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Combined blazed grating and microlens array for color image sensing

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A combination of a blazed grating and a microlens array is discussed for high-efficiency color image sensing. Each image segment includes a microlens with blazed grating and three photodiodes assigned to red, green, and blue colors. Color-splitting performances of design examples were simulated by the two-dimensional finite-difference time-domain method. It was found that the spectral characteristics were similar to the ideal NTSC specifications for a segment size of 10 µm with a polymer microlens and a TiO_2 blazed grating. A prototype consisting of a honeycomb array of microlenses of 15 µm cell diameter and a TiO_2 blaze grating of 1.22 µm period and 0.35 µm height was fabricated and characterized. Power utilization efficiency of about 60% was predicted theoretically and estimated experimentally, which is much higher in comparison to a conventional image sensor utilizing color filters.

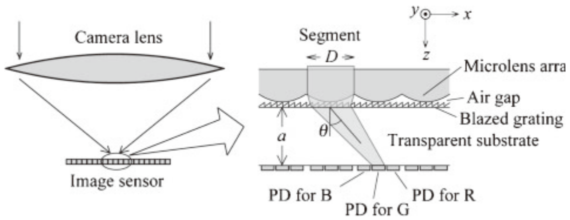

Fig. 1. A concept image of the proposal structure.

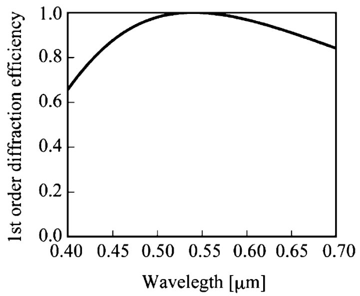

Fig. 2. Calculated wavelength dependence of the 1st-order diffraction efficiency.

Table I. Designed structural parameters for D =10 and 5 µm.

Parameter	D = 10 µm	D = 5 µm
Focal length of the microlens f (µm)	30	15
Refractive index of grating material n_g	TiO_2: 2.60	
Refractive index of substrate n_s	SiO_2: 1.46	
Substrate thickness a (µm)	27.5	14
Grating height h (µm)	0.338	
Grating period Λ (µm)	1.22	

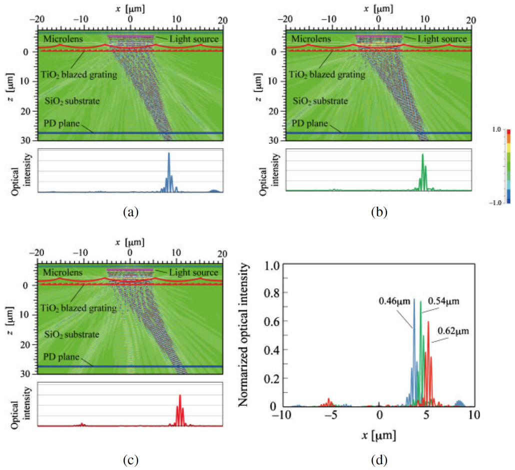

Fig. 3. Examples of electric field distributions calculated by 2D FDTD method with D = 10µm and wavelengths of 0.46 (a), 0.54 (b), and 0.62µm (c). Optical intensity distributions on the PD plane (d).

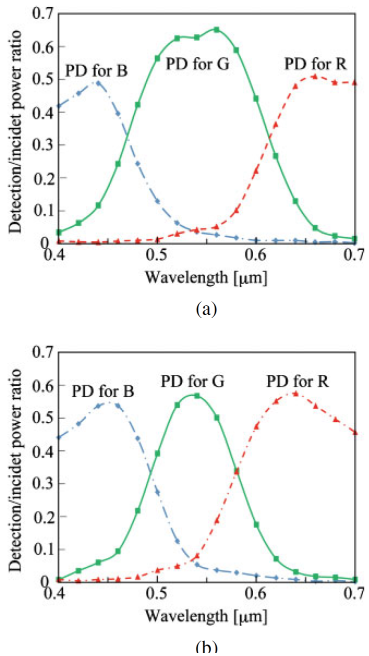

Fig. 4. Calculated spectral sensitivity curves for D = 10µm and PD sizes of 2.6µm for all RGB (a), and PD sizes of 3.0µm for B, 1.6µm for G, and 3.4µm for R (b).

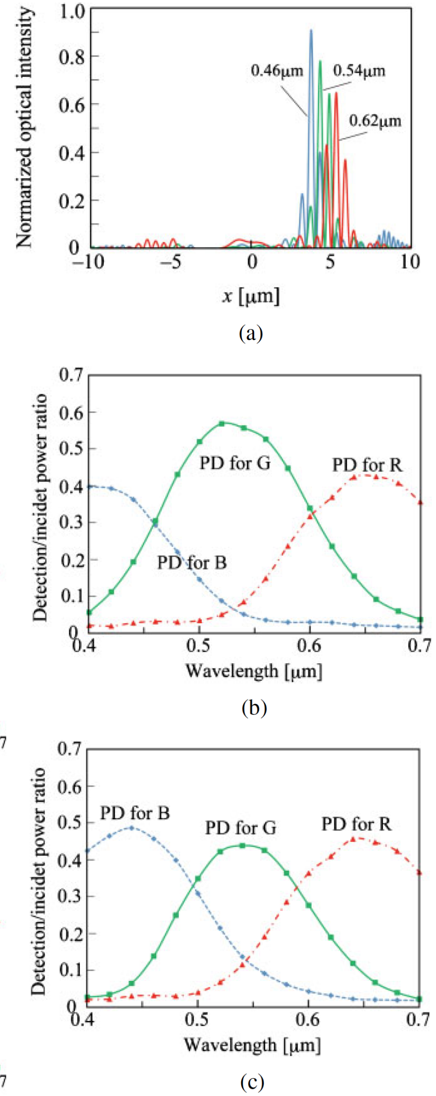

Fig. 5. Electric-field distribution examples calculated for D = 5 µm (a), and spectral sensitivity curves for PD sizes of 1.3µm for all RGB (b), and PD sizes of 1.5µm for B, 0.9µm for G, and 1.6µm for R (c).

Table II. Predicted detection power normalized by the incident power and color separation degree in the proposal structure with $D = 10$ µm.

	Incident wavelength (µm)		
	0.46	0.54	0.62
Detected by PD for R (%)	1	8	55
Detected by PD for G (%)	10	57	7
Detected by PD for B (%)	54	6	2
Power utilization efficiency (%)	65	71	64
Color separation degree	$0.83 = 54/65$	$0.80 = 57/71$	$0.86 = 55/64$

Table III. Predicted detection power normalized by the incident power and color separation degree in the proposal structure with $D = 5$ µm.

	Incident wavelength (µm)		
	0.46	0.54	0.62
Detected by PD for R (%)	3	12	41
Detected by PD for G (%)	14	44	19
Detected by PD for B (%)	46	14	3
Power utilization efficiency (%)	63	70	63
Color separation degree	$0.73 = 46/63$	$0.63 = 44/70$	$0.65 = 41/63$

Table IV. Predicted detection power normalized by the incident power and color separation degree in Bayer mosaic with typical RGB filters.

	Incident wavelength (µm)		
	0.46	0.54	0.62
Detected by PD for R (%)	1	4	25
Detected by PD for G (%)	14	45	8
Detected by PD for B (%)	22	5	1
Power utilization efficiency (%)	35	54	34
Color separation degree	$0.63 = 22/35$	$0.83 = 45/54$	$0.74 = 25/34$

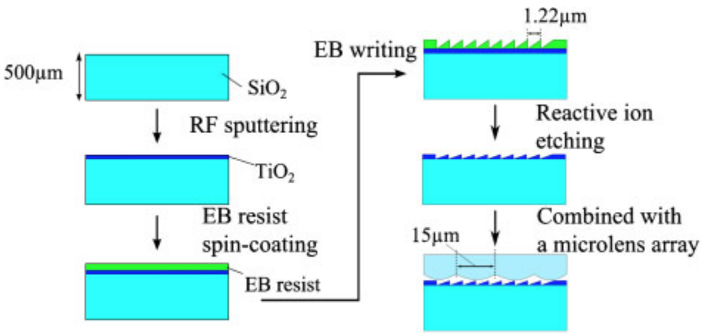

Fig. 6. Fabrication process of a test sample.

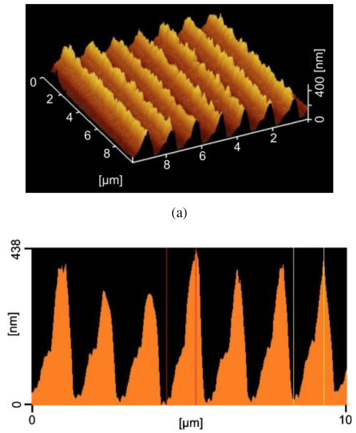

Fig. 7. 3D (a) and cross-sectional (b) views of the fabricated blazed grating measured by atomic force microscope.

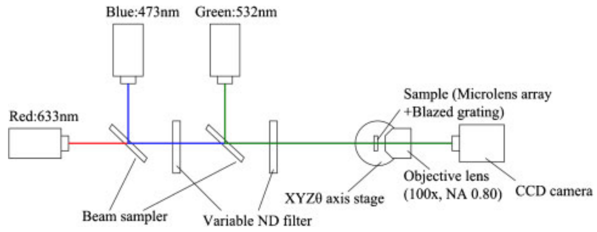

Fig. 8. Optical setup for characterization.

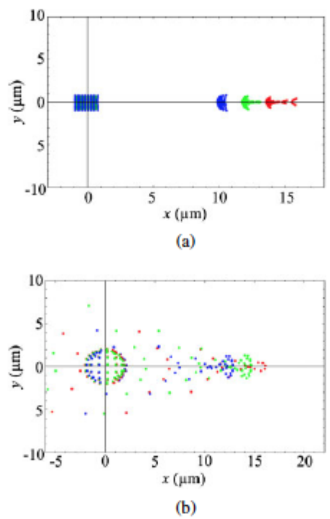

Fig. 10. Ray crossing points on the PD plane calculated by ray tracing method for estimating refraction effect. The 0th- and 1st-order diffractions are shown. (a) Results for 27.5-µm-thick substrate with no refraction effect. (b) Imaginary ray crossing points of the 1st-order diffractions when 500-µm-thick substrate was used.

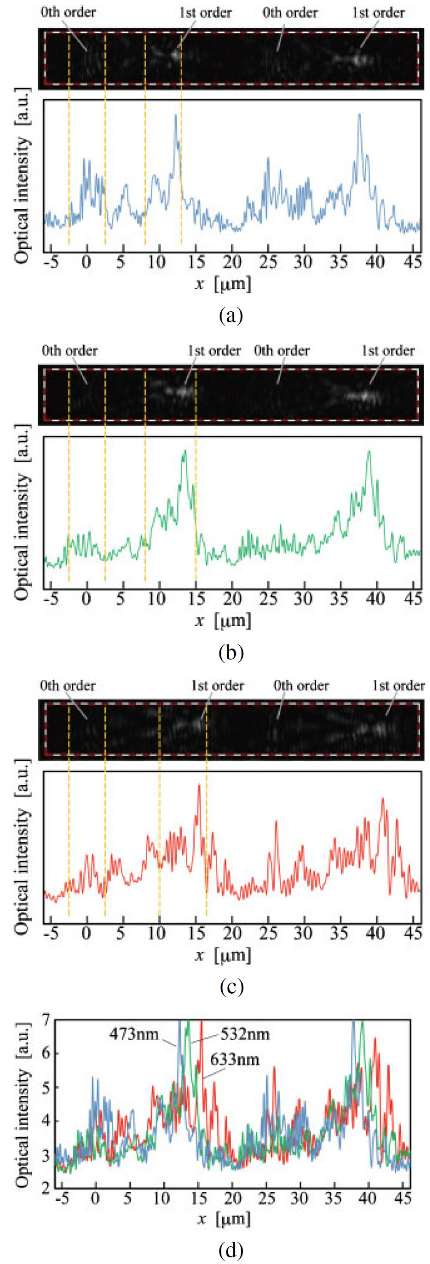

Fig. 9. Optical intensity images and intensity distribution curves on the same plane for wavelength 473nm (a), 532nm (b), and 633nm (c). Three curves are shown in (d) together.