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Large-area Quartz Glass Microlens Array Fabricated by Ion Beam Etching for Focal Plane Detectors

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Abstract: A large-area quartz glass refractive microlens array mounted on a large-area focal-plane detecting architecture was fabricated using a multiple-process, including photolithography, heat treatment, and argon ion beam etching. The experimental measurements show that the optical filling factor of the focal-plane dtectors with refractive microlens array is more than 95% (for square-based arch microlens) and 70% (for spherical microlens), respectively, the focal length of the square-based arch microlens and spherical microlens is about 90μm and 80μm, respectively. Both the scanning electron microscope and the surface style measurement were used to determine the dimensions and the surface morphology of the microlens fabricated. The techniques utilized can be applied to fabricate microlens array of larger area.

Key words: refractive microlens array, IR focal plane structure.

Introduction

At present, large-area staring infrared (IR) focal plane arrays (FPAs) have been used in many fields, such as IR astronomical imaging, industrial inspection, thermal imaging, medicine, night vision. earth resources, advanced military sensor systems, etc. Although monolithic FPAs architecture can offer marked advantages in uniformity, manufacturability and opto-electronic properties, the element size of the imaging sensor is usually much less than the overall pixel area, and therefore, the filling factor (the ratio of sensor area to the pixel area) of the detector is poor, which reduces opto-electronic sensitivity of the image sensor. Micro-optics components such as monolithic refractive microlens array have recently been paid considerable attention to for they can increase the filling factor of the FPAs, thus improving the photosensitivity of the FPAs device. The onchip refractive microlens array with a high optical fill-factor and good optical quality, as a focal-plane optical concentrator mounted on an IR FPA, can concentrate almost all incident infrared radiation from the pixel area of microlens onto a much smaller photosensitive area of the de-

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tector, and therefore improves the signal-to-noise ratio of the IR FPAs device.

In 1991, the use of monolithic refractive microlens to improve the performance of IR detector arrays was reported for the first time by N. T. Gordan, et al[1]. The improvement in GeSi/Si FPAs opto-electronic sensitivity was demonstrated by Bor-Yeu Tsaur, et al. in 1994, who developed the 320×240-element and 400×400-element GeSi/Si IR CCD detectors with the two-dimensional refractive microlens array (monolithic Si microlens array) for increasing the detector fill-factor and FPAs sensitivity[2]. In this paper, we report the fabrication of monolithic quartz glass refractive microlens arrays coupled with a kind of FPAs device for effectively increasing the optical fill-factor ratio. The outline of this paper is as follows. In Section 1 we discuss the design of refractive micro-optics components, the fabrication procedures and resuts are described in Section 2, and a brief summary is drawn in Section 3.

1 Design of refractive microlens array

The performance of FPAs involves a trade-off among three independent factors i. e. the uniformity of IR optoelectronic response, spacing resolving power, and sensitivity. In general, the enhancement in spacing resolving power depends on reducing the unit cell size, and increasing the number of elements. For an IR detector, the responsivity is proportional to the photosensitive area, which is usually much smaller than the pixel size. So the improvement in the fill-factor has been one of the most important in the development of FPAs. The technologies developed for providing the sensor with a high fill-factor to obtain a maximum signal-to-noise ratio cover the readout architecture, detector structure and fabrication of micro-optics components coupled with the IR imager array. In order for a sensor to achieve a high signal-to-noise ratio, an effort using an onchip refractive microlens array to concentrate almost all incident IR radiation falling on the pixel area onto a much smaller detector photosensitive area to increase the fill-factor of the image sensor and detectors ensitivity, while retaining a given detector thermionic-emission dark-current-noise, has been exerted. We have designed and fabricated two types of quartz glass refractive microlens array to couple with a kind of square-based pixel FPAs device.

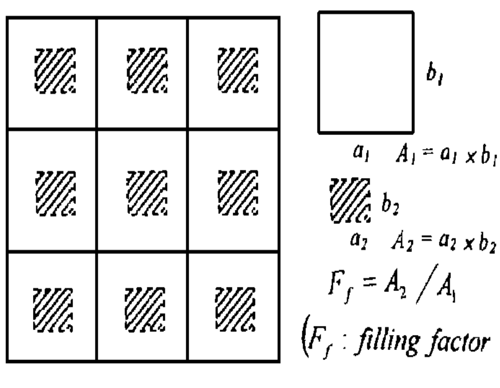

Fig. 1 The fundamental structure (a kind of the large-area IR FPAs device)

Figure 1 shows the fundamental structure of FPAs. The unit cell of each pixel is 50μm × 50μm, and active detector area is only 32μm × 30μm. From the data introduced as above, we know that the fill-factor of the device is less than 40 percent. Two kinds of two-dimensional refractive microlens array are designed to increase the optical fill-factor ratio of the FPAs from < 40 percent to a geometrical limit value of approximately 100 percent (or 75 percent for spherical microlens.)

Common and effective fabrication techniques of refractive microlens may use thermal treatment after photolithography and argon ion beam etching. In our experiments, the lithography master pattern has been designed to be consistent with the structure of the FPAs. During the design of photolithographic master pattern, several factors should be considered, i.e. the focal length of the refractive microlens, the smooth finish of the substrate polished at both sides, and the thermal consolidation level of the photoresist mask pattern (square-based arch microlens pattern and spherical microlens pattern).

2 Fabrication of microlens array

Fabricating a uniform array of refractive microlens with a high fill-factor and optical quality requires acccurate control of photoresist lithographic process, thermal annealing, and etching step. The main fabrication issues are spatial uniformity, the control of photoresist microlens sag and shape, the reproducibility of ion beam etching rate and selectivity, and the surface roughness of the etched substrate materials. Figure 2 shows the technological steps. Our monolithic refractive microlens array has been produced through four steps: photolithography, thermal treatment and reflow to form photoresist microlens array, argon ion beam etching, and thinning at backside of the samples with microlens array. In photolithography, developing of the samples should be sufficient. After developing, any remaining photoresist on the sample surface should be completely washed away to avoid affecting the heat treatment procedure while the square-shaped or circle-shaped photoresist islands (pixel size) patterns are heated and reflowed to form into square-based arch photoresist microlens or spherical photoresist microlens. The expansion of each square or circle photoresist islands in melting process is affected by many factors. So the maximum fill-factor ratio of the microlens is obtained by accurately controlling the technological parameters. The experiments show that the surface morphology of the quartz glass

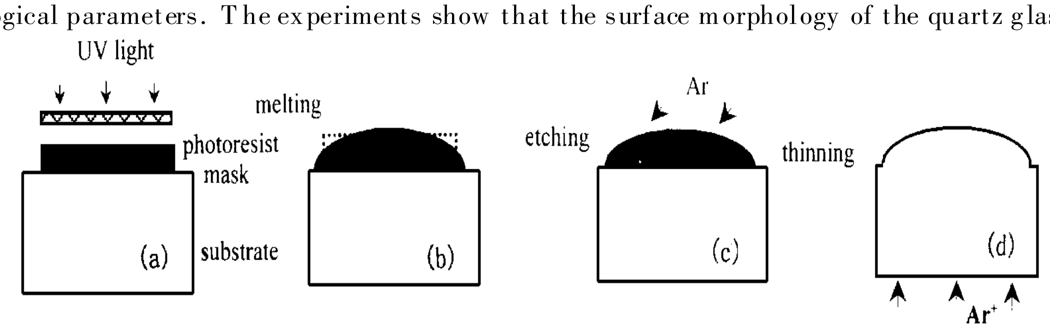

Fig. 2 Fabrication procedures to get the refractive microlens array in quartz glass substrate.

refractive microlens is different at varied fabricating conditions, for instance, the incidence angle of ion beam, ion energy, and the diameter of ion beam. The last procedure is to thin the samples from backside of the monolithic microlens array device to the required thickness which equals the focal lenght of the lens, so that the samples can be effectively coupled with FPAs device.

In our experiment, the photolithography and annealing are carried out according to the custom methods. Argon ion beam etching is undertaken using the LD-3 ion beam sputter-etching apparatus. Argon is introduced through the Kaufmann ion source into the vacuum chamber of the apparatus. Before etching, the vacuum chamber is evacuated to the pressure of 10^{-4} Pa or above, while argon gas pressure during etching is kept at 10^{-2} Pa. The incidence angle of argon ion beam is about 25°. The energy of argon ion is about 500 eV. The etching rate is around 40 nm/min. The sag of refractive microlens is about 7.5μm. The aperture size of each square-based arch microlens is about 49μm×49μm, the diameter of each spherical microlens is about 48μm. The focal length of the square-based arch microlens (in the spectral range 3～5μm) is about 90μm, the spherical microlens about 80μm. The pictures of Fig.3 and Fig.4 taken by scanning electron microscope show the 6×6 lens arrays of refractive microlens, which illustrate the high quality of the surface of the lens fabricated. The small white dots on the photographs are dust sticking to microlens device in SEM measurement.

Fig.3 The SEM photograph of the square-based arch microlens array in quartz glass substrate

Fig.4 The SEM photograph of the spherical microlens array in quartz glass substrate

The measurement results of SEM and profile measurements show that the refractive microlens have very smooth surface and extremely uniform dimensions. Figure 5 shows a schematic cross section of two-pixel architecture of FPAs with refractive microlens (square-based arch microlens). Incident infrared radiation through refractive microlens, which serves as a field lens between the primary objective lens and the FPAs, is focused on the backside of FPAs.

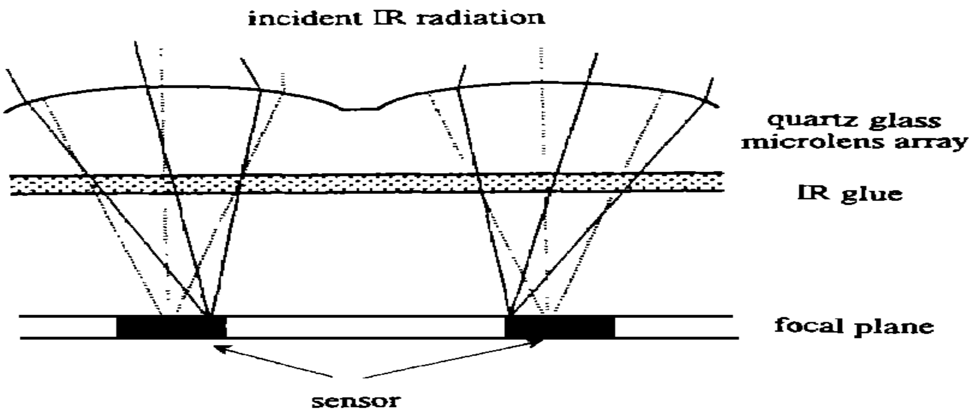

Fig. 5 The schematic cross section of two-pixel architecture of the IR FPAs device with refractive microlens

3 Summary

It is a relatively simple and effective method to incorporate monolithic refractive microlens array with the FPAs device for efficiently increasing the fill-factor of the device, and improving the opto-electronic response performance of the device. We expect to see the improvement of the opto-electronic response performance of IR FPAs through the study of the operating principle, the architecture of FPAs device, and the fabrication of the two-dimensional refractive microlens arrays mechanically attached to the FPAs or refractive microlens arrays etched directly onto the backside of back-illuminated FPAs image sensor.

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离子束刻蚀制作用于红外焦平面探测器的面阵石英微透镜

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摘要 面阵红外焦平面结构由于具有体积小、重量轻、功耗低、噪声小、灵敏度和可靠性高等特点而在军事及民用领域获得了应用, 国外已有文献报道填充系数为40%左右的面阵红外焦平面凝视阵列的情况, 国内也已制成了填充系数为35%的面阵肖特基势垒红外焦平面阵列. 红外焦平面阵列的红外响应均匀性及空间分辨率和灵敏度是衡量其性能优劣的几项重要指标. 通常情况下, 空间分辨率的提高可以采取缩小像素面积, 增大阵列规模来实现, 但像素的减小将导致信号的减弱. 为改善具有低填充系数的红外焦平面器件的性能可以采取增大器件的填充系数以获得足够的信噪比的办法进行. 利用折射微透镜阵列对入射红外辐射所具有的会聚作用, 在维持器件原有暗电流水平不变的基础上, 增大器件的填充系数进而提高器件的红外光电响应性能是有效的手段之一. 本文给出了利用面阵石英折射微透镜来提高一种国产红外凝视焦平面成像器件的填充系数进而增大其信噪比的方法. 折射微透镜的制作方法很多, 离子束刻蚀是其中较为实用和可行的技术手段之一. 在我们的实验中, 与红外焦平面结构匹配的石英折射微透镜阵列的制备利用光刻热熔法及氩离子束刻蚀进行, 所制石英折射微透镜分别为矩底拱面形和球冠形. 实测表明, 所制矩底拱面石英折射微透镜阵列的光学填充系数高于95%, 球冠形折射微透镜阵列的光学填充系数高于70%, 矩底拱面折射微透镜和球冠形折射微透镜近轴光(3~5μm 光谱波段)的典型焦长分别为90μm和80μm. 通过扫描电子显微镜(SEM)和表面轮廓仪测试了所制微小光学元件的表面微结构形貌. 利用折射微透镜阵列来显著改善红外焦平面结构的光电性能是一种简便有效的技术途径, 在综合考虑红外焦平面结构的工作方式和结构特点及与之匹配的微小光学阵列元件的基础上, 制出复合光电器件, 或在背入射式红外焦平面结构的光入射面上直接蚀刻出折射微透镜图形, 对提高红外焦平面结构的光电响应性能具有重要意义, 所开发的制备技术可用于大面阵的折射微透镜阵列.

关键词 折射微透镜阵列, 红外焦平面结构.

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