Research of High Sensitivity Uncooled Infrared Detector Array

Ping-chuan Zhang
HUAZHONG University of Science& Technology, WUHAN China 430074
LUOHE Vocational Technology College, LUOHE China 462002
E-mail: redmoon123456@126.com

Bo Zhang
LUOHE Vocational Technology College, LUOHE China 462002
E-mail: lhzyzb@126.com

Abstract---The infrared thermal imaging technology has been widely used in military and civilian fields and the field of the infrared detection and infrared thermal imaging technology has been of concern for a long time. On infrared thermal imaging, its core components for the infrared focal plane arrays, how to develop a high sensitivity of the multi-focal plane infrared detector is a key issue. Although the Common focal plane array of quantum has high sensitivity, but it requires low temperature cooling work environment and led to complexity and high cost, difficult to compact. Conventional uncooled infrared focal plane array is contrast to the quantum focal plane arrays. Therefore, this article preceded by the uncooled infrared detector array to improve the wide temperature sensitivity in examining the feasibility PMN composite film, materials composition, structure design and preparation process technology.

Keywords: Pyroelectric effect; Pyroelectric detectors; Infrared radiation; Etching process

1. Introduction
Pyroelectric detectors[1-5] is the light receiving device using the pyroelectric effect to detect infrared radiation, its advantages are: able to work at room temperature; a broad spectrum of responses, can be used to detect any radiation caused by body temperature changes in the pyroelectric; tight structure, simple operation, high mechanical strength; no external bias field: only response to the temperature change rate, can detect transient signals and so on.

The pyroelectric detector can be divided into two categories, the photon detector of required cooling and thermal detector without cooling. Photon detector response rates, response time, have a wide range of military applications, but the range of applications was affected by the wavelength selectivity, to work at low temperature, high cost and large power consumption, etc., the thermal detector, although its response rate and the sensitivity of devices is less than the high-photon detectors,
but with no wavelength selectivity, without cooling, simple structure, low price and therefore have more extensive application prospects [6]. The pyroelectric detector is a kind of hot detectors, its structure mainly consists of five parts, radiation modulation system, absorbing layer, thermal insulation layer, sensitive element and reading circuit, in which the sensitive element is the core [7,8].

Using the both broadening effects of inorganic phase change materials and the multiple- multiphase of composites, to design a new type of wide temperature range composite response pyroelectric materials[9], to get a good overall performance 0-3 composite pyroelectric materials by casting, hot pressing and simultaneous electric field induced polarization techniques, also studied the broadening mechanisms of the film composite pyroelectric effect in the temperature zone;

On the other hand, a new micro-bridge with thermal insulation and good conductive properties of Si3N4 insulation core / Pt thermal conductivity shell was achieved by etching micro-channel - steamed Pt electrode-filled organic material- membrane- a new type of corrosion process by filling.

And designed-distributed-temperature human identification system using the development of 16*16 Element Array PMNST / PVDF composite uncooled infrared detector array. This would have important theoretical and practical value in the promotion of research and development for uncooled infrared detector array and raising its application level.

2. the pyroelectric mechanism and materials analysis
2.1 Pyroelectric Effect
Pyroelectric effect refers to the dielectric polarization phenomena change with temperature [10]. When some of the strong dielectric material of the surface received infrared radiation, its surface effect of thermal change, as the temperature up or down, in which generating electric charges on the material surface, a phenomenon known as the pyroelectric effect, is a thermoelectric phenomenon, a phenomenon in Barium ferrite of dielectric material was particularly notable. Imagine a single domain of a ferroelectric material, which are arranged so close to the polarization vector across the surface near the bound charge. In thermal equilibrium, the bound charge is from the body of the equivalent number of free charge against the shield, so ferroelectrics on the role of the outside world does not show power. When the temperature changes, the polarization changes, the original charge can not be completely free screen bound charge, then the surface free charge, which formed in the space near electric field on charged particles are attracted or repulsion. If it’s connected with the external circuit, the circuit can be observed in the current, heating and cooling in both cases the current in the opposite direction.

Since coating electrodes on the two surface perpendicular to the crystal (the direction of spontaneous polarization Ps) of Pyroelectric detector in the polar axis, the thermal sensor is similar to the plate capacitor. The working mechanism [3] shown in Figure 1.

![Fig.1 the theory of pyroelectric detectors](image)

Under the assumption that the pyroelectric infrared film temperature distribution is uniform, square wave pulse function modulated infrared radiation is given by:

\[
T(t) = \begin{cases} 
\frac{aP_o}{H}(1-e^{-t/\tau_o}) + T_o & 0 \leq t \leq \tau_o \\
\frac{aP_o}{H}(1-e^{-t/\tau_i})e^{-t/\tau_i} + T_o & t > \tau_o 
\end{cases}
\]  \tag{1}
H for the heat capacity; \( \tau = \varepsilon / \sigma \), \( \varepsilon \) for dielectric constant, \( \sigma \) the conductivity of the crystal; \( a \) for heat detector for the absorption rate; set the ambient temperature is consistent with \( T_0 \) said.

2.2 pyroelectric material
Polyvinylidene fluoride [11]. PVDF resin mainly refers to the fluoride homopolymer or a small amount of fluoride and other fluorinated vinyl monomer copolymer. PVDF resin, fluorine resin, and both General of the resin, in addition to good chemical resistance, high temperature resistance, oxidation resistance, weather resistance, radiation properties, also with piezoelectricity, dielectric property, thermal resistance, and other special properties.

It’s a crystal materials with the spontaneous polarization. Spontaneous polarization is intrinsic polarization of the material itself, because the centers of structure of positive and negative charge in one direction do not overlap. Under normal circumstances, the bound charges on the crystal surface produced by the spontaneous polarization are adsorbed. The spontaneous polarization changes when the temperature changes, thus freeing up some of the Adsorption of charge. It’s opposite for the polarity charge when crystal cooling and heating. Pyroelectric material is a piezoelectric material, is not a centeral symmetry of the crystal. There are thousands of materials with pyroelectric properties, but only a dozen widely used, mainly such as, sulfuric acid peptide in three glycosides, lead lanthanum zirconate titanate transparent ceramics, and polymer film. Pyroelectric materials can be used in industrial infrared detectors, thermal camera tube has some special purpose in the military defense. Its advantage is not low-temperature cooling, but the sensitivity lower than the corresponding semiconductor devices.

3. Process implementation
The proposed schematic design of the infrared detector structure shown in Figure 2.

Conventional lithography employs UV of wavelength from 2000 to 4500 angstrom as the image information carrier and photo resist as intermediate (image record) media to achieve the transformation graph, transfer and processing of image data ultimately delivered to the chip (mainly refers to silicon), or dielectric layer on a process (Figure 3). In a broad sense, this includes two main aspects of light copying and etching.

- Optical copying process: The exposure system accurately passes the prefabricated components in the mask or the circuit on the graphic to the desired location, which is the pre-coated photo resist layer on the chip surface or a dielectric.
- Etching process: using the chemical or physical methods, to remove surface resisting mask wafer of thin dielectric layer or the chip surface of a dielectric material on the resist layer, on which to get a graphic exactly the same as the copied. The integrated circuits functional layer is overlapped in three-dimension, and therefore always lithography process repeated several times. For example, large scale integrated circuit lithography have to go through about 10 times to complete the full transfer.
In the narrow sense, the optical lithography process refers only to copying process, that is, from ③ to ⑤ or ④ to ⑤ of the process in Figure 3.

The electrode under the microscope after graphic photos shown in Figure 4. Response curve shown in Figure 5.

Exposure is the most critical lithography technology processes, it is directly related to the resolution of the resist pattern, leaving film rate, line width control and register accuracy. In certain light, the effect is due to the exposure time. Exposure time is too short, then the photoresist sensitive enough not to fully resist chemical reactions, poor graphics resolution; if exposure time is too long, will resist the edge of a weak non-sensitive part of the light-sensitive, have a "Halo" phenomenon is
also made worse resolution of the resist pattern. In the experiment using contact exposure, exposure time is in 45s, the best graphic lithography. Graphic imaging is the mask to the photoresist to achieve the transfer of graphics. In the developer solution unchanged, must control a good visualization of the time. Experiment is impregnated with visualization, imaging time control at 1 minute 30 seconds.

Generated by sputtering on silicon base to get Si3N4, and then etching the Pt film, MgO single crystal, MgO film deposited Pt substrate, and the mica substrate film, about 20μm thick deposited Si3N4 film, the Si3N4 film on evaporated A1 electrode, then evaporating a layer of gold black as electrodes for the infrared absorption, with 20V voltage for polarization 20min. The heat capacity Si3N4 film is small, so its sensitivity can be very high, its response is proportional to the input infrared light intensity, its voltage responsivity \( R_v \) is 465V/W, detectivity \( D^* \) is \( 1.7 \times 10^8 \text{cmHz}^{0.5}/\text{W} \).

4. Conclusions
A typical semiconductor lithography and metal electrode stripping technology are combined with DC sputtering method, to achieve a graphic of infrared pyroelectric detector sensitive element for the lower electrode. Achieved the preparation for the uncooled infrared detector ferroelectric thin film composite structure (absorbing layer of top electrode / ferroelectric film / bottom electrode / insulating layer / Si substrate), including the insulation layer, bottom electrode, ferroelectric thin films, semi-permeable membrane electrode and absorption layer of the preparation and performance optimization, cell detection rate was \( 2.8 \times 10^8 \text{cmHz}^{0.5}/\text{W} \).

references
[1] LANG S B. Pyroelectricity: from ancient curiosity to modern imaging tool[J]. Physics Today, 2005, 58(8): 31-36.
[2] ROGER W W. Pyroelectric arrays: ceramics and thin films[J]. J Electroceram, 2004, 13(1-3): 139-147.
[3] ZHONG Wei-lie. Ferroelectric Physics [M]. Beijing. Science Publishing House, 1998.
[4] KULWICKI B M, AMIN A, BERATAN H R, et al. Pyroelectric imaging[C]. Proceedings of IEEE, Inter Sympos Appl Ferroelectric, 1992, 90, CH3080-9-1-10.
[5] Cooper A W, Lentz W J, Walker P L, et al. Infrared Polarization Measurement of Ship Signature and Background Contrast[C]. SPIE, 1994, 2223: 301-309.
[6] WHATMORE R W, AINGER F W. Pyroelectric ceramic materials for uncooled IR detectors[C]. Proceedings of SPIE, Advances in Infra-Red Sensor Technology, 1983, 395: 261-26.
[7] WHATMORE R W, BELL A J. Pyroelectric ceramics in the lead zirconate-lead titanate-lead iron niobate system[J]. Ferroelectrics, 1981(35): 155-160.
[8] SHAW C P, GUPTA S, STRINGFELLOW S B, et al. Pyroelectric properties of Mn-doped lead zirconate-lead titanate-lead magnesium niobate ceramics[J]. J Euro Ceram Soc, 2002, 22(13): 21-23.
[9] WATTON R F. Ferrite materials and IR bolometer arrays from hybrid arrays towards integration[J]. Integr Ferroelectr, 1991, 14, 4(22): 175-186.
[10] WHATMORE R W, WATTON R F. Pyroelectric ceramics and thin films for uncooled thermal imaging[J]. Ferroelectrics, 2000, 236(11): 259-279.
[11] Shoucair F, Hwaug W, Jain P. Electrical characteristics of Large scale integration (LSI) MOSFETs at very high temperatures[J]. Micro electron reliability, 1984, 24(3): 46-485.