Bifocal and negative microlens arrays in hard optical materials

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Abstract- **Using the methods of photoresist reflow and moulding, bifocal and negative microlens arrays, with diameters down to 10 μm, have been fabricated in GaN-on-sapphire. The optical properties of these microlens arrays were characterised by a recently developed reflection/transmission confocal microscopy technique and agree well with calculated values.**

I. INTRODUCTION

Recently, convex microlenses made of III-nitride semiconductor [1] and other hard materials such as sapphire [2] and diamond [3] have become attractive for such applications as integrating with micro-size light-emitting diode (micro-LED) arrays [4] and vertical cavity surface-emitting lasers [5]. To improve the performance and broaden the scope of applications of these optoelectronic devices, the development of other novel types of microlenses is urgently required. Micro concave (negative) lenses, for example, are required in micro-optoelectronic systems for image reduction or light beam expansion.

In this paper, we report the fabrication and characterisation of bifocal and negative microlens arrays with diameters as small as 10 μm based on gallium nitride (GaN) epilayers. These nitride microlens arrays will be important components in achieving monolithic integration of optoelectronic devices based on III-nitride semiconductors. The techniques developed are also applicable to other hard optical materials including silicon carbide and diamond.

II. FABRICATION

Bifocal GaN microlens arrays were fabricated by using multiple-stage photoresist reflow and inductively coupled plasma (ICP) dry etch processes. Negative microlens arrays were fabricated on GaN using photoresist moulding followed by ICP etching. Both techniques can be employed to fabricate microlenses in other hard materials. In this work, Cl_2/Ar plasma gas was used for ICP etching. ICP dry etch technology allows control of selectivity between the GaN epilayer and the photoresist mask, permitting adjustment of the lens profile. Full details of the fabrication process will be reported.

III. CHARACTERISATION

A three-dimensional atomic force microscopy (AFM) image of a representative GaN negative lens is shown in Fig 1. The diameter of this particular lens is 35 μm at surface with a lens height of 1.2 μm. By fitting the observed lens surface profile, it was confirmed that the negative microlenses fabricated had a spherical shape. For optical applications, the microlenses should have a very smooth surface. The AFM measurements show that both GaN bifocal and negative lenses have a root-mean-square (rms) surface roughness value of 3 nm for a scanned area of 3.0 μm x 3.0 μm.

In order to characterise the optical properties of microlens arrays, we have recently developed a novel laser scanning reflection/transmission confocal microscopy technique [3]. This technique can produce extremely high-quality images of specimens, termed optical sections, at various depths and enables the surface profile of the microlenses to be measured simultaneously with optical parameters including focal length and spot size. A reflection image focused at the substrate surface of a bifocal microlens is shown in Fig. 2. It can be seen that the bifocal lens consists of bottom and top lenses. Our bifocal lenses were fabricated in such a way that the bottom and top lenses have the same height.

A cross-sectional (*X–Z* section) reflection/transmission confocal image of a GaN bifocal microlens array is shown in Fig. 3. For these bifocal lenses, the bottom lens has a diameter of 66 μm and the diameter of the top lens is 42 μm as shown in Fig. 2. It is evident that collimated light rays, after they pass through the lenses, converge on two focal points. The distance from the focal point to the lens is the focal length. From this image, the two focal lengths of the bifocal lens are measured to be f_1 = 74 μm and f_2 = 124 μm respectively. These measured focal lengths are quite close to the calculated values of 78 μm and 130 μm, confirming that these GaN bifocal lenses have a high-quality surface profile. This image also shows that all the lenses have the same focal length, demonstrating high uniformity of the microlens array.

Fig. 4 shows the cross-sectional confocal image of a GaN negative microlens array of lens diameter 35 μm. It can be seen clearly that collimated light rays diverge after they pass through the lenses, showing the functionality of the negative lens. By extending traces of the light rays passing through the lens to a virtual focal point behind the lens as shown in Fig. 4, the focal length of these negative lenses can be determined. From this image, the focal length of these negative lenses is measured to be 125 μm, which is again close to the calculated value. Negative microlens arrays with various lens diameters have also been measured.

IV. SUMMARY

GaN bifocal and negative microlens arrays have been fabricated and characterised. These lens arrays have high quality surface profiles and also show high uniformity. These GaN bifocal and negative microlenses will be used for the integration of nitride-based optoelectronic devices such as blue/UV light emitters and detectors.

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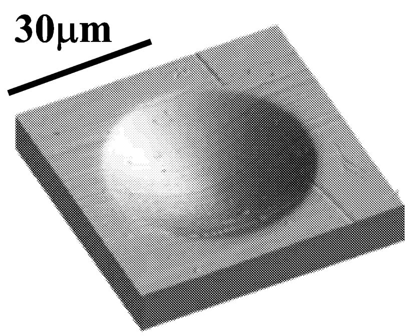

FIG. 1 A three-dimensional AFM image of a GaN concave negative microlens.

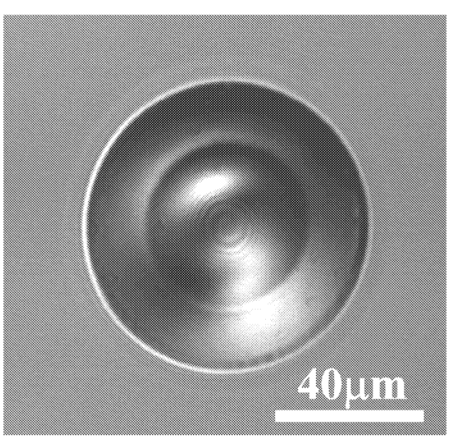

FIG. 2 Confocal plane view reflection image of a GaN bifocal microlens.

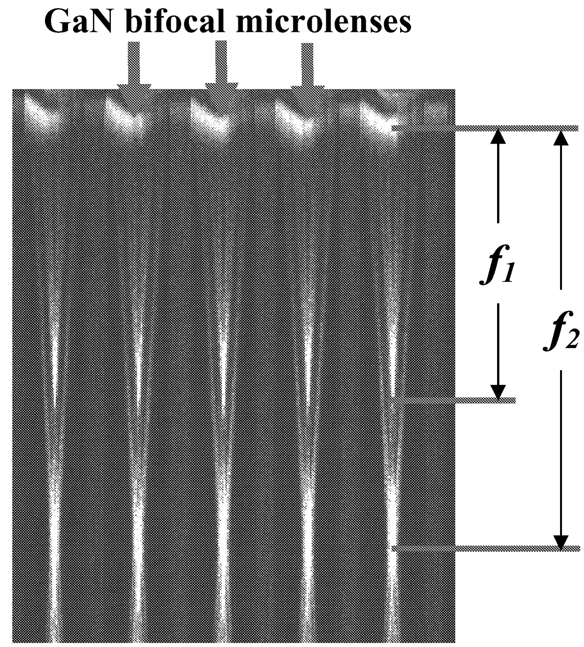

FIG. 3 Confocal reflection/transmission *X–Z* scan image of a GaN bifocal microlens array.

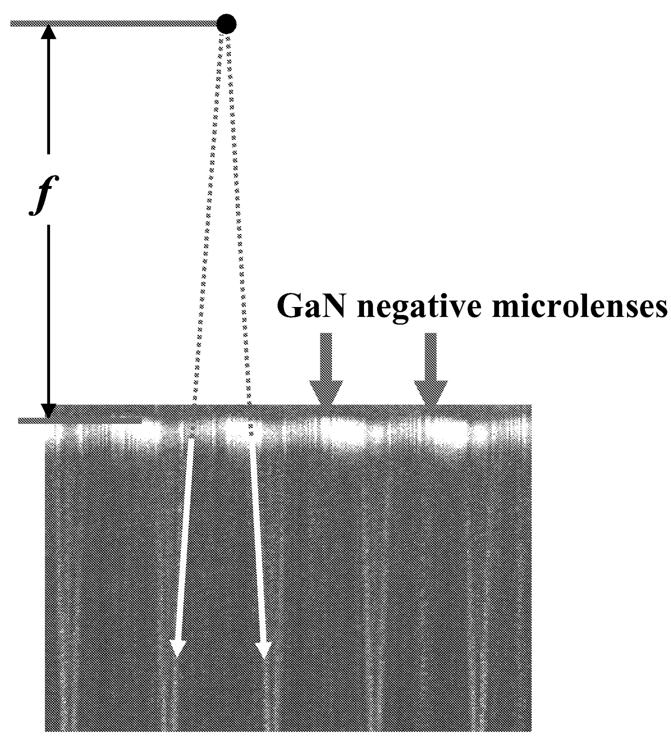

FIG. 4 Confocal reflection/transmission *X–Z* scan image of a GaN negative microlens array.