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FABRICATION OF GaAs MICROLENSES ARRAY WITH LONG FOCAL LENGTH FOR IMPROVING RESPONSIVITY OF PtSi IRFPA DEVICE*

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Abstract Refractive square-based arch GaAs microlenses array was fabricated by a novel method, i. e., the curvature compensation method. The new method was proposed to increase the focal length of refractive microlenses array. Scanning electron microscopes (SEM) show that microlenses are square-based arch arrays, and surface-stylus measurement shows that the focal length of the microlenses array is 3861.70μm, which is much longer than 200μm and it is the longest focal length of the microlenses array of the same size fabricated by conventional methods including photolithography, melting and ion beam milling. The microlenses array (MLA) device and infrared focal plane array (IRFPA) device were aligned under an IR microscope and coupled with a kind of infrared glue. The IR response characteristics of the hybrid device were improved greatly.

Key words GaAs, microlenses array, ion beam milling, hybrid device, IRFPA device.

用于改善PtSi红外焦平面阵列器件响应特性的长焦距GaAs微透镜阵列器件的制作研究*

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摘要 提出了一种新的曲率补偿法用于长焦距微透镜阵列的制作。扫描电子显微镜（SEM）显示微透镜阵列为表面极为平缓的方底拱形阵列，表面探针测试结果显示用曲率补偿法制作的微透镜的焦距可达到3861.70μm，而常规光刻热熔法很难制作出焦距超过200μm的相同尺寸的微透镜阵列。微透镜阵列器件与红外焦平面阵列器件在红外显微镜下对准胶合，显著改善了红外焦平面阵列器件的响应特性。

关键词 GaAs，微透镜阵列，离子束刻蚀，组合器件，红外焦平面阵列器件.

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Introduction

Nowadays refractive microlens array (MLA) devices have been used in many fields such as focal-plane optical concentrations, laser alignments, large area displays, optical calculations, coupling and interconnection in optical processors. So its fabrication technique has been researched deeply. Of many methods for fabricating microlens arrays, heat-forming photoresist method has many advantages, such as simple technique, low expense and no serious polution. But long-focus microlens array is difficult to be fabricated by the method due to the critical angle effect. In normal situation, the focal length of microlens array made by conventional methods is about several hundred micrometers shorter than the thickness of microlens array device itself (because a thinner microlenses array is easy to be broken). In order to realize the function of microlens arrays device as a focal-plane optical concentrator, many scholars[1-6] have been exploring new ways to increase the focal distance of refractive microlens array since 1990's. In this paper we present a new method, named curvature compensation method, to increase the focal length of microlens array greatly. Owing to its wide spectral response range, GaAs material is chosen to fabricate the microlens array. The MLA device and infrared focal plane array (IRFPA) device are aligned under an IR microscope and coupled with a kind of infrared glue. The IR responsivity of the hybrid device is doubled.

1 Curvature Compensation Method

Figure 1 illustrates the sequence of processes for forming GaAs microlenses array (MLA). The procedure can be divided into two steps as follows: 1) The BP212 positive acting photoresist is spin coated on GaAs substrate. The photoresist is patterned with conventional photolithographic technique. The mask is an array of two dimension (The size of an element is 45μm × 45μm, and the distance between adjacent elements is 50μm). Then the GaAs substrate with the photoresist mask is heated at a temperature higher than the glass-transition point of photoresist so that square-based arc contour is formed by the effect of surface tension on the photoresist surface. Then the substrate is subject to Ar ion-beam milling in order that the square-based arc mask contour is transferred to the GaAs substrate surface. 2) On the basis of MLA made by the conventional method, several new layers of photoresist is covered on it. The photoresist coated on convex place will flow to the concave place under the action of gravity. In the meantime, surface tension will make the surface of photoresist concave. The collective action of the gravity and the surface tension forms a more gently concave surface. Then MLA is heated and consolidated, so photoresist and GaAs substrate form an integer, which is etched again. At last, more gentle surface of photoresist will transfer into GaAs substrate.

In our experiment, argon ion beam milling is carried out on LD-3 ion beam sputter and milling apparatus. Ar is introduced through the Kaufmann ion source into the vacuum chamber of the apparatus. Before milling, the vacuum chamber is evacuated to a pressure of 6.0×10^{-4} Pa, while Ar gas pressure during milling is kept at 4.0×10^{-2} Pa. The energy of Ar ion is about 550eV. The Ar ion beam

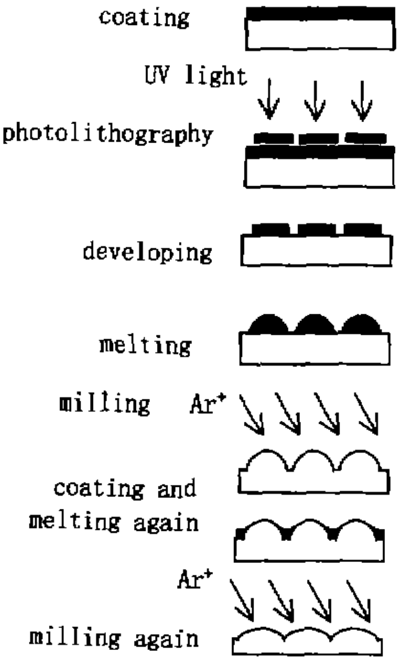

Fig. 1 The schematic diagram of fabrication of 128×128 GaAs microlens array

图1 128×128元GaAs折射型微透镜阵列的制备工艺流程

current is 50mA. The incidence angle of Ar ion beam is about 40°.

2 Experiment Results

Figure 2, taken by scanning electron microscope (SEM), shows a square-based arc GaAs MLA with a relatively gentle surface. Figure 3 shows the distinct profile of GaAs MLA taken by Detak-Ⅱ A surface style measurement. The measurement results show that the refractive microlens array has very smooth surface and extremely uniform dimensions. Sag of a microlen (h) is equal to 0.094μm, aperture size of a microlen (a) approximates 49μm, and optical filling factor can be calculated by 49μm × 49μm/(50μm × 50μm) = 98%.

The size of radiation sensing element of PtSi IRFPA device is 32μm × 30μm. The size of pixel element is 50μm × 50μm, so only 38.4% objective radiation is incident on the radiation sensing area. In order to concentrate almost all incident infrared radiation from the pixel area of microlens onto a relatively smaller sensitive area of PtSi IRFPA, we combine 128×128 element PtSi IRFPA device with 128 × 128 element refractive MLA device, and align them with MJB3 IR/Visible Aligner made by Karl Suss Company, then place the former on the focal plane of the latter. The MLA device is mounted on the back of the PtSi device. At last, we fill a kind of IR glue in the space between them to form a hybrid device. In this way, we improve the response of PtSi device. Figure 4 shows the structure of the hybrid device.

The thickness of microlens ($d_0 \approx 540\mu m$) can't be negligible when it is compared with image distance. So the calculation of focal length in image space can't use thin lens approximation. Thus, we deduce the following thick lens formulae

$$R = (a^2/4 + h^2)/2h$$

$$f = n^2 R/(n_0 - 1) + (n_0/n - 1)d$$

$$F/ = f/a. \tag{1}$$

In the former formulae, R is the redius of curvature of microlens, d (≈ 100μm) represents the thickness of the filled IR glue layer. n is the refractive index of IR glue and is equal to 1.66 in the spectral range 3 − 5μm. n_0 is refractive index of GaAs material and is equal to 3.27 in the spectral range 3−5μm. f and $F/$ are the focal length and $F/$ number in image space, respectively. With the formulae, we can calculate the following results: the average redius of curvature R is 3324.47μm, the average focal length f in image space is 3861.70μm, average $F/$ number in image space is 77.23.

We discuss IR response of hybrid device and IRFPA device without MLA. Responsivity (R) and specific detectivity (D^*) of a detector unit are defined as

$$R = V/P$$

$$D^* = R(\Delta f A_d)^{1/2}/V_n. \tag{2}$$

In the former formula, P represents power of radiation incident on a detector, V represents voltage of response, V_n is noise voltage generated in the

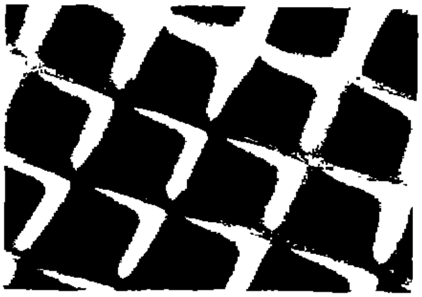

Fig. 2 The SEM photograph (430×) of 128×128 square-based arch GaAs microlens arrays

图 2 128×128 元 GaAs 方底拱形微透镜阵列的 SEM 照片(430×)

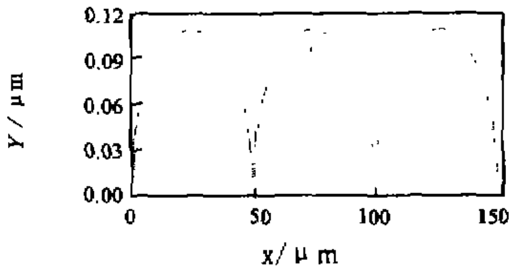

Fig. 3 The profile of 128×128 square-based arch GaAs microlens arrays measured by the surface stylus(unit: μm)

图 3 用表面探针测量的 128×128 元 GaAs 方底拱形微透镜表面轮廓(单位:μm) detector, Δf is detector bandwidth and is usually taken to be 1 Hz, and A_d is sensitive area of the detector. According to the size and structure of IRFPA device, it can be concluded that introducing MLA can increase the response of opto-electronic signal by 2.5 times in ideal situation. Due to the effects of reflection, absorption and scatter on the incident IR radiation and the influence of various factors in the composite device, factual IR response is less than the theoretical value. The testing experiment is carried out at liquid nitrogen temperature zone, the temperature of blackbody is 500K, modulation frequency is 10kHz, the response of signal is read out by a phase-locked amplifier and processed by a computer. The testing results are as follows: For IRFPA device without MLA, the average responsivity ($\overline{R}_0$) of a detector unit is 8.54×10^5V/W, the average specific detectivity ($\overline{D}^*$) of a detector unit is 1.69×10^8cmHz$^{1/2}$W^{-1}, the nonuniformity of D^* is 8.94%. For hybrid device, the average responsivity ($\overline{R}$) is 1.82×10^5V/W, the average specific detectivity ($\overline{D}^*$) is 3.61×10^8cmHz$^{1/2}$W^{-1}, the nonuniformity of D^* is 9.17%. The average responsivity ($\overline{R}_0$) and the average specific detectivity ($\overline{D}^*$) of a detector unit in a hybrid device are improved by 2.13 times, when it is compared with that in IRFPA without microlens array device. The uniformity of D^* isn't changed significantly.

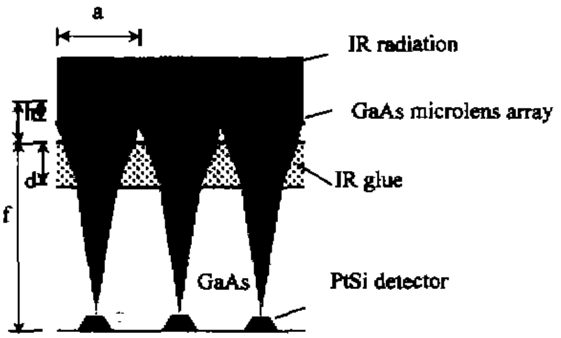

Fig. 4 Schematic cross section of three-pixel architecture of the hybrid device

图 4 组合器件的结构剖面图

3 Conclusion

(1)The curvature compensation method is an effective method to increase the focal length of microlens and it can promote filling factor to near 100%.

(2)Testing results show that the characteristics of IR response of the hybrid device are improved significantly as compared with that of the IRFPA device without MLA.

(3)IRFPA device is combined with MLA device by IR glue, which is a buffer medium and can absorb and decompose some destructive strain. So the total rigidity level of the hybrid device is greatly promoted. Thus the hybrid has obvious advantages in atrocious circumstance such as violent impact and high acceleration.

(4)In the hybrid device, the micro-optical element separates the IRFPA device from circumstance, thus, bad imfluences on the IRFPA device are avoided, and life and stability of IRFPA device are improved significantly.

REFERENCES

[1]Popovic Z D, Sprague R A, Connell G A N. Technique for monolithic fabrication of microlens arrays. *Appl. Opt.*, 1998, **27**:1281—1284

[2]Haselbeck S, Schrelber H, Schwider J, *et al.* Microlenses fabricated by melting a photoresist on a base-layer. *Opt. Eng.*, 1993, **32**(6):1322—1327

[3]Jay T R, Stern M B. Preshaping photoresist for refractive microlens fabrication. *Opt. Eng.*, 1994, **33**(11): 3553—3555

[4]Lars Erdmann, Dirk Efferenn. Technique for monolithic fabrication of silicon microlenses with selectable rim angles. *Opt. Eng.*, 1997, **36**(4):1094—1098

[5]ZHANG Xin-Yu, YI Xin-Jian, MIAO He, *et al.* Large-area quartz glass microlens array fabricated by ion beam etching for focal plane detectors. *J. Infrared Millim. Waves*, 1999, **18**(2): 97—102.

[6]ZHANG Xin-Yu, YI Xin-Jian, ZHAO Xin-Rong, *et al.* Study on microlens array for linear IR detectors. *J. Infrared Millim. Waves* (**张新宇，易新建，赵兴荣，等. 微透镜阵列用于线列红外探测器的研究. 红外与毫米波学报**), 1998, **17**(2): 147—152.