Standards for microlenses and microlens arrays

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Structure of talk

- National Physical Laboratory
- Microoptics and microlenses
  – applications and history
- Measurements for microlenses
- International standards for microlenses
- Conclusions
National Physical Laboratory

• NPL is the UK’s National Measurement Institute

• Owned by Department for Innovation, Universities & Skills (DIUS) and privately operated by Serco.

• It is world-leading centre of excellence in developing and applying the most accurate measurement standards, science and technology.

• Work includes optical metrology to support industry

• Previous work included development of measurement techniques for microoptics
Microlens arrays

Example shows lenses formed in photoresist on glass substrate.
Lens spacing = 125 micrometres (µm)

Microlenses generally defined as lenses having diameters less than 1mm.
Simple lenses – smaller size means, in principle, fewer aberrations.
Applications

• A common application is in digital cameras where microlenses are used to increase the fill-factor of the detector array
Applications

Other applications include:
Novel imaging systems for photocopiers
Shack-Hartmann wavefront sensor

• The incident wavefront is focused by the microlens array to the CCD.
Shack-Hartmann wavefront sensor

tilted wavefront

- wavefront slope at each lens can be deduced from the displacement of the spot
- wavefront is reconstructed by integrating the wavefront slope values
History of microlenses

Robert Hooke made small lenses by melting glass filaments to form small spheres. Held close to eye he used them as simple microscopes and sketched what he saw.

Stanhope lenses

- Stanhope lens invented by Charles, Earl of Stanhope. Popular in 1800s with small images such as advertising on the back face.

Held close to eye to reveal images.
Integral photography

- 1908, Gabriel Lippmann assembled an array of Stanhope lenses
  
  \textit{(Lippmann G. Epreuves reversibles. Photographies integrales. Comptes Rendus, 1908, 146, 446-451)}

- Used to record and reconstruct an integral image – integral photography.

- Reversal of ray bundles generates pseudoscopic 3D image
Integral images

Two views from one recording, showing parallax. Recorded on colour reversal film using array of microlenses 250 micrometre diameter.
Microlens fabrication

- Microoptics and microlens lens technology has developed rapidly over the last two decades with the growth in the microelectronics and optical fibre telecommunication industries.
- Advances in microfabrication techniques for integrated circuits - multilevel diffraction lenses.
- Technique also explored by NPL. Went on to research needs and develop metrology for microlens arrays.
- Japanese conferences on microoptics 1987 onwards.
- Need for international standards became apparent.
Microlenses by melting photoresist

Typical dimensions:
- layer thickness = 15\,\mu m
- lens diameter = 100\,\mu m
- focal length = 100\,\mu m(f/1)

Microlens arrays
Optical measurements at NPL

Reference flat calibrated with respect to liquid surface, used to calibrate commercial interferometer used to measure customer’s mirrors and lenses.
However our instrument cannot measure very small components.
Solution was to build micro-optic interferometer in which the test surface is imaged using a high quality microscope objective.
Mach-Zehnder interferometer for measurement of wavefronts transmitted by microlenses
Need for international standards

Participants included:

• University of Erlangen, Nürnberg, Germany
• Optoelectronic Industry and Technology Development Association (OITDA) Japan
• University of North Carolina at Charlotte, USA
• Vrije Universiteit Brussel, Belgium
• Various international companies such as: Nippon Sheet Glass, GRINTEC Germany, Kodak USA, Wavefront Sciences.
Microlens parameters

Typical parameters:

- Lens diameter
- Focal length
- Distance between lenses (pitch)
- Uniformity of array
- Wavefront quality
- Lens thickness (sag)
- Substrate thickness

Simple design may mean less correction and large spherical aberration
Microlens parameters (ISO 14880-1)
BS EN ISO 14880-1:2005 Microlens arrays – part 1 vocabulary

• Defines optical properties and geometrical parameters
• Focal length in particular
• Difficult to locate principal plane and optical image plane
Optical surface shape useful for lens manufacturer and supplier
Surface profile measured using stylus in contact
Non-contacting methods include interferometry

**BS EN ISO 14880-2:2006 Microlens arrays** - part 2 Test methods for wavefront aberrations

- Optical surface shape useful for lens manufacturer and supplier
- Surface profile measured using stylus in contact
- Non-contacting methods include interferometry

**BS EN ISO 14880-3:2005 Microlens arrays** – part 3 Test methods for optical properties other than wavefront aberrations

- This includes focal length, chromatic aberration, uniformity of spot positions

**BS EN ISO 14880-4:2006 Microlens arrays** – part 4 Test methods for geometrical properties

- Properties such as pitch, modulation depth, thickness, radius of curvature, uniformity of array.
- Moire magnifier
Microlens arrays (ISO14880 series) standards development road map
Conclusions

• Microlenses were made as long ago as 1660. The technology has developed rapidly over the last 15-20 years.
• International manufacturing and use has led to the need for standard nomenclature and measurement methods.
• The ISO 14880 series of standards contributes to ensuring consistent specification and guidance to good measurement practice.
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References:

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