ULTRATHIN CAMERA INSPIRED BY VISUAL SYSTEM OF XENOS PECKII

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ABSTRACT

This paper reports ultrathin digital camera inspired by the visual system of Xenos peckii, which is an endoparasite of paper wasps. Males of the Xenos peckii have an unusual visual system that consists of a large lens and multiple photoreceptor cells. This optical scheme exhibits distinguished benefits in resolution and sensitivity. Xenos peckii vision inspired camera consists of microprism arrays, microlens arrays, and aperture arrays. The microprism arrays were implemented by using a ball lens and backside exposure with prepatterned metal mask. And the light absorbing structures were formed between the microprism arrays using black polymer. Each channel of the camera detects different part of the total field of view, and captured partial images are reconstructed in the image processing step.

INTRODUCTION

Compound eyes have attracted great research interests due to their unique anatomical features and optical characteristics [1]. The ommatidium, which is the basic optical unit of compound eyes receives light from slightly different direction with a small angular acceptance. This optical designs are expected to have figures-of-merit in field of view, visual acuity, high sensitivity of motion, polarization detection and spectral sensitivity. Their diverse visual schemes provide engineering inspirations for optical devices available in the industrial, medical, and military field [2].

Compound eye inspired cameras have been conventionally constructed on a glass substrate due to fabrication technology limitations. These cameras consist of imaging optics and light blocking structures such as aperture arrays or signal separator layers [3-7]. Three dimensional artificial compound eyes can have wide field of view like that of natural compound eyes, but require additional methods or components to relay optical signals to the photodetector due to the curved image plane. Waveguide, optical fibers, or prisms are typically used as relay or beam steering optical elements [8-10]. Recently, curved photodetectors were developed and combined with the compound eye inspired optical devices, but the detectors are yet to be commercialized [11, 12].

Nature offers unusual type of compound eye, which is not included in the conventional categories. The eye of Xenos peckii has intermediate design between single eye architectures and compound eyes [13-15]. An individual optical unit (an eyelet) becomes independent camera type imaging system with its own facet lens and multiple photoreceptor cells (Figure 1 (a), (b)). Each eyelet receives visual information of different area within whole field of view and the final image is obtained by stitching the partial images [13-15]. Spherically arranged eyelets facilitate wide field of view imaging like other compound eyes. This visual system has distinguished benefits in resolution and sensitivity compared to conventional compound eyes.

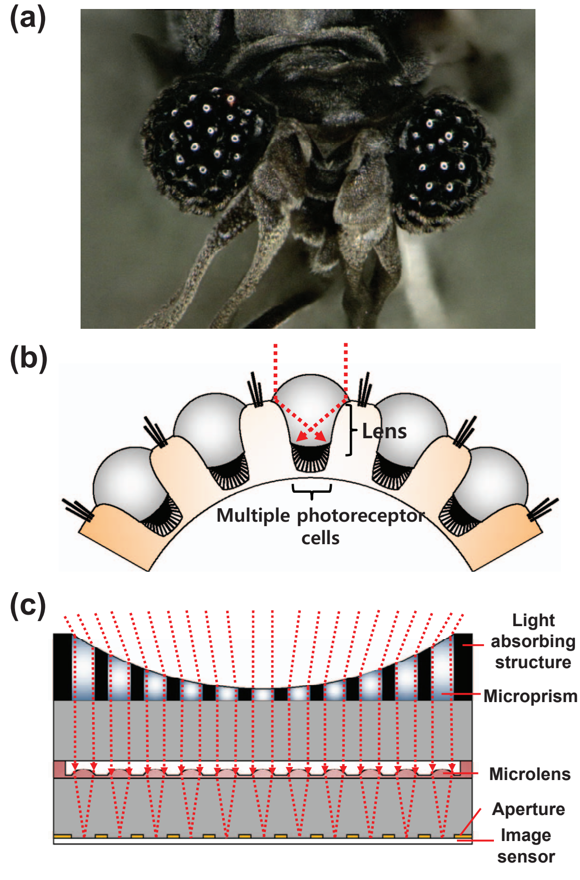

Figure 1: (a) Optical image of the eye of Xenos peckii. (b) Schematic imaging principle of the eye of Xenos peckii. Each optical unit (an eyelet) contains its own facet lens and multiple photoreceptor cells. This configuration allows the eyelet to detect image of portion area within total field of view. (c) Schematic diagram of the Xenos peckii vision inspired ultrahin camera.

This work presents ultrathin camera inspired by working principle of Xenos peckii's eye. Figure 1 (c) gives the schematic diagram of the proposed camera. A single channel comprises a microprism, a microlens, and an aperture. Microprism is used to tilt optical axis of the channel, and the microlens focuses the light passing through the microprism. Each channel captures visual information from its own direction, and the detected images are reconstructed in the image processing step.

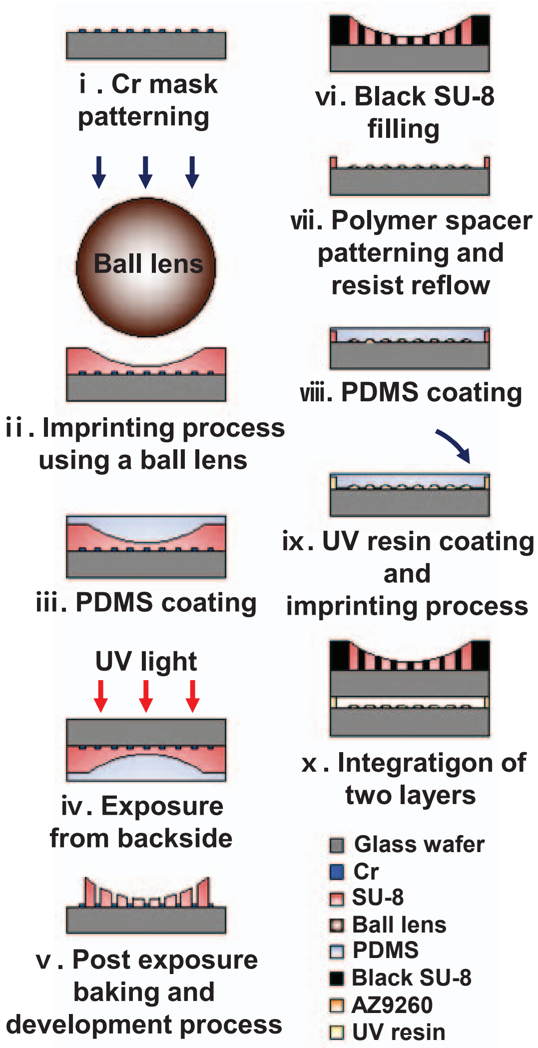

Figure 2: Fabrication procedure of the compound eye camera. Microprism arrays were fabricated by imprinting process using a ball lens and backside exposure with a pre-determined metal mask. Microlens arrays were formed using resist reflow process.

FABRICATION AND MEASUREMENTS

Figure 2 shows the fabrication procedures of the camera. The microprism arrays were fabricated by imprinting process using a ball lens and backside exposure with a pre-determined metal mask. Chrome mask was first patterned on a glass substrate using a lift-off process, and then SU-8 was coated on the metal mask. Concave surface was formed by downward movement of a ball lens during softbaking process. After finishing softbaking, polydimethylsiloxane (PDMS) was coated and cured on the photoresist to maintain the curved shape during post exposure baking (PEB) process, and UV light was exposed from bottom side of the substrate. PDMS membrane was removed after PEB, and finally microprism arrays were fabricated after development process. Black SU-8 (Gersteltec, GMC 1040) was filled between the microprism arrays to prevent the light entering from side wall of the microprism. Microlens arrays were formed using resist reflow process after patterning of polymer spacers. Then, PDMS mold was replicated from the microlens arrays and imprinted into UV curable resin. Microprism and microlens layers were aligned and combined in the last step (Figure 2).

Figure 3 (a) show the microprism arrays with light absorbing structure. Each microprism has different viewing direction respective to its location, allowing omnidirectional light detection. After integrating microprism and microlens layers, the device was combined on a CMOS image sensor as shown in Figure 3 (b). Figure 3 (c) is the captured image from the image sensor. Target object is a Lena image displayed on a laptop screen. Each channel of the camera detects different part of a target object while sharing some portion of the field of view. The overlap region between the channels can be used to improve the image quality in the image processing step.

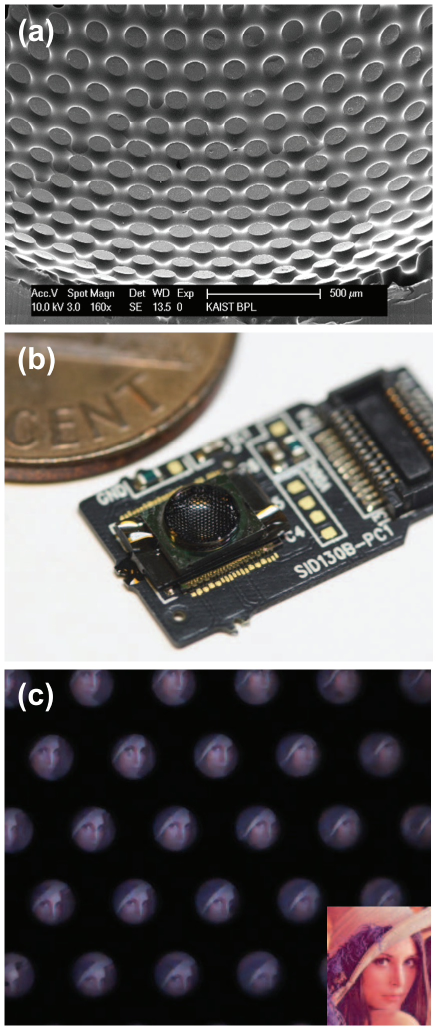

Figure 3: (a) SEM image of microprism with light absorbing structure. (b) Fully assembled ultrathin compound eye camera. (c) Captured image from the camera (Inset is a target object.).

Figure 4 (a) and 4 (b) are a single channel image and a reconstructed image from multiple channels, respectively. The image reconstruction process is as follows: The image of the center channel was chosen as a reference image, and then the relative shift value from an adjacent image was obtained by comparing the intensity difference between two images. After, the adjacent image was translated to the reference image by relative shift value. Finally, each pixel value of the combined image was determined by the mean value of two images. This process was applied to other channels, repeatedly. Figure 4 (c) is the resolution comparison between the single channel image and the reconstructed image. Modulation transfer function (MTF) was increased after image reconstruction process. For future work we plan to improve the image quality by combining other super-resolution method with this algorithm.

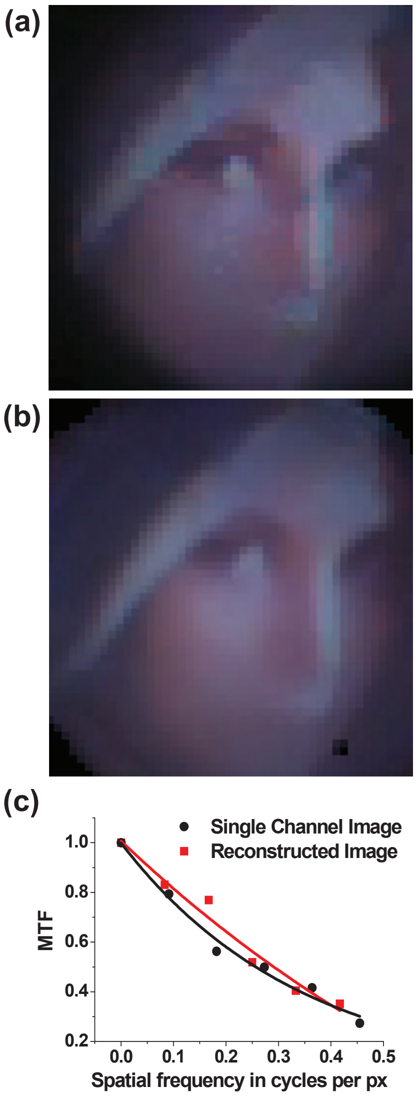

Figure 4: (a) Image of a single channel. (b) Reconstructed image from multiple channels. (c) Comparison of MTF between the single channel image and the reconstructed image. The resolution is improved after image reconstruction.

CONCLUSION

In summary, the ultrathin camera inspired by the visual system of Xenos peckii was designed, fabricated and characterized. A single imaging channel consists of a microprism, a microlens, and an aperture. Microprism arrays on a top substrate were formed by imprinting process using a ball lens and backside exposure. Microlens arrays were fabricated by resist reflow process. Flat image plane of the device facilitate direct integration with a commercialized image sensor. Each channel of the camera receives visual information from a slightly different direction, and the captured images are used to reconstruct final image. Overlap area between the channels was utilized to improve image resolution. The proposed camera can be effectively utilized for diverse applications including miniaturized imaging devices.

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