Micro-Optics
Introduction
Agenda

- What are Micro-Optics?
- Refractive / Diffractive Optics
- Fabrication Methods
What are micro-optics?

Many Possible definitions of “micro-optics”
- Have dimensions best measured in micrometers: Lens diameters, focal lengths, grating periods, etc…
- Are built up of features that are best measured in micrometers

We will focus on diffractive and refractive micro-optics
- Diffractive micro-optics: manipulate light through diffraction
- Refractive micro-optics: manipulate light through refraction
Refractive Optics

- Focus light through refraction
- Can be fabricated using lithographic techniques
- Operate across a wide range of wavelengths with very high efficiency
- Surface shape determines how the lens performs!
  - Diameter
  - Radius of curvature
  - Figure, etc
Micro Refractive Optics

diameter = 358nm

2011-1 Design & Fabrication of Micro-optics
Diffractive Optics

- **DOE (diffractive Optical Element)**
  - Traditional Lens (등위상면)
  - Kinoform (diamond turned)
  - Multi-level DOE (photo-etched)
  - Binary Optic (photo-etched)
  - Zone Plate
Micro Diffractive Optics

Design & Fabrication of Micro-optics

600 nm

60 nm

Yonsei University
Typical Process Flow for Micro-Optics

1. Incoming materials
   - Clean Room Processing
     - Fabrication of micro-optics
   - Testing
   - Dicing
   - Final Inspection

2. Optical Design
   - Translate design to manufacturable format (mask generation)

3. Ship!
Optical Design and Optimization

- Design approach depends on the functionality of the optic.

- Limitations on fabrication and of diffraction theories must be understood.

- Cannot defy the laws of physics!

- Design and fabrication constraints can be incorporated into the design algorithm

**Methods**

- Direct solution (simple design only)
- Conventional optical design software (Code V, Zemax, etc)
- Iterative Optimization

**Most design software is custom written**
Lithographic Techniques

- The surface relief structures are fabricated with techniques (rooted in the microelectronics industry) that make use of light-sensitive polymer and controlled etching or deposition methods.

Direct Machining

- The surface relief structures are generated through direct removal of optical material in a controlled manner without the use of intermediate processes.

Replication

- Copies of surface relief structures are fabricated in polymers or other materials from a ‘master’ element produced using another technique, such as those described above.
Lithographic Techniques

Binary Optics

Exposure1

Etch1

Exposure2

Etch2

Binary Optics example

Mask 1

Mask 2

Mask 3
Lithographic Techniques

Grayscale lithography

- Mask: Special High-Energy Beam sensitive (HEBS) glass;
changes opacity when hit with a beam of high-energy electrons
Direct Machining

Mechanical Ruling and Diamond Turning

• Cut directly with a sharp tool
• Weak Point
  - Requires precise mechanical control
  - **Not perfectly** smooth profile
  - Limited flexibility (~ linear gratings ; mechanical ruling

Circularly symmetric gratings ; diamond turning)

![Diagram of Direct Machining](image)
Focused Ion Beam Milling

- Using a focused stream of ions to sputter the surface
- Binary or multi-level
- Sub-micron patterning
- Serial process ~ very slow

Laser ablation

- Using an excimer laser to ablate materials
  - polymers, glasses
- Binary or multi-level
- Minimum feature determined by laser spot size ~1 μm

Diagram of laser ablation process:
- UV Laser Light
- Focusing Object
- Computer controlled precision X_Y stage
- Substrate
The process of melting raw plastics inside a barrel and injecting the melt into a mold cavity, where it cools until it keeps the shape of the cavity.

An all-electrical Injection Machine
In the recent years, plastic parts with nano/micro-patterns have gained attention.

For the manufacturing of the microcomponents:
- large-volume fabrication
- high-aspect ratio
- low production cost
- 3D features

**PMMA LENS**

**MICRO MOLD INSERT**

**MICRO GEAR**
Produce of MIMIC Process

- PDMS mold is placed on the surface of a substrate and makes conformal contact with that surface.
- The relief structure in the mold forms a network of empty channels.
- When a low-viscosity liquid prepolymer is placed at the open ends of the network of channels, the liquid spontaneously fills the channels by capillary action.
- After filling the channels and curing the polymer into solid, the PDMS mold is removed, and a network of polymer material remains on the surface of the substrate.
Jet Molding

- Mixture of gas and ultra-fine particles (<100nm) is heated and ejected to substrate to form microstructure
- The heating system is installed to heating the powders (For bonding)
- Have Three major types of forming method
- High aspect ratio structure
Hot Embossing

- Production advantages: simple operation, a relatively low cost for embossing tools (Si), and high replication accuracy for small features.

- The basic principle of hot embossing: A polymer substrate is first heated above $T_g$ and pressing mold down on substrate. After a certain time between the mold and the substrate, the system is cooled down below $T_g$, followed by separating the mold from the substrate (de-embossing).

- The small thermal cycle makes better micro-optical products (lens, fiber connector, LCD backlight plate) because of minimizing the thermally induced stresses.
Some Application of Micro-Optics

- Laser Modules
- Laser Machining
- Imaging Systems
- Displays
- Bar Code Scanning
- Illumination Systems
- Position Encoders
- Data Storage Systems
- Photolithography enhancement
- Optical Communications