Novel optical filter to identify the connected defective elements in focal plane array

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Abstract: The connected defective elements identifications has always been the research difficulty of focal plane array (FPA) detector. It is difficult to identify connected defective elements by FPA test-bench because the response voltage of connected defective elements is basically the same as that of normal elements. Novel optical filter for connected defective elements identifications was proposed. The presented filter had sorted elements of FPA detector into two kinds of detection units. The two kinds of detection units were designed in pairs and staggered arrangement closed to each other. The response voltage of the connected defective elements was 50% of that of normal elements. The connected defective elements were identified markedly by using the proposed filter.

Key words: FPA; filter; connected defective elements; identification

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用于识别面阵探测器相连缺陷元的新型光学滤光片

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摘 要: 相连缺陷元识别一直是面阵探测器研究难点。面阵探测器相连缺陷元的光电信号与正常元基本相同,因此采用现有面阵测试方法无法识别相连缺陷元。提出了一种新型光学滤光片来识别面阵探测器中的相连缺陷元。在提出的滤光片结构中,有两种不同透光率、且交错排列的阵列组成。采用该滤光片后,相连缺陷元的响应电压值是正常单元响应电压的 50%,面阵探测器相连缺陷元可以被显著识别。

关键词: 面阵探测器; 滤光片; 相连缺陷元; 识别

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0 Introduction

Infrared focal plane array (IRFPA) detector nowadays serves military and commercial equipment fields, such as infrared imaging system because of its high sensitivity and strong anti-interference[1-2]. As for working in medium infrared band(3-5 μm) of a typical photovoltaic detector, the InSb IRFPA[3-10] has occupied an extremely important position and been applied in the field of staring imaging, which was due to its high sensitivity (compared to PtSi) and high maturity process in batch production(compared to HgCdTe).

The infrared system puts forward the requirement of the defect in IRFPA detector. The number and distribution of the defects in the infrared array detector was proposed by the infrared system. Meanwhile, the defects of the IRFPA detector are not completely avoided due to the limitation of materials and preparation process. Therefore, it urgently needs to distinguish the position distribution of the defect element in the FPA detector. Herein, by the compensation methods, the target information can be compensated. Therefore, the detector can satisfy the system requirements for detecting. In addition, defect element cannot be avoided in the manufacturing of FPA detector with large scale and small pixel array[11-13], caused by effect of material defects and production process level. According to the different causes of the formation, the defects can be divided into the missing defects, the connected defects, and so on. The missing defects are due to lack of element indium bump or electrode caused by the process of lithography or etching, etc. The connected defects are due to the surface of the tables with connecting or the electrodes with connecting or the indium bumps with connecting caused by material defects or by the process of lithography, etc.

On the one hand, we can use the high power optical microscope to observe the defects on the surface of material, caused by the conventional testing process. On the other hand, the encapsulated FPA detector was analyzed by FPA testing system. Reference the record data, the location and quantity of the defect elements can be judged. Under normal conditions, it is difficult to identify the connected defective elements caused by the internal defect of the material or the tiny indium residue, which is observed by the optical microscopy. Similarly, it is also difficult to identify the connected defective elements by the response of FPA testing system, because the response voltage of the connected defective elements is basically the same as that of normal elements. Theoretically, we can identify the connected defective elements by crosstalk of FPA testing method [14]. However, it is very difficult to achieve in practical application. It was because crosstalk is mainly refers to the normal photosensitive element. Generally, crosstalk is defined as interference of a photosensitive element to its adjacent photosensitive element. If we can identify the connected defective elements by the crosstalk of FPA detector testing method, all of the photosensitive units in IRFPA detector need to be analyzed. And with the size of the IRFPA detector increasing, calculation and analysis turned into be complicated. In summary, we cannot use the existing defect detection method for FPA to identify the connected defective elements. It seriously impacts on the image quality and system performance when the IRFPA detector with connected defective elements is applied to infrared system. It is because that it may cause image distortion when the target imaging falls in the connected defective elements. The missing of the evaluation of the connected defective elements not only restricted the performance of the array detector, but also seriously impact on the system performance.

In this paper, in order to improve the defect detection method of IRFPA detector and provide the basis for the compensation of the defects in IRFPA detector, the filter is designed to change the response voltage of FPA detector in order to realize the connected defective elements identifications. Through the connected defective elements analyzing, the comprehensive performance of the FPA detector is improved for satisfying the performance of system.

1 Filter design, fabrication and application

1.1 Filter design

In this paper, the filter is designed to change the response voltage of FPA detector in order to realize the connected defective elements identifications. The presented filter has sorted elements of FPA detector into two kinds of detection units. The two kinds of detection units are arranged alternately like a conventional latticed structure, as shown in Fig.1. The special structure of filter used in this paper is divided FPA detector into several sections in which the characteristic of connected defective element is clear and easy to analyze. Compared to without filter, as the response voltage is broken into several segments, the special structure of filter has better filter performance. The two kinds of detection units are designed in pairs and staggered arrangement closed to each other. The response voltage of connected defective elements is significantly different from that of the two kinds of detection units. Therefore, the connected defective elements based on the novel optical filter can be obtained.

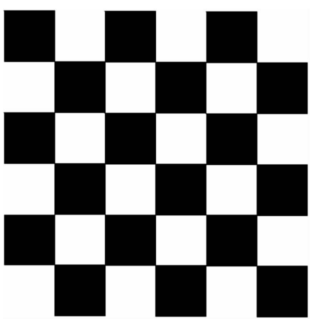

Fig.1 Pattern of the novel optical filter applied in the connected defective elements identifications

1.2 Filter fabrication and application

In this experiment, according to the transmittance of film materials, two kinds of film materials were chosen. Transmittance of one film is 0, the other is 100%. Herein, it is only necessary to consider the substrate material with high transmittance about 100%, without the consideration of the film material on the substrate surface. In order to achieve the full stop of the filter, the gold film with transmittance about 0 was deposited on the surface of substrate. Meanwhile, Gem is used for substrate, which was cleaned by the standard method.

Photolithography can be used to transfer a wide variety of patterns from a mask to a substrate. Etching and peel-off are very different methods to obtain the final pattern. After these treatment, a special filter pattern is presented, which has sharp edges and micron size device feature on the substrate. The gold layer thickness of a filter about 0.1 μm is passivated with Cr/Au film by the chemical vapor deposition or vacuum evaporated method.

Meanwhile, the filter is fixed at front of InSb IRFPA detector. It must ensure all the filter units alignment with each photosensitive element of the focal plane array, as shown in Fig.2.

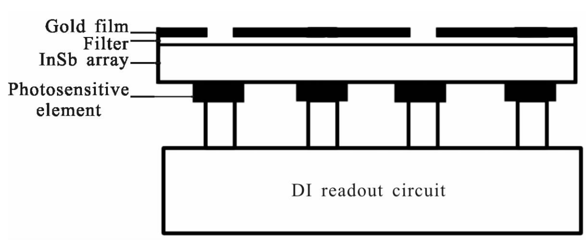

Fig.2 Configuration of element aligning

The InSb IRFPA detector with the novel optical filter is tested by FPA testing system called OPTDET. The test data of response voltage of IRFPA detector are analyzed. Finally, the connected defective elements in IRFPA are identified based on the novel optical filter. The temperatures of surface blackbody in the FPA testing system are 305 K and 300 K. The distance between surface blackbody and detector is 300 mm. The integral time of the detector is 40 μs.

2 Theoretical analysis

2.1 Connected defects elements analysis

It is difficult to identify the connected defective elements by FPA testing system because the response voltage of the connected defective elements is basically the same as that of the normal element. The connected defective elements are analyzed by using circuit. Fig.3(a) shows that the circuit of normal elements in FPA. Fig.3(b) shows that the circuit of connected defects between two elements in FPA.

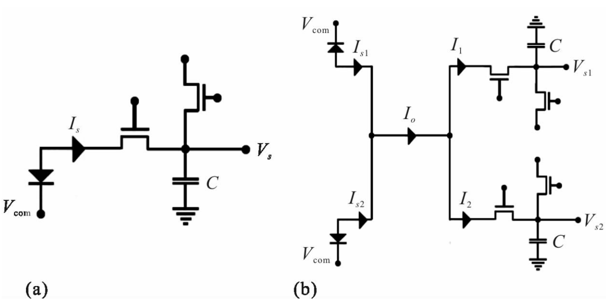

Fig.3 Circuit of (a) normal elements; (b) connected defects between two elements in FPA

Form Fig.3(a), the response voltage of normal elements in FPA can be expressed as:

$$V_s=I_st/C \tag{1}$$

where, I_s is the photocurrent of normal elements, C is the capacitance of ROIC, t is the integrate time of ROIC. Form Fig.3(b), the response voltage of connected defective elements in FPA can be obtained, as follows:

$$V_{s1}=I_1t/C \tag{2}$$

$$V_{s2}=I_2t/C \tag{3}$$

where, I_i is the current of connected defective elements flowing into the ROIC, V_{si} is the response voltage of connected defective elements.

The photocurrent of connected defective elements in FPA can be expressed as:

$$I_1+I_2=I_o=I_{s1}+I_{s2} \tag{4}$$

where, I_{s1} and I_{s2} are respective the photocurrent of connected detective elements.

Generally when manufacture technology has no difference, it was assumed that the transistor and capacitance of CMOS is equal, which was obtained, as shown:

$$I_1=I_2=I_o/2 \tag{5}$$

Then, the Eq.(5) was substituted into Eq.(2), Eq.(3) and Eq. (4) respectively, the response voltage of connecting defective elements can now be obtained as:

$$V_{s1}=V_{s2}=(I_{s1}+I_{s2})t/2C \tag{6}$$

The photocurrent of each normal element in FPA without filter by the same testing parameters can be expressed as:

$$I_{s1}=I_{s2}=I_s \tag{7}$$

Substituting Eq.(7) into Eq.(6), it can be obtained:

$$V_{s1}=V_{s2}=V_s=I_st/C \tag{8}$$

Form Eq. (8), it was obtained that the response voltage of connected defects between two elements is equal with that of normal elements because all the response current of normal elements in FPA is equal. The non-uniformity of ROIC circuit which originates in CMOS process should be considered in the analysis because of readout circuit working in the threshold area.

As for suitable silicon CMOS process, it causes CMOS matching between the tubes and CMOS capacitance problem, which is due to error, such as the size of tube due to the limitation technology level.

In this experiment, the two tubes have the same and close matching accuracy about 1%, MOS capacitor matching accuracy is 0.05%. With multiple pixels contacting, the maximum mismatch between two adjacent CMOS appeared at 2.1%. The biggest mismatch between four adjacent CMOS also is to be 4.2%, which is still within the normal range of response voltage in FPA. The response voltage of the connected defective elements is basically the same as that of normal element. The above analysis and experimental data show that the connected defective elements cannot be identified by existing FPA testing method.

2.2 Connected defect elements identification

In order to realize the connected defective elements identifications, the filter is designed to change the response voltage of detector. By using the filter, the response voltage of detector is divided into two sections units.

For illustrating the above problem, it is not considered to the non-uniformity of CMOS between the tubes and CMOS capacitance that caused by level of technology in readout circuit. The response current of two kinds of normal elements in FPA with filter by the same testing parameters can be expressed as,

$$V_{sa}'=I_{sa}'t/C \tag{9}$$

$$V_{sb}'=I_{sb}'t/C \tag{10}$$

where, I_{sa}' and I_{sb}' are the response current of two kinds of normal elements.The response voltage of the connected defective elements in FPA with filter can be expressed as:

$$V_{s1}'=V_{s2}'=(I_{sa}'+I_{sb}')t/2C \tag{11}$$

The response current of two kinds of normal elements in FPA with filter which are not equal can be expressed as:

$$I_{sa}'\neq I_{sb}' \tag{12}$$

Eq.(12) is substituted into Eq.(11), it can obtain

$$V_{s1}'=V_{s2}'\neq V_{sa}'\neq V_{sb}' \tag{13}$$

If $I_{sa}'<I_{sb}'$, it can obtain

$$I_{sa}'t/C<(I_{sa}'+I_{sb}')t/2C<I_{sb}'t/C \tag{14}$$

Eq.(14) can be also expressed as:

$$V_{sa}'<V_{s1}'=V_{s2}'<V_{sb}' \tag{15}$$

Form Eq.(13), (14) and (15), the response voltage of the connected defective elements is average of corresponding response voltage of the two sections units. It should ensure the non-uniformity of readout circuit caused by technological level is far less than the difference between two adjacent both in the three steps. Therefore, the connected defective elements can be identified significantly. In order to illustrate the function of method better, we choose two transmission with a method of boundary, transmission of 100% and transmission of 0. At the same time, the response voltage of one kind of detection unit is the biggest when transmission is 100% , while the response voltage of another is 0 when transmission is 0. It is useful to simplify the design process and compare the test results clearly.

In Fig.1, the detection units are divided into two kinds of detection units. The one kind of detection unit which passes filter has all IR radiation and the other kind of detection unit which passes filter has none IR radiation.

3 Results and verification

This paper focuses on the connected defects between two elements. As for InSb IRFPA using InSb arrays and DI Si ROIC, the response voltage plays an important role in the defective elements parameter, which was analyzed by FPA testing system at an operating temperature of 77 K, as shown in Fig.4.

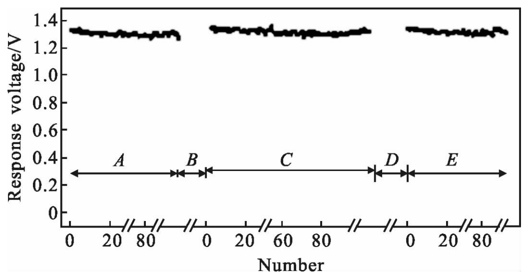

Fig.4 Response voltage of IRFPA

Form Fig.4, the *A* and *E* sections are the response voltage of the initial and terminal circuitry in the IRFPA, respectively. *C* section is where the response voltage of connected defects between two elements in the IRFPA. *B* and *D* sections are the response voltage of other circuitry in the IRFPA. According to *C* section in Fig.2, there were no detective elements in this figure.

Test results of the IRFPA with filter are shown in Fig.5. From Fig.5, the response voltage of the connected defects between two elements is approximately half of that of normal elements.

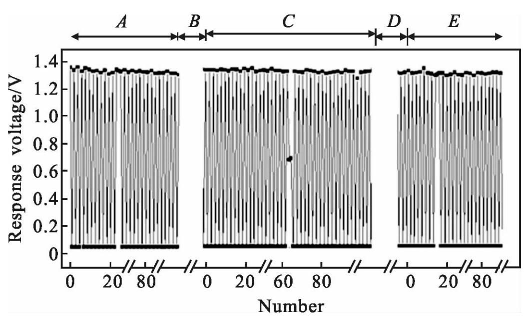

Fig.5 Response voltage of FPA with filter

By calculating the test data of the response voltage of FPA detector, the average of the measured response voltage is 1.332 V, and the non-uniformity of the response voltage in IRFPA is to be 10%.

In addition, Tab.1 shows parameters of the connected defects between two elements in the IRFPA without filter. According to the Tab.1, compared to the average value of response voltage of FPA 1.332 V, the response voltage of the connected defects between two elements 1.330 V and 1.335 V, and the maximum value of fluctuation 0.3% is far less than the non-uniformity of the response voltage 10%. It is difficult to identify the connected defective elements by IRFPA testing system because the response voltage of the connected defects between two elements is within the normal range and cannot get recognition. This is consistent with the previous analysis.

Corresponding in Tab.1 in the position of the connected defects between two elements, the experimental data of the response voltage of the connected defective elements in FPA detector from Fig.5 was obtained, as shown in Tab.2.

Tab.1 Parameters of connected defects between two elements in FPA without filter

	Response voltage/V	
Connected defects between two elements in FPA	1.330	1.335

Tab.2 Parameters of the connected defects between two elements in FPA with filter

	Two different detection units		Connected defects between two elements in FPA	
Theoretical response voltage	1.330	0	0.665	0.665
Actual response voltage	1.322	0.023	0.662	0.675

From Fig. 5 and Tab.2 can be seen with the filter, there is a certain ratio between the response voltage of the connected defective elements and normal detecting unit. The connected defective elements can be significantly identified because the response voltage of connected defective elements is obviously different from that of normal detecting unit. Test data from Tab.2 for calculation, the ratio between the response voltage of connected defective elements and normal detecting unit is 0.5. This is consistent with the analysis below. The I_{sb}' is 0 because the response voltage of another kind of detection unit is 0 when transmission is 0. Form Eq.(11), the response voltage of the connected defective elements in FPA with filter also can be expressed as:

$$V_{s1}'=V_{s2}'=I_{sa}'t/2C \tag{16}$$

Eq.(16) shows that the response voltage of the connected defective elements is average of corresponding response voltage of the two sections units. The results of Fig.5 and Tab.2 are consistent with this situation.

From Tab.2, it can still be seen, the actual response voltage of two different detection units deviate theory value. According to the theoretical analysis, the detector has no response under full cutoff, and the response voltage should be 0 V. The test results show that the actual response voltage is 0.023 V, which is closed to the ideal theoretical analysis. Furthermore, it is found that the detection unit has response voltage even if the detecting unit completes occlusion. This phenomenon is due to the presence of crosstalk among the detection unit. Owing to the response presence of adjacent detection unit, the carrier can be diffused into the detecting unit for forming voltage. However, it was speculated that this does not affect the validity of the method according to the experimental data.

4 Conclusions

In this paper, a novel optical filter which realizes the connected defective elements identifications is proposed. The FPA detector is divided into two different transmittance detecting units based on the filter. It is obtained that the voltage response is 1.322 V and 0.023 V respectively. According the response voltage of the connected defective elements is 0.662 V and 0.675 V. It indicated that the response voltage of detector can be changed to realize the connected defects elements identifications. The response voltage of the connected defective elements is average of corresponding response voltage of the two sections units. The connected defective elements are identified markedly by using the proposed filter.

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