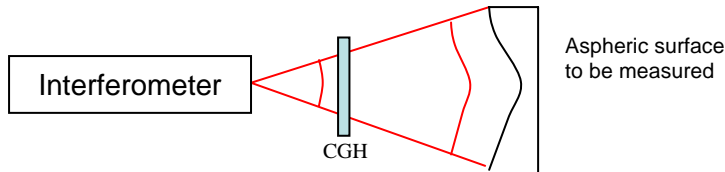


Concept

- Interferometer can measure flat or spherical surfaces to ~1nm accuracy
- CGH can control the shape of aspheric wavefront to $< 0.01\lambda$ with calibration
- A parametric model is developed to relate the wavefront performance to CGH fabrication errors
- Measure the CGH fabrication uncertainties for duty-cycle, etching depth and surface roughness
- Calibrate and estimate the wavefront performance based on the measured fabrication errors of CGHs

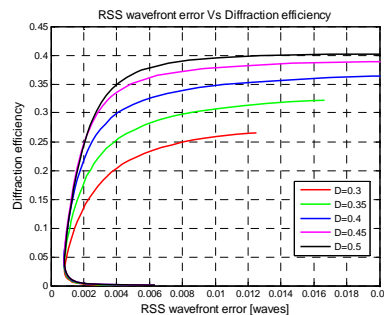


CGH fabrication errors

- **Amplitude CGHs (lower diffraction efficiency)**
 - *Substrate irregularity*: can be backed out by subtracting 1st order wavefront from 0th order.
 - *Pattern distortion*: with the line position error of 0.1 μ m and 20 μ m line spacing, pattern distortion is 0.005 λ for the first order diffraction
- **Phase CGHs (higher diffraction efficiency)**
 - *Substrate irregularity*: can be backed out as the amplitude CGHs, but the wavefront error from duty-cycle and etching depth in the 0th order measurement will be coupled in
 - *Pattern distortion*: same as the amplitude CGHs ~0.005 λ
 - *Duty-cycle*: duty-cycle variation only affects the 0th order wavefront
 - *Etching depth*: variations in etching depth affect both the 0th and higher order diffracted wavefronts for phase CGHs
 - *Surface roughness*: imperfections in the etching process can cause small-scale surface roughness vary across CGHs. The coupling surface roughness to the wavefront can be treated as scattering loss, which affect both the 0th order and higher order diffracted wavefronts. In our model, the scattering loss can be treated as an amplitude effect.

Technical Approach

- Fabrication non-uniformities in duty-cycle, etching depth and surface roughness can be obtained by measuring a set of sampling points over the CGHs
- Duty-cycle and etching depth can be obtained by measuring the diffraction efficiencies up to +/- 11th order or higher
- Surface roughness can be measured on the interference microscope
- Amplitude CGHs have better measurement accuracy than phase CGHs. Pattern distortion is the only error left after the substrate calibration.
- Phase CGHs have higher diffraction efficiency. In some special cases, phase CGHs is needed for optical testing.
- Figure in the right shows the RSS wavefront error Vs diffraction efficiency for phase CGH. Assume the phase CGH has
 - 2% etching depth variation
 - 1% duty-cycle variation
 - 0.5% intensity variation
- There is a tradeoff between diffraction efficiency and measurement accuracy



Test Result

- The fabrication non-uniformities of a 5-in diameter phase CGH with 50% duty-cycle and 0.33 λ etching depth were measured.

Source of Errors	Fabrication Tolerances
CGH substrate	13.6 nm
Etching depth	0.67%
Duty-cycle	0.18%
Amplitude	0.0033%

- CGH substrate error is a major error in optical testing, which is typically in the order of tens of nm. It can be removed by subtracting the 1st order measurement from the 0th order one.
- Pattern distortion is the main error after CGH substrate calibration, which is about 0.005 λ .
- The wavefront errors from duty-cycle, etching depth and amplitude are usually not significant (<1nm) in optical testing. It can be ignored.
- For different fabrication tolerance, there is a tradeoff between diffraction efficiency and wavefront error for CGH design.

For more information:

Fabrication error analysis and experimental demonstration for computer-generated holograms, *Applied Optics*, Vol.46, No.5, Feb. 2007

Analysis of phase sensitivity for binary computer-generated holograms, *Applied Optics*, Vol.45, No.18, June 2006