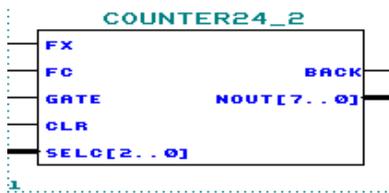


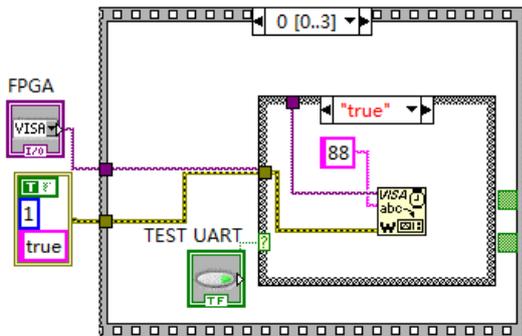
Figure 5. Counting Module

5.2 The software design based on virtual instrument

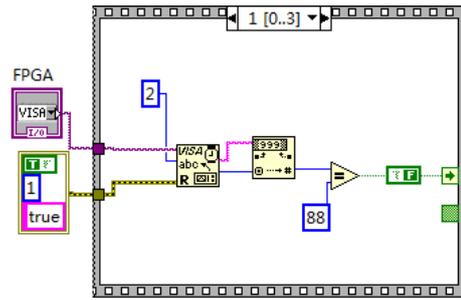
The host computer control part in this system is the core part of the whole system. It processes and displays data, which achieves the function of information detection, data processing and command center. It adopts virtual instrument software LabVIEW to design friendly human-computer interaction interface^[9].

In this system LabVIEW has five serial communication nodes which respectively achieve the function of serial port settings, serial port writing, serial port reading, detecting serial buffer and interrupt, etc.

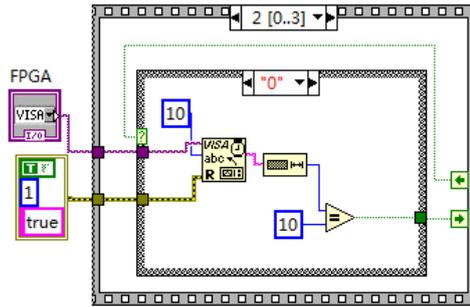
The block diagram of serial port detecting and data transmitting and processing is shown in figure 6. a: Test the serial port and transmit data to the single chip microcomputer. b: MCU returns a value to compare with the value sent. If they are the same, the serial port works well. c: PC receives 10 data sent by the microcontroller. d: After receiving 10 data correctly, the PC shut the serial port.



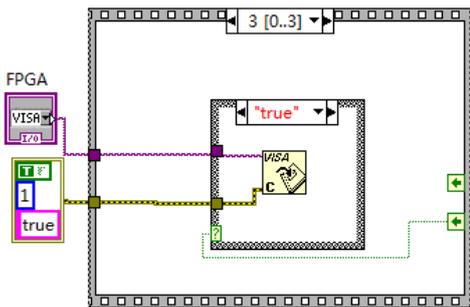
a Testing the serial port



b The serial port works well



c MCU sends data



d PC receives data correctly

Figure 6. Diagram of the serial data transmitting software

It transmits the middle six data of the data series respectively to different connection port of calculation module for processing. The block diagram of calculation module program is shown in fig.7. Ten data are sent into PC via the serial port. Then it calculates the final result.

Through calculation can be The measured signal frequency can be obtained by the formula $f_x = \frac{N_x}{N_s} \cdot f_s$. The program is shown as follow:

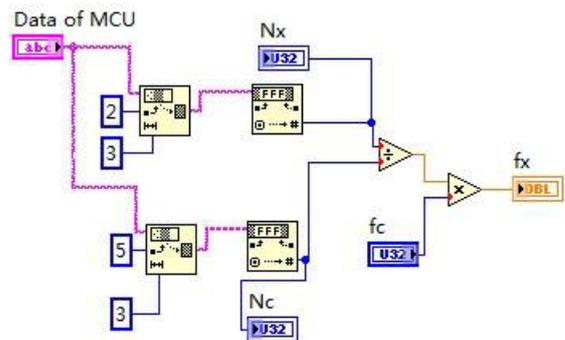


Figure 7. The block diagram of total program

6 The experimental result

The measured signal frequency can be shown on the front panel of the total program with a green light for transmitting data. When the single-chip microcomputer and PC are transmitting data, the green light shines. In the front panel of the LabVIEW program, it can display the whole process of serial communication, data transmission and data processing clearly, as shown in figure 8.

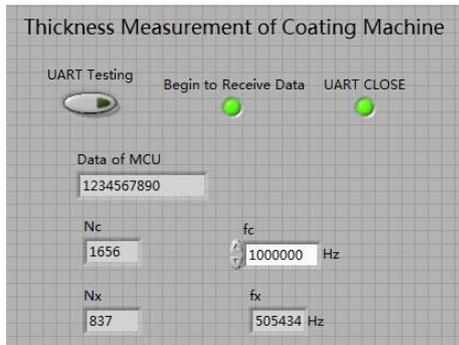


Figure 8. The front panel

According to the above design, it completed the implementation of measuring frequency, data processing and communication of dual-computer. The experimental results are as follows:

Table 1. The system test results when the gate time is 1 second (Unit: MHz)

	1	2	3	4
Test results	5.00000	5.0000003	4.9999997	5.0000000

Table 2. The test results of general frequency meter when the gate time is 1 second (Unit: MHz)

	1	2	3	4
Test results	5.000002	5.000001	4.999998	5.000002

When it measures the frequency 5 MHz, the relative measurement error of general frequency meter is:

$$r=1/5000000=2 \times 10^{-7}$$

When it measures the frequency 5 MHz, the relative measurement error of this system is:

$$r=1/16000000=6.25 \times 10^{-8}$$

It can be seen that, using the equal precision measurement, it can meet the requirements of system design with small relative error.

If you want to get high measurement precision, it is required to use the more fashionable time frequency.

When the gate time changed to 10 seconds, we can see that the longer the gate count, the greater the frequency standard during this time. According to the formula, the measurement error is smaller while the measurement precision is higher. But due to time base accuracy, when the gate time is 10 seconds, the measured frequency has some deviation from the theoretical value. In order to solve this problem, it needs the precision instrument for calibration in the actual application.

7 Conclusion

This system completes the research of device for measuring film thickness of intelligent coating machine. It uses ion beam sputtering technology, FPGA, MCU host computer, and LabVIEW. It realizes intelligentization, instrumentation and virtualization of the entire system. It improves the measurement precision greatly.

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