Development of High Temperature Pressure Sensor for Oil and Gas Field Based on SOI

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Abstract. According to the pressure testing requirements under high temperature and high pressure environment in oil and gas field, this paper introduced the design and development of a kind of high temperature high pressure sensor chip, and solved the problems of thermal stability of traditional piezoresistive sensors in special environment. The method of packaging SOI piezoresistive chip of high temperature resistance and glass plate in one through technology of anodic bonding under circumstance of vacuum, solved the problem of wide measurement range of pressure under high temperature circumstance. Meanwhile, insulating the medium under investigation from sensor chips by adopting corrugated diaphragm and high-temperature silicon oil as isolation materials, improved the adaptability of sensors.

Introduction

To meet the pressure testing requirements under high temperature application environment in the field of petrochemical and aerospace industry etc, high temperature and pressure sensors have been widely used.[1]

Currently, high performance pressure sensors in oil and gas field in china mainly depends on import, which seriously restrict the improvement of petrochemical industry.

Aiming at the pressure measurement in oil and gas field and other special fields, by using MEMS process and manufacturing all-silicon structure piezoresistive force-sensitive chip which based on SIMOX technology, the high temperature pressure sensor this paper proposed solves the problem that it is difficult for traditional diffusion silicon pressure sensor to work over 120℃. Meanwhile, insulating the medium by adopting corrugated diaphragm improve the thermal stability and reliability of sensor chip. The high temperature pressure sensor devoloped could work stably in the range between 0℃ and 200℃, and could meet the requirements of pressure measurement in petrochemical and other automation field.

Structure Design of Force-Sensitive Chip of High Temperature Pressure Sensor

The basic principle of piezoresistive pressure sensor is to transform the changes of pressure value measured into that of the pressure-sensitive elements resistance value by using the silicon piezoresistive effect, and then transform the changes of resistance value into that of the voltage value via conversion circuits. It is refered to as piezoresistive effect that the values of resistance or resistivity of a material changes significantly when stesses being applied on.[2]

The piezoresistive effects of semiconductor materials, such as silicon and germanium,are much more stronger than metal materials. When stesses are applied on semiconductor crystals, changes of resistance are maily caused by changes of resistivity. In orthogonal coordinate system, when the coordinate axis accord with crystal axis, the relation between the relative change of resistance and the stress as following:

$$\frac{\Delta R}{R} = p_l s_l + p_t s_t. \tag{1}$$

Where s_l and s_t are stress along longitudinal and transverse; p_l and p_t are piezoresistive coefficient along longitudinal and transverse.

According to the principle of silicon piezoresistive effect, varistors which form the wheatstone bridge are made by using the Si planar technology of ion implantation or diffusion. And then, signal conversion could be achieved via the wheatstone bridge. Thus, silicon piezoresistive sensors which could transform pressure signals into voltage signals are manufactured.

On the basis of the thoery of membrane deformable and performance requirements of sensors, models of force-sensitive chips are analyzed, and structure of periphery fixed square membrane is proposed.

In order to bring better linearity to the sesor, the design of membrane thickness h must accord with the demand of that maximum center deflection of the membrane should smaller than membrane thickness, and center deflection less than 1/5 of membrane thickness is regulated.

Under effect of pressure p, maximum stress occurs at center of each boundary.

$$s_{\max} = \frac{0.308 pa^2}{h^2}. \tag{2}$$

Maximum deflection occurs at center of plate center.

$$w_{\max} = \frac{0.0138 pa^4}{Eh^3}. \tag{3}$$

Where p is uniformly distributed pressure; a is side length of square membrane; h is thickness of square membrane; E is Young modulus.

Analysing stress-strain by finite element method through ANSYS, stress-strain simulation results of pressure sensor force-sensitive chip is obtained and is shown in Fig.1. It accord with the theoretical calculation.

For making full use of maximum stress and improving sensitivity, piezoresistor strips in force-sensitive chip should be arranged at the points of maximum stresses occuring. Structure diagram of square membrane force-sensitive chip is shown in Fig.2.

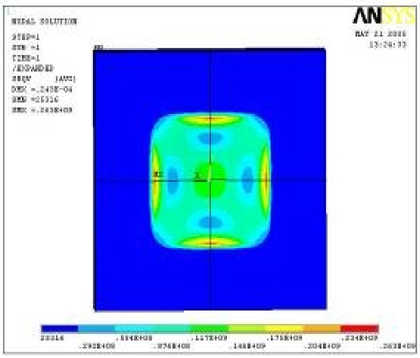


Fig.1 Stress-strain simulation results of force-sensitive chip

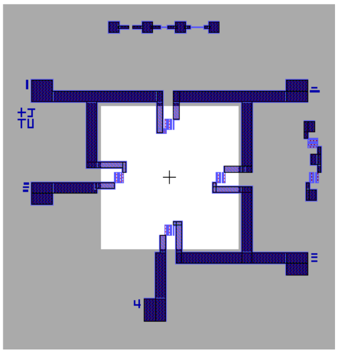


Fig.2 Structure diagram of square membrane force-sensitive chip

Fabrication Process of Force-Sensitive Chip of High Temperature Pressure Sensor

Higher demands on thermal stability are put forward for pressure sensor due to the high temperature high pressure characteristics in oil and gas wells. When the working temperature is higher than 120℃, traditional piezoresistive pressure sensors are apt to be performance degradation or even invalidation because of the leakage current of PN junction which isolate the piezoresistor and silicon substrate. So, it is difficult for traditional piezoresistive pressure sensors to solve the problem of pressure measurement above 120℃. Aiming at the pressure monitoring environment of high temperature high pressure in the field of petrochemical and aerospace industry etc, technology of SOI chip manufacturing is adopted in processing of sensor. The purpose of development high temperature resistance piezoresistive force-sensitive chips by using SOI material is to insulate detection circuit layer of force-sensitive chips from silicon substrate through Silica insulating layer, and to avoid the production of leakage current between them. Hence the characteristics of high temperature resistance of force-sensitive chips are improved.

Silicon piezoresistive force-sensitive chips are manufactured by using technologies of MEMS(Micro Electro Mechanical Systems) and SIMOX(separation by implantation of oxygen). Detection circuit layer and silicon substrate in chips are insulated by Silica layer which made by the technology of SIMOX to implement the pressure measurement under high temperature circumstance of higher than 200℃. Meanwhile, sensing units are formed by packaging SOI Silicon piezoresistive force-sensitive chip and heat-resistant glass sheet of PYREX7740 in a vacuum environment through the technology of low temperature anodic bonding. For the good mechanical characteristic, piezoresistive Wheatstone Bridge which serving as the transform circuit is integrated on the square membrane of all-silicon structure. So, elastic and sensitive elements of sensor and transform circuit are integration. This kind of structure could significantly decrease the hysteresis and repeatability error of the sensor in pressure messurement, and improve the measuring accuracy. Technological process of the high temperature pressure sensor chip is shown in Fig.3.

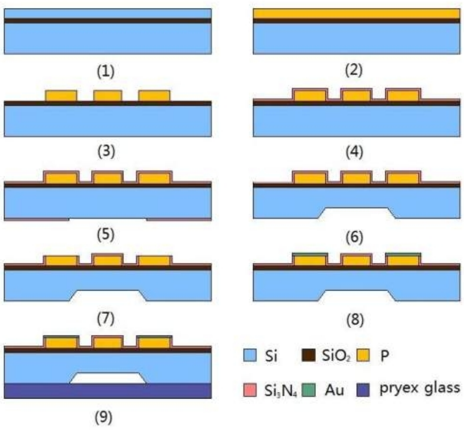


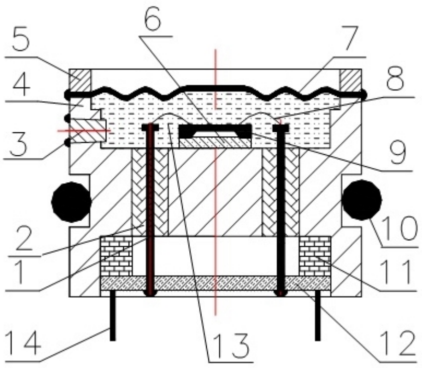
Fig.3 Technological process of the high temperature pressure sensor chip

Packaging Process of Force-Sensitive Chip of High Temperature Pressure Sensor

To ensure the stability and corrosion resistance of pressure sensor under high temperature environment in oil and gas fields, reliable processes of wire bonding and isolated encapsulation are designed. Wire bonding of the high temperature high pressure sensor is accomplished by application of bonding equipment with deep cavity welding function.

Stucture of diaphragm isolating and silicone oil filling are adopted in the packaging of the high temperature pressure sensor. The basic principle is that, by using the incompressibility of the silicone oil and good characteristic of linear displacement of diaphragm, external pressure could act on corrugated diaphragm directly and then be transferred to force-sensitive chip via silicone oil.

So, direct contact between medium messured and sensitive element is avoided by using isolated stucture, and adaptability of sensors are improved accompanied by better stability. Packaging structure principle diagram of the high temperature pressure sensor is shown in Fig.4.Packaging diagram of the high temperature pressure sensor is shown in Fig.5.



1. Electrode, 2. Glass insulator, 3. Pin hole, 4. Base,5. Chuck ring
6. Pyrex7740 glass,7. Corrugated diaphragm,8. Gold wire
9. All-silicon force-sensitive chip,10. Seal ring,11. insulating covering
12. Compensating plate,13. high-temperature silicon oil,14. lead wire

Fig.4 Packaging structure principle diagram of the high temperature pressure sensor

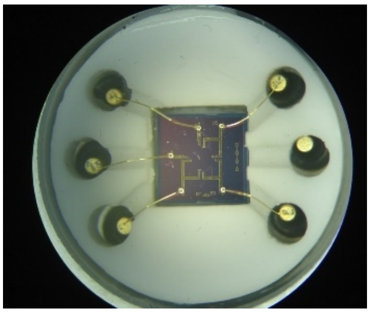


Fig.5 Packaging diagram of the high temperature pressure sensor

Testing Experiment of High Temperature Pressure Sensor

Testing experiments of high temperature pressure sensor are developed at room temperature by loading pressure with the piston gauge. For testing the performance under high pressure, loading pressure ranged from 0 Mpa to 150 Mpa, and excitation applied by the 5V DC regulated power supply. Testing results of output characteristic curve of the pressure sensor is shown in Fig.6. Test data of the pressure sensor is shown in Table 1.

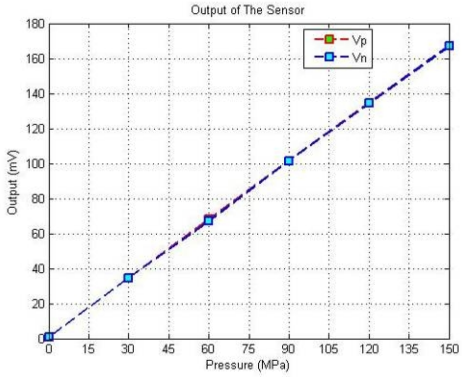


Fig.6 Testing results of output characteristic curve of the pressure sensor

Table 1. Test data of the pressure sensor

Pressure[Mpa]	Load,V_p[mV]	Unload,V_n[mV]
0	0.68	0.76
30	34.48	34.58
60	68.04	67.85
90	101.35	101.28
120	134.33	134.29
150	166.96	166.96

According to the curve and data of the test, static parameters of the sensor are obtained as follow: Nonlinear is 0.28% FS, hysteresis is 0.39% FS, precision is 0.56%. Therefore, the pressure sensors designed possess a high performance.

Conclusion

(1)The high temperature pressure sensor this paper designed have characteristics of high temperature resistance, wide range, high precision and miniaturization. Meanwhile, it could maintain a long-term working stability.
(2)The high temperature pressure sensor based on SOI force-sensitive chip this paper developed have a measurement range of 150MPa and could work between 0℃ and 200℃, and therefore be suitable for the pressure measurement in petrochemical and other high temperature high pressure environment.

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