

**Polymer-Based Chirped Grating Lens
Working at Visible Wavelengths on a GaAs Substrate**

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We report the formation of a graded index (GRIN, $n = 1.4 - 1.6$) single-mode polymer waveguide lens on a GaAs substrate. The physical dimension of the waveguide lens is defined by the pre-designed mask pattern. The photo lime gel we used is extracted from animal tissue. When dried, this biophotopolymer is a rigid glass film that shows very little absorption or optical scattering. It is soluble in aqueous solutions and insoluble in most organic solvents such as benzene, acetone, petroleum ether, and absolute alcohol. As a result of this, negative photoresist was used as a masking layer for emulsion sensitization. The recording of the chirp grating lens can be realized either by lithographic tool or by holographic recording. In the reported demonstration, the waveguide lens was recorded holographically using the geometry suggested by Ref. [1]. A schematic showing the reconstructed waveguide lens is included in Figure 1. This figure shows that the reconstruction of the chirped grating lens. The incident guided beam is diffracted by the chirped grating lens at angles in the range of θ_l and θ_h . For the off-axis chirped grating lens shown in Figure 1, the incident beam cannot be at the Bragg angle across the entire aperture of the lens. It is easy to show that

$$\theta_l = \cot^{-1} \left(\frac{\cos \theta_i}{\sin \theta_i - \frac{\lambda}{\Lambda_l \cdot N_{\text{eff}}}} \right) \quad (1)$$

and

$$\theta_h = \cot^{-1} \left(\frac{\cos \theta_i}{\sin \theta_i - \frac{\lambda}{\Lambda_h \cdot N_{\text{eff}}}} \right) \quad (2)$$

where θ_i , θ_l , and θ_h are defined in Figure 1, λ is the optical wavelength, N_{eff} is the effective index of the waveguide mode and $1/\Lambda_l$ and $1/\Lambda_h$ are the grating spatial frequency of the chirped grating at the indicated locations. The diffracted beam coming out of the grating region will thus cross at a distance f , which is defined as the focal length of the chirped grating lens and is determined geometrically by

$$f = \frac{L}{\tan \theta_h - \tan \theta_l} \quad (3)$$

where L is the lens aperture. It is clear from Eqs. (1) through (3) that the focal length of the guided wave chirped grating lens is controlled by the chirp rate $\frac{1}{L} \frac{\Lambda_h - \Lambda_l}{\Lambda_l}$ and the effective wavelength, i.e., λ/N_{eff} of the waveguide. Chirp rate of 680/mm is demonstrated in our case. Higher chirp rate can be realized by using a fast cylindrical lens for recording. The depth of the phase grating (z direction of Figure 1) is equivalent to that of the polymer waveguide. As a result, the diffraction efficiency derived from coupled mode theory is stronger than for a surface relief grating structure with a partial overlap. The formation of a phase grating structure also reduces scattering when compared with a surface-relief structure because of the existence of the surface corrugation caused by etching processes such as chemical etching and ion milling.

The polymeric material we employed has a transmission bandwidth from 280 nm to 2800 nm, which covers UV, visible and near infrared optical wavelengths. A polymer-based chirped grating lens working in the UV and visible spectra can thus be realized on high index substrates [2] such as GaAs, Si and LiNbO₃. A GRIN polymer waveguide lens working at a wavelength of 632.8 nm is shown in Figure 2 where a guiding layer and a focusing waveguide lens are clearly shown. Demonstration of a waveguide lens at other visible wavelengths was also conducted and the results are not presented in this paper. The performance features and the design parameters for this waveguide lens are summarized in Table 1. The range of index tuning is around 1.4 to 1.6. The output end face of the device was further cleaved to facilitate near-field imaging. The profiles of the main lobe of the focal spot in both the horizontal and vertical directions are further illustrated in Figure 3. These profiles are very close to the theoretical prediction ($\lambda_{eff} \cdot F = 4.2 \mu\text{m}$). The diffraction efficiency at $\lambda=632.8\text{nm}$ was measured to be 56%. The linear dimension of the spot size in the depth direction is confined by the waveguide depth which is 10 μm for the reported device shown in Fig.2. The wide transmission bandwidth and the GRIN characteristic of the polymer thin film allows the formation of visible waveguide lens on a lossy high index substrate. The GRIN characteristic makes the formation of guided wave device transferable to any substrate of interest and the wide transmission bandwidth significantly expands the communication bandwidth of the signal carrier beams. Availability of waveguide hologram[2] and the integrated transceiver circuitry [3,4] will greatly enhance the chip to chip and module to module optoelectronic interconnects using the polymer/III-V material system combination. Furthermore, the large transmission bandwidth of the polymer film (280 nm to 2800 nm) significantly enlarges the optical signal bandwidth for GaAs-based waveguide lens[5].

In summary, we report for the first time the formation of a polymer based off-axis chirped grating lens working at 632.8 nm wavelength on a GaAs substrate. Both single and multiplexed waveguide lenses were formed. The GRIN characteristic of the polymer film allows the formation of such a waveguide circuit on any substrate of interest. In this paper, a chirped grating lens with chirp rate of 680/mm, focal length of 35 mm, and F# of 10 was successfully demonstrated. A diffraction-limited spot was also demonstrated. Unlike surface-relief gratings, where grating multiplexibility is not achievable because of their binary nature, the holographic waveguide emulsion we employed is a phase grating material with index modulation as high as 0.2. A large number of grating lenses can be multiplexed onto the same area. Finally, two-dimensional pixels, for example, CCD arrays, can be fully integrated onto the same integrated optical circuit. Therefore, an extra degree of freedom for optical signal processing and computing can be provided using the polymer-based guided wave devices.

References

1. A. Katzir, A. C. Livanos, J. B. Shellan, and A. Yariv, IEEE J. Quantum Electron., QE-13, 2961 (1977).
2. R. T. Chen, W. Phillips, T. Jansson, and D. Pelka, Opt. Lett 14, 892 (1989) and Ray T. Chen, Critical Review on Integrated Optics and Optoelectronics, The International Society of Optical Engineering, Vol. CR-45, 198-235(1993).
3. J. C. Campbell, R. Kuchibhotla, A. Srinivasan, C. Lei, D. G. Deppe, Y. S. He and B. G. Streetman, 1991, OSA Topical Meeting on Integrated Photonics Research, WE5, 73(1991).
4. S. R. Forrest, G. L. Tangonan, and V. Jones, J. Lightwave Technol. LT-7, 607(1989).
5. T. Q. Vu, J. A. Norris, and C. S. Tsai, Appl. Phys. Lett. 54(12), 1098 (1989).

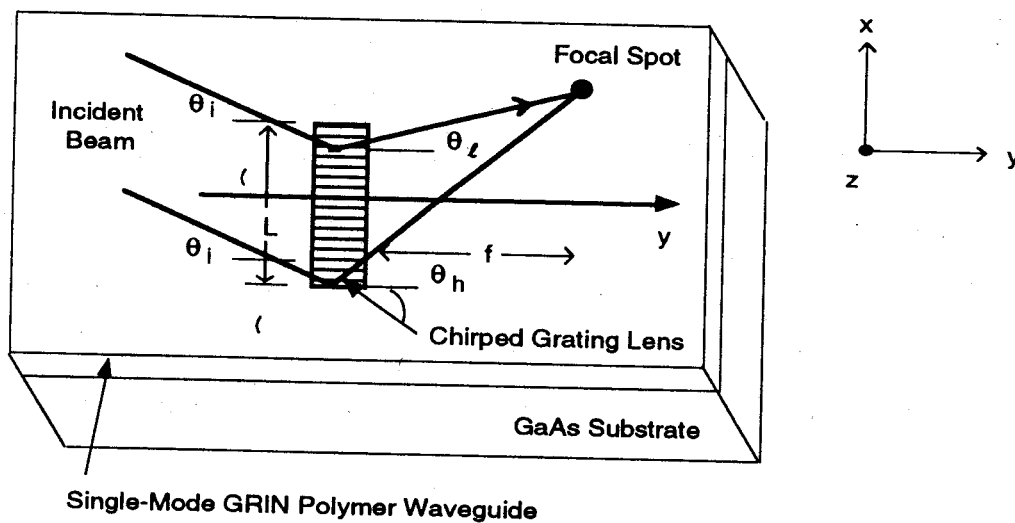


Figure 1 Schematic of the Single-Mode Graded Index Polymer Waveguide Lens on a GaAs Substrate

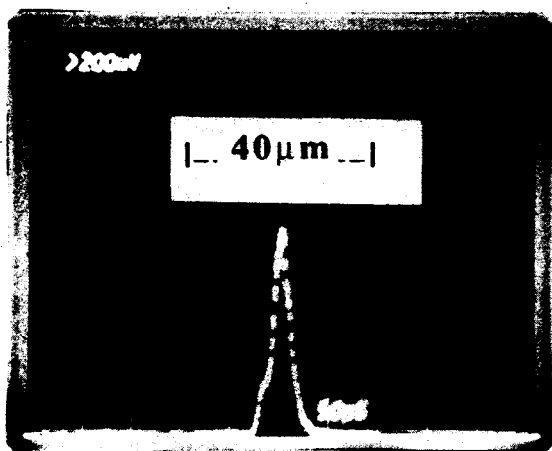


Figure 2 Observation of a Polymer-based Chirped Grating Lens on GaAs Working at 632.8nm

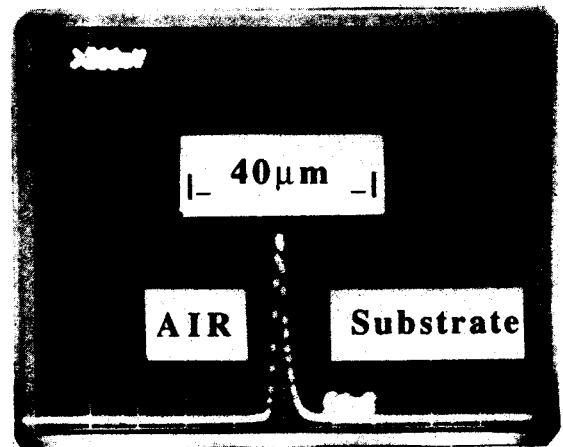
Table 1

Design Parameters and Measured Performance of Off-Axis Chirped Grating Lens

Film Index	1.4 - 1.6 (graded index)
Substrate Material	GaAs
Waveguide Thickness	10 μm
Waveguide Effective Index	1.47
Chirp Rate	680/mm
Focal Length	35 mm
F#	10
Δn_{eff}	to 0.2
Diffraction Limited Spot Size (μm) (1/e)	4.2 μm
Measured 3 dB Width (1/e, main lobe)	5.6 μm
Angular Field of View (degree)	6°
Waveguide propagation Loss	0.1 to 1.0dB/cm



(a)



(b)

Figure 3

Measured Focal Spot Intensity Distribution Profiles in the (a). Horizontal and (b). Depth Directions Using a Linear Charge Coupled Photo Detector Array