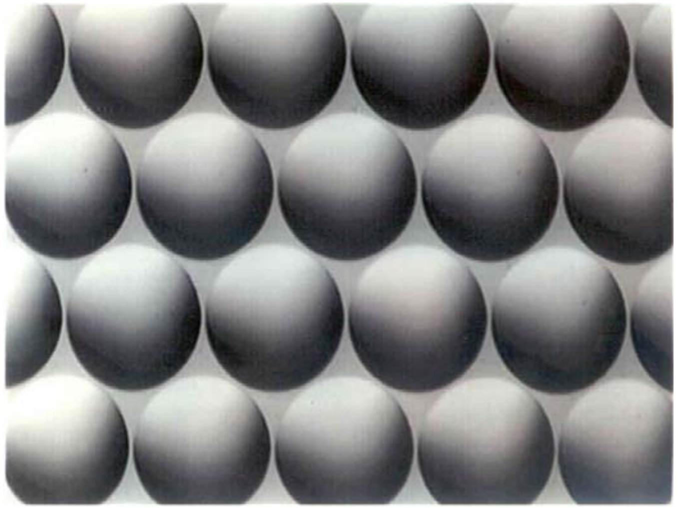
Digital Futures 2008

Institute of Physics, London 28 October 2008



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**

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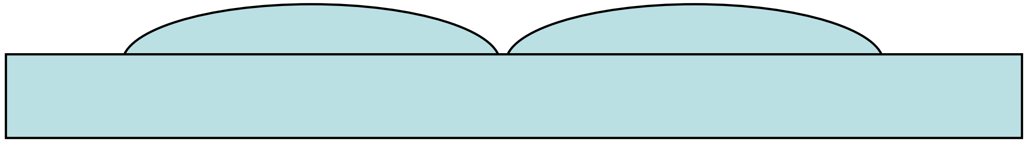
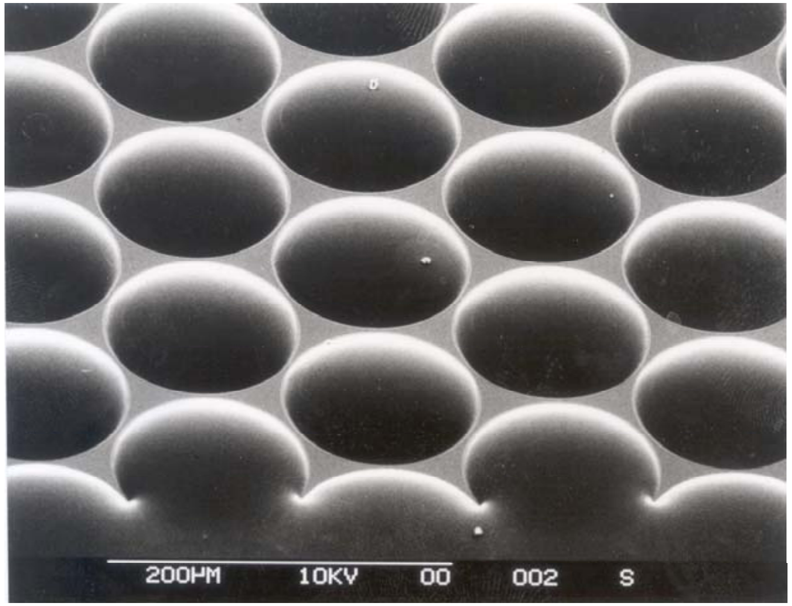
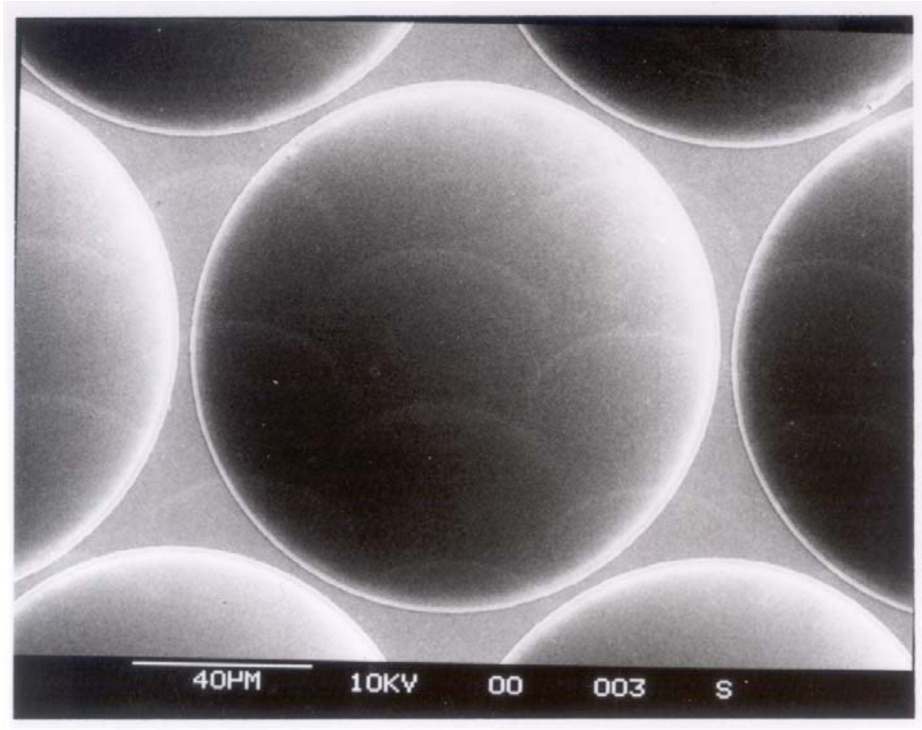
Microlens arrays



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.

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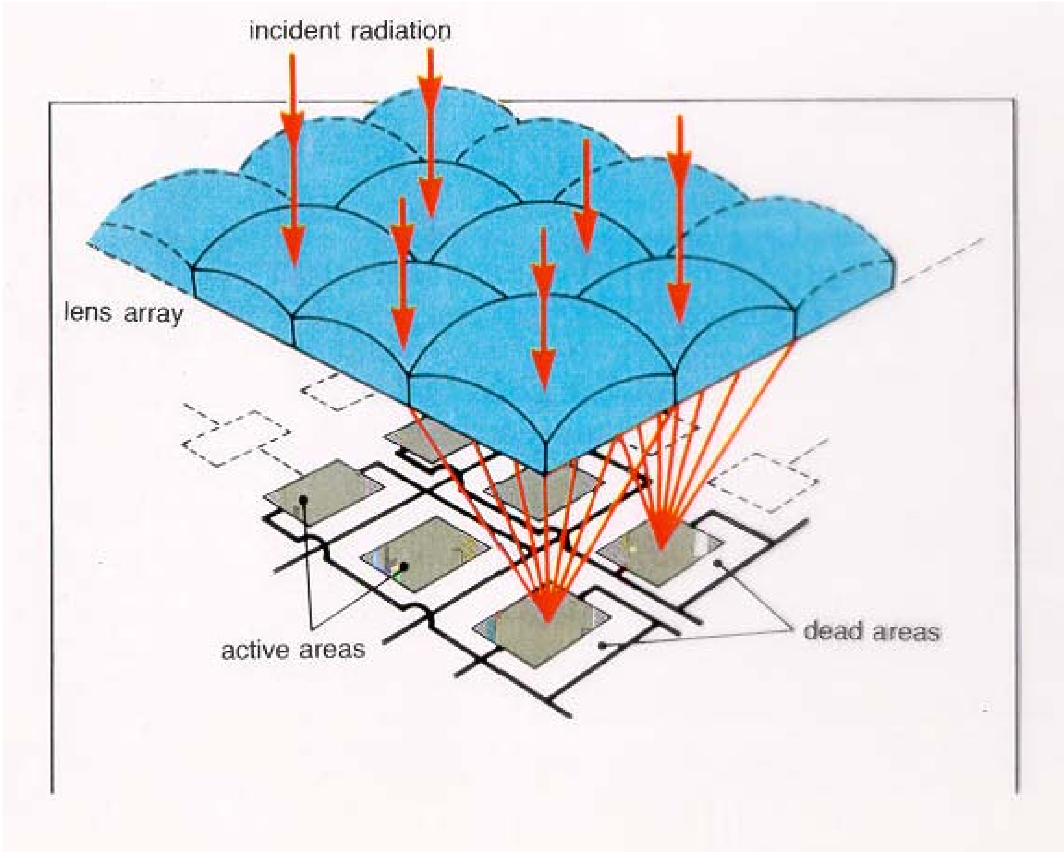
Applications

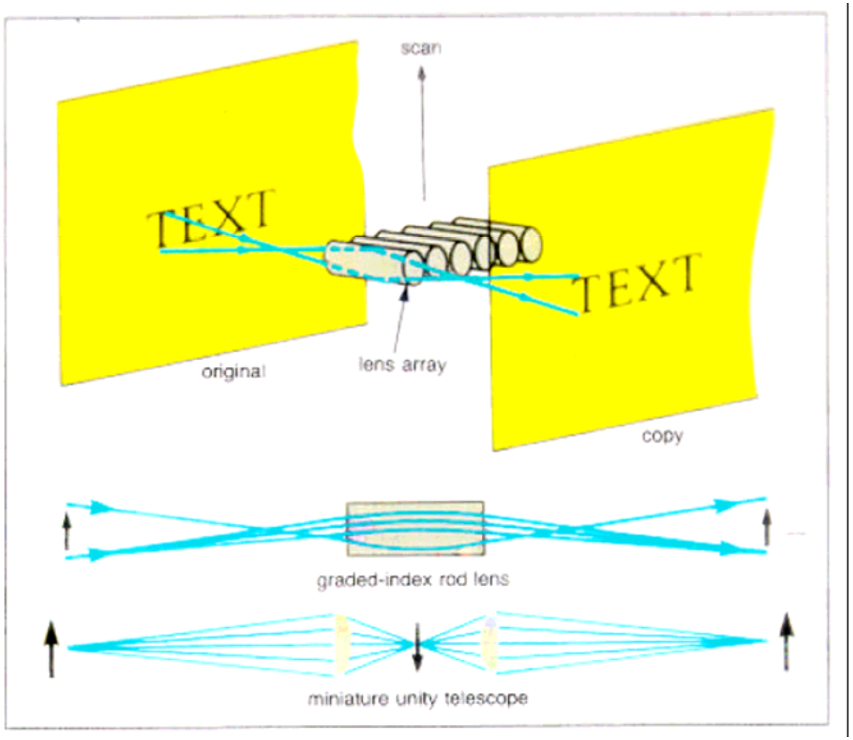
- A common application is in digital cameras where microlenses are used to increase the fill-factor of the detector array

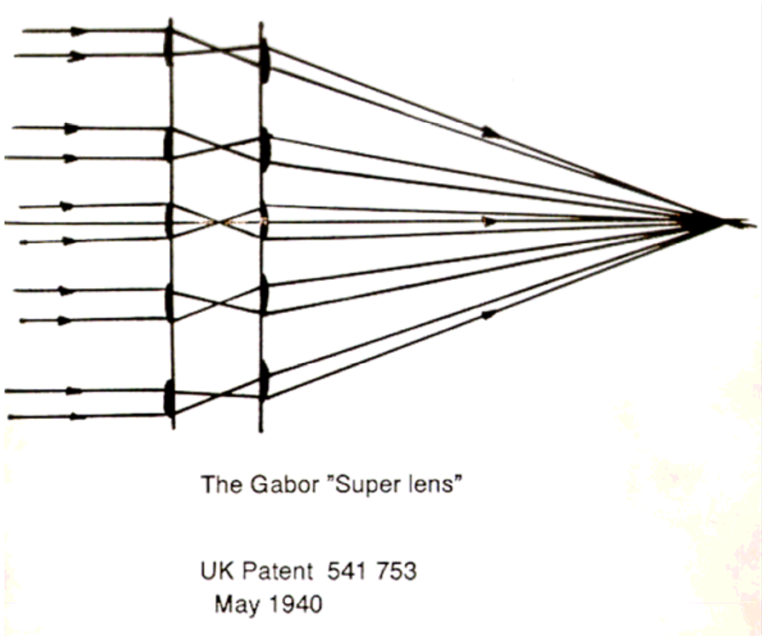


Applications

Other applications include:

Novel imaging systems for photocopiers





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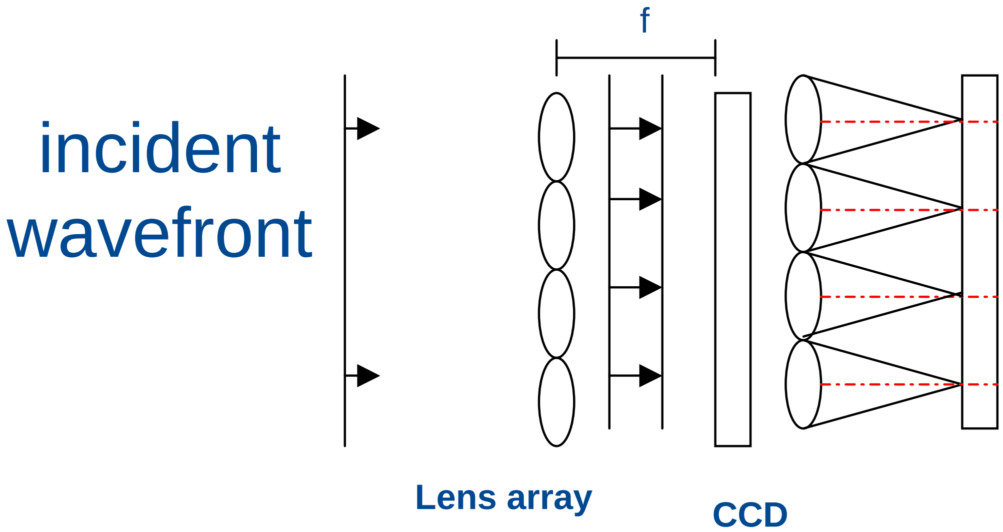
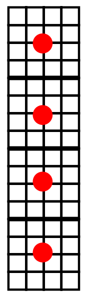
Shack-Hartmann wavefront sensor

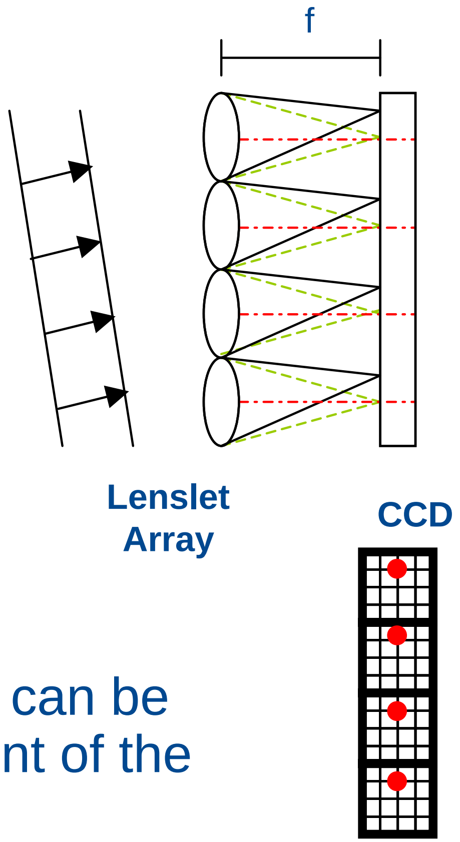


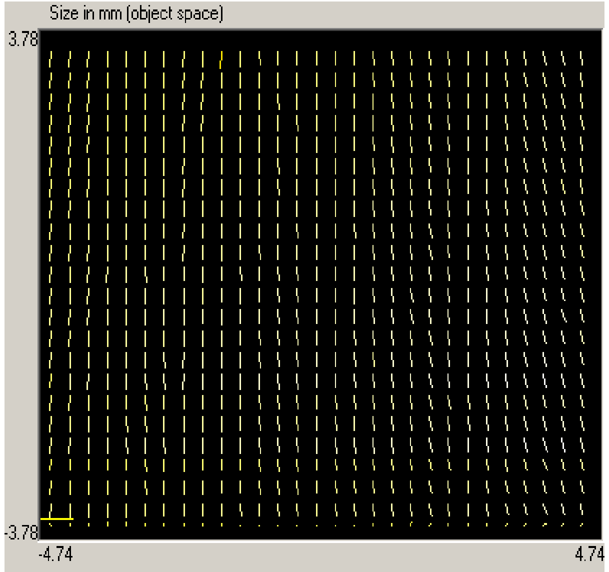
•The incident wavefront is focused by the microlens array to the CCD.



Shack-Hartmann wavefront sensor

tilted wavefront

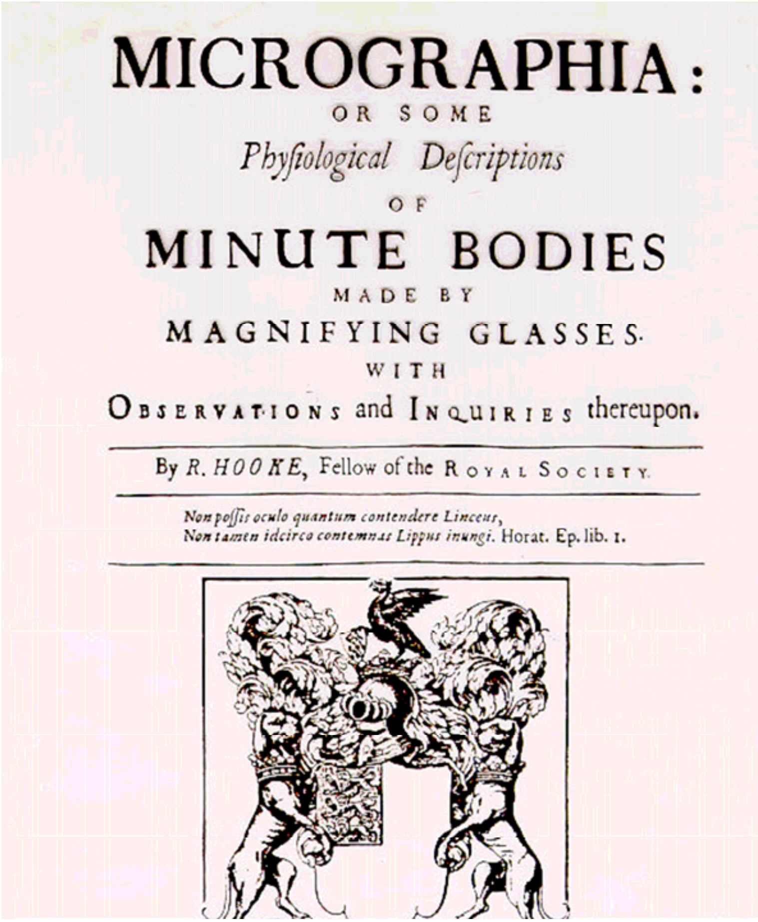




•wavefront slope at each lens can be deduced from the displacement of the spot

•wavefront is reconstructed by integrating the wavefront slope values

History of microlenses


MICROGRAPHIA:
OR SOME
Physiological Descriptions
OF
MINUTE BODIES
MADE BY
MAGNIFYING GLASSES.
WITH
OBSERVATIONS and INQUIRIES thereupon.
By R. HOOKE, Fellow of the ROYAL SOCIETY.
Non possis oculo quantum contendere Linceus,
Non tamen idcirco contemnas Lippus inungi. Horat. Ep. lib. 1.

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.

Hooke R. Preface to Micrographia. The Royal Society. London.1665

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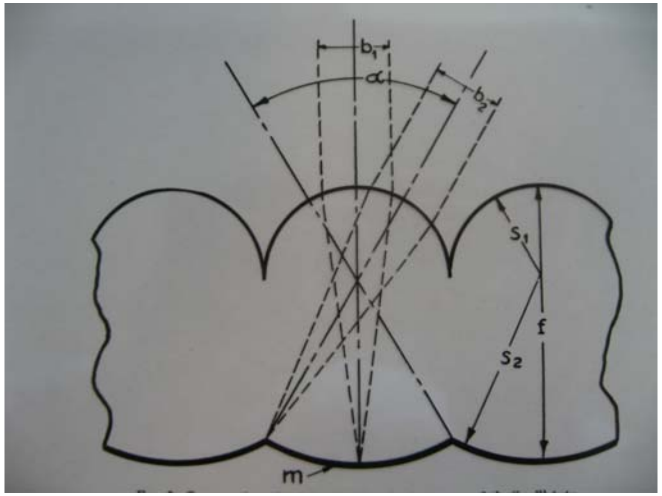
Stanhope lenses



- 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.

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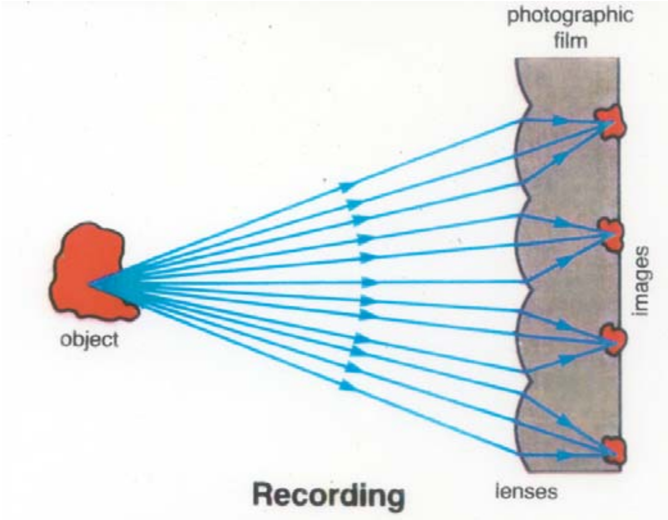
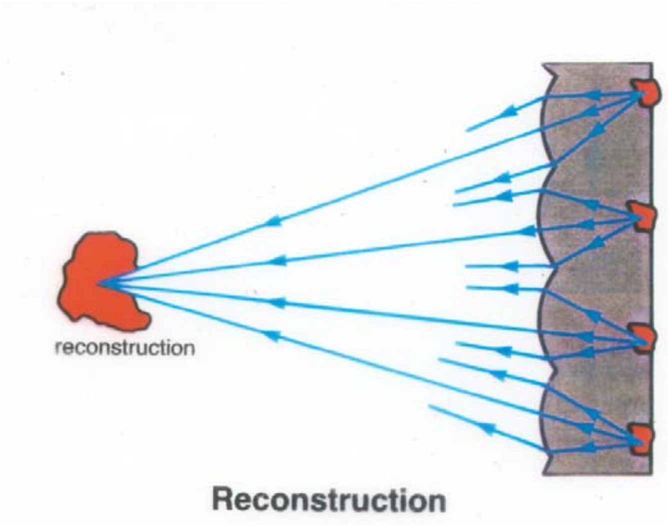
Integral photography

- 1908, Gabriel Lippmann assembled an array of Stanhope lenses

  (*Lippmann G. Epreuves reversibles. Photographies integrales. Comptes Rendus, 1908, **146**, 446-451)*

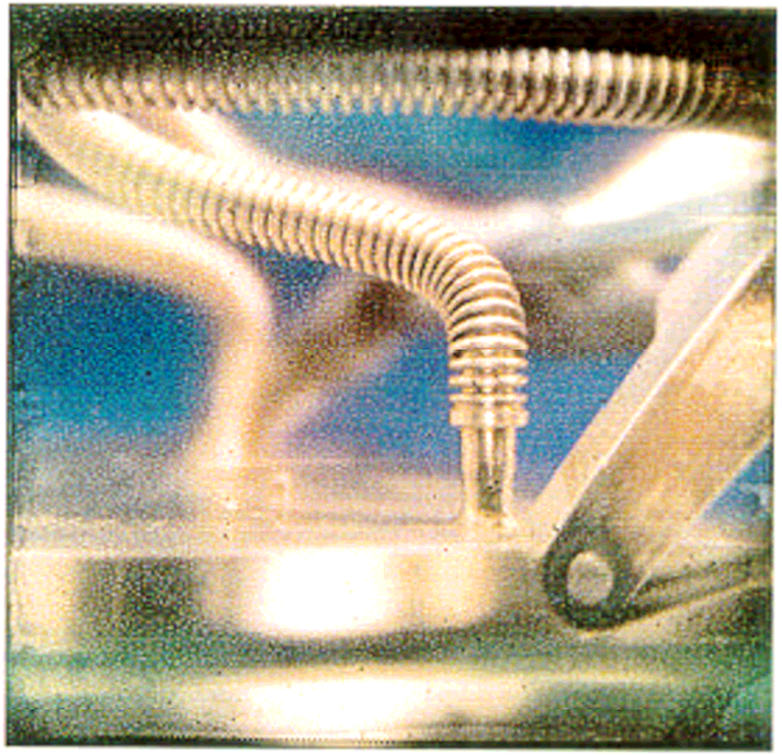


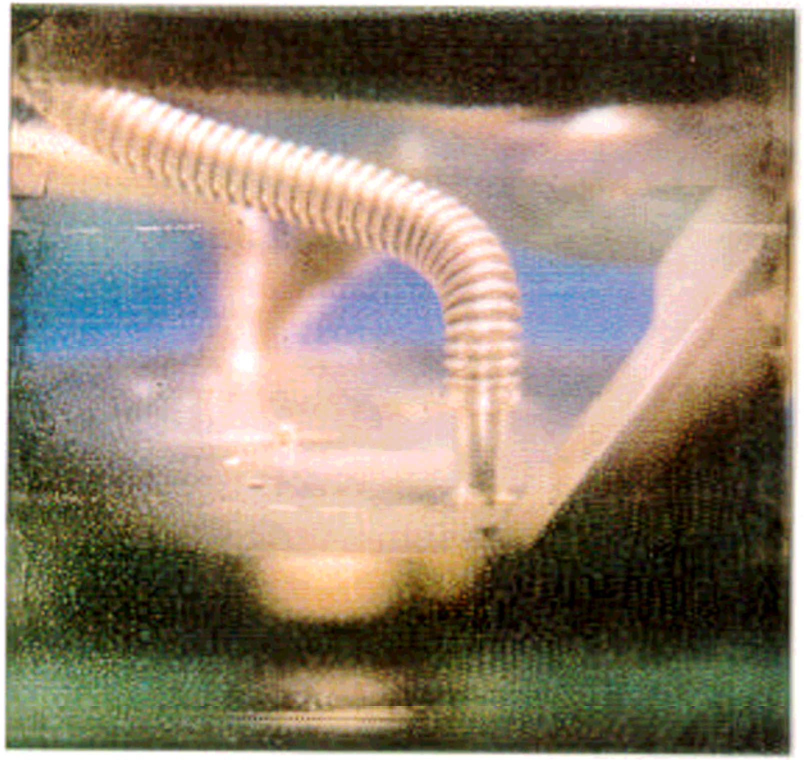
- Used to record and reconstruct an integral image – integral photography.



- Reversal of ray bundles generates pseudoscopic 3D image

Integral images





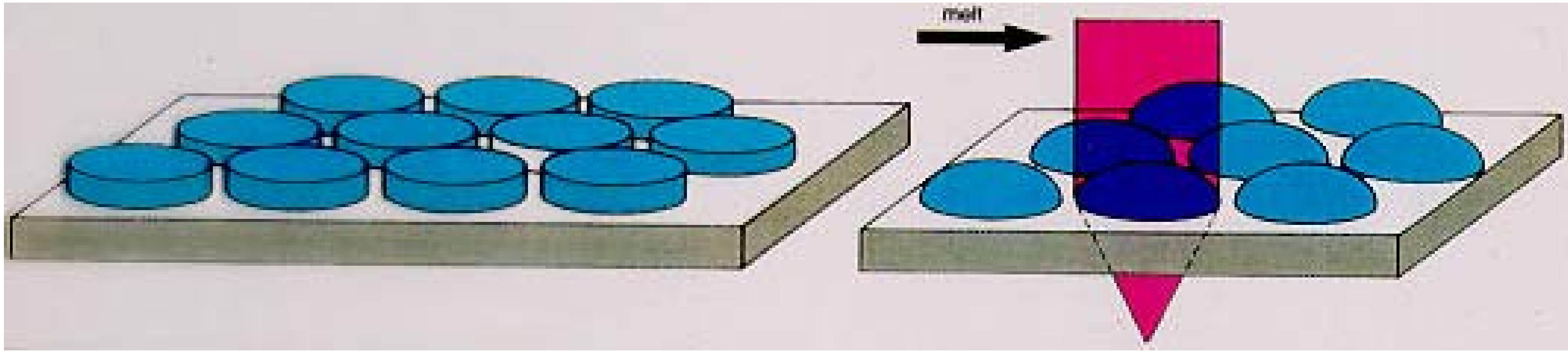
Two views from one recording, showing parallax.
Recorded on colour reversal film using array of microlenses 250 micrometre diameter.

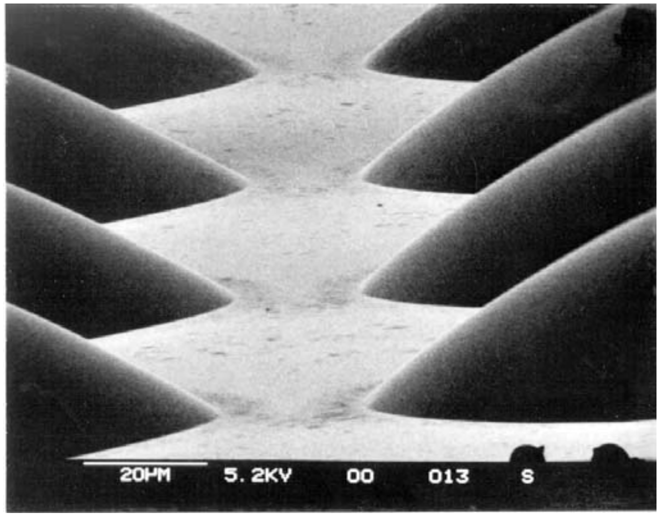
Microlens fabrication

- 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.
- In 1988 Zoran Popovic at the Xerox Research Centre made microlenses by melting photoresist.

  Popovic, ZD, Sprague RA, Neville Connell GA. Appl.Opt. 27(7) 1281-1284 (1988)
- Technique also explored by NPL. Went on to research needs and develop metrology for microlens arrays.
- NPL held with the IOP a series of conferences on microlens arrays in 1991, 1993, 1995, 1997, 2001.
- Japanese conferences on microooptics 1987 onwards.
- Need for international standards became apparent.

Microlenses by melting photoresist





Typical dimensions:

layer thickness = 15μm	22μm
lens diameter = 100μm	400μm
focal length = 100μm(f/1)	800μm(f/2)

Daly D, Stevens R F, Hutley M C and Davies N, "The manufacture of microlenses by melting photoresist". Meas.Sci. Techn. 1, 759-766, 1990.

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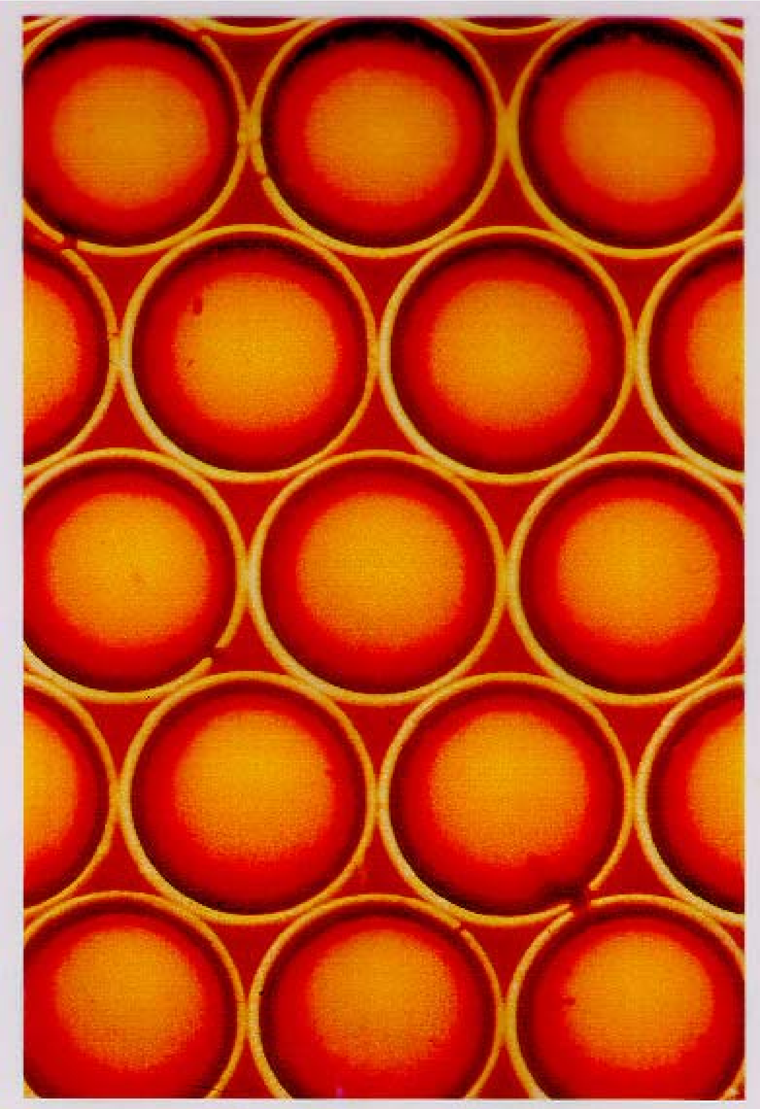
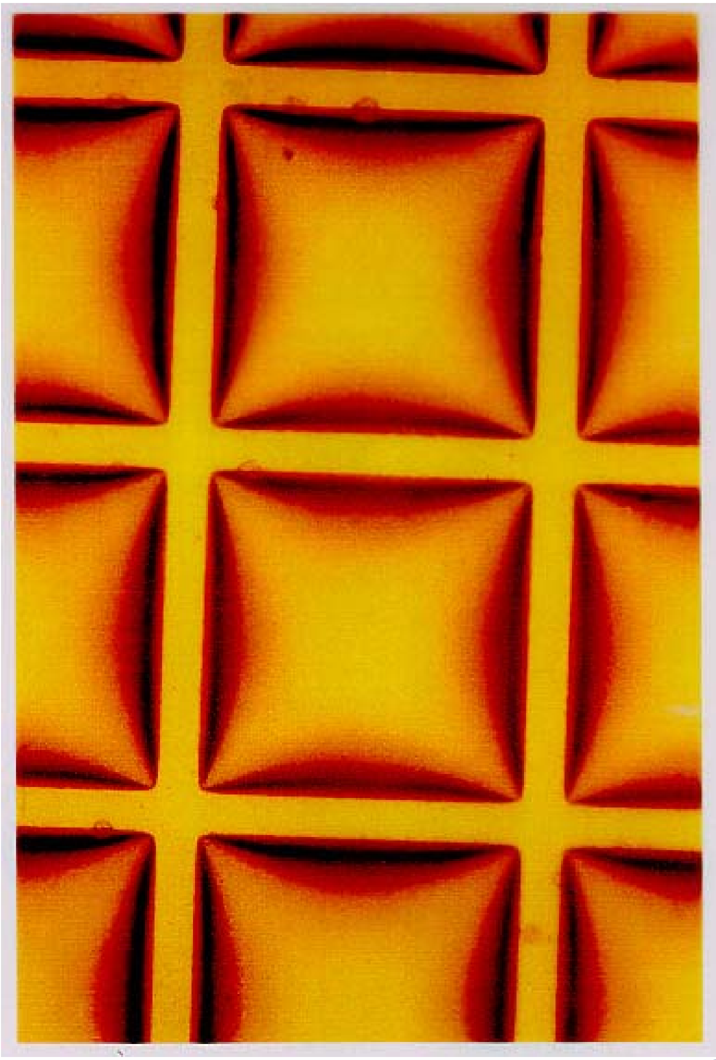
Microlens arrays





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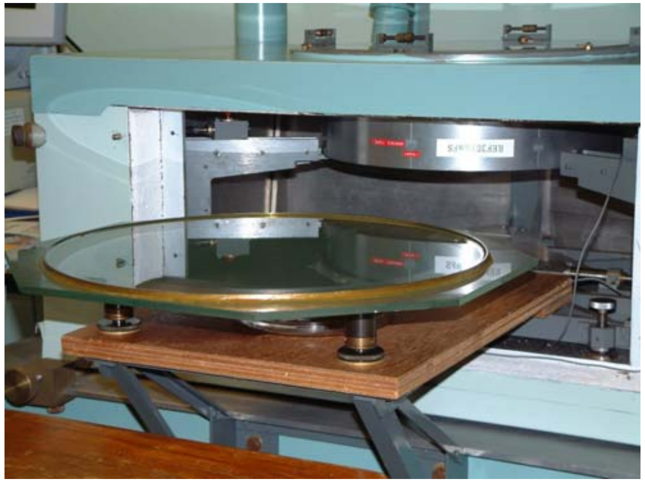
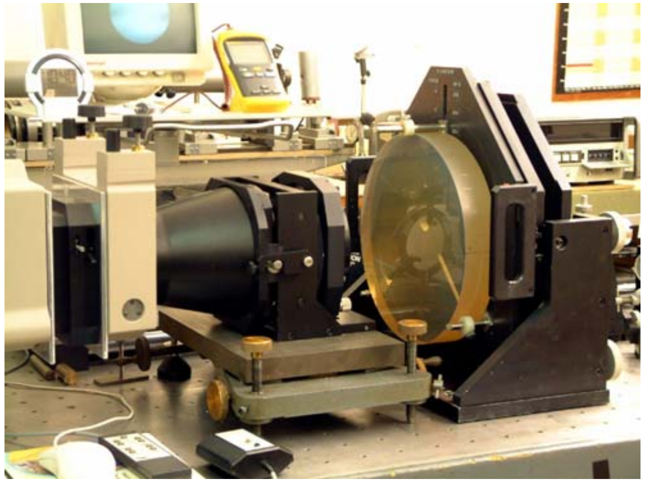
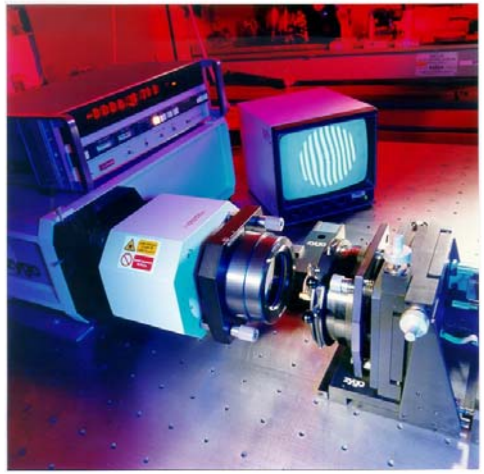
Optical measurements at NPL







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.

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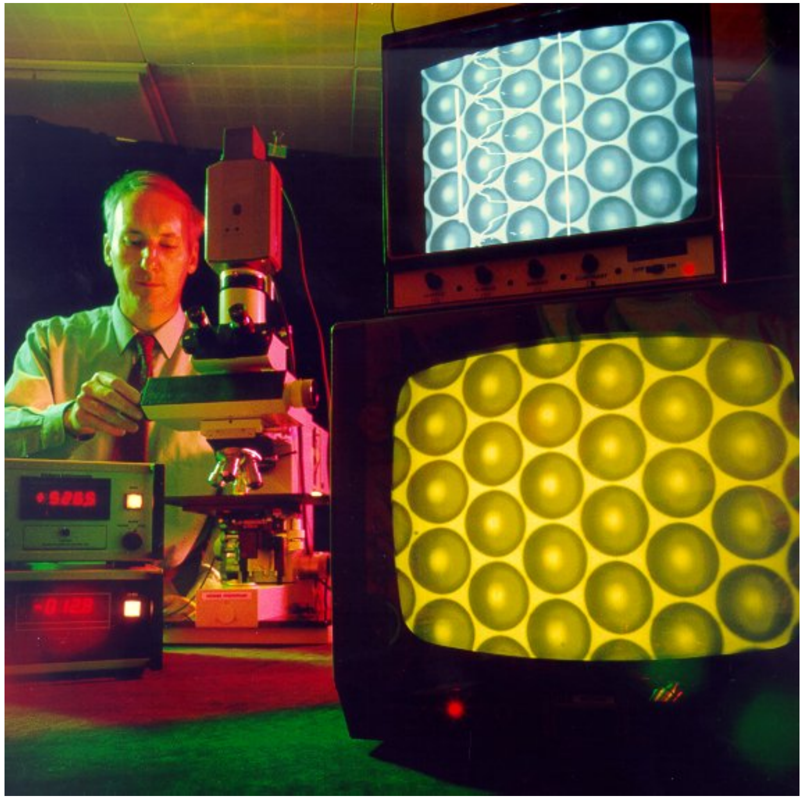
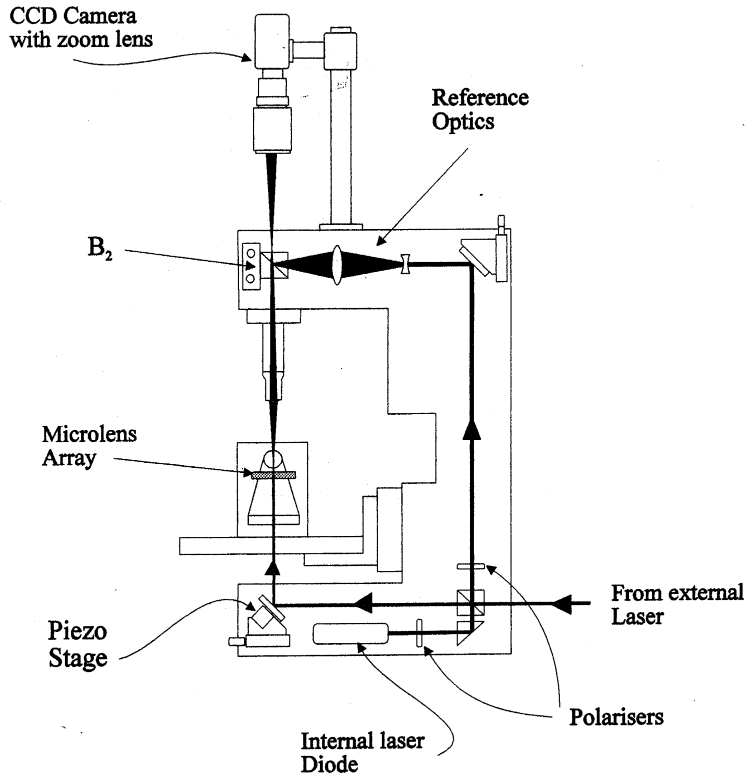




Mach-Zehnder interferometer for measurement of wavefronts transmitted by microlenses

Need for international standards

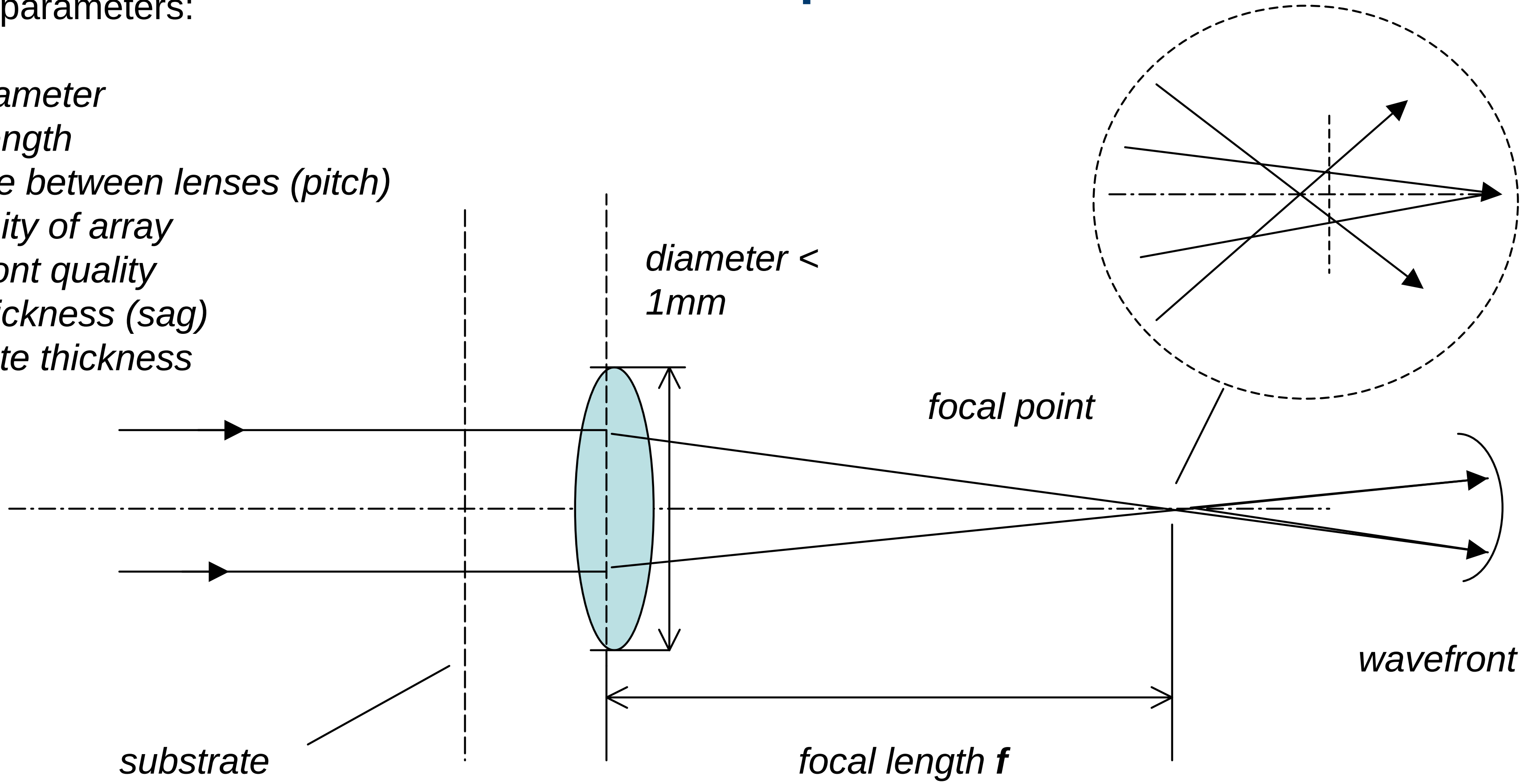
Participants included:

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

Microlens parameters

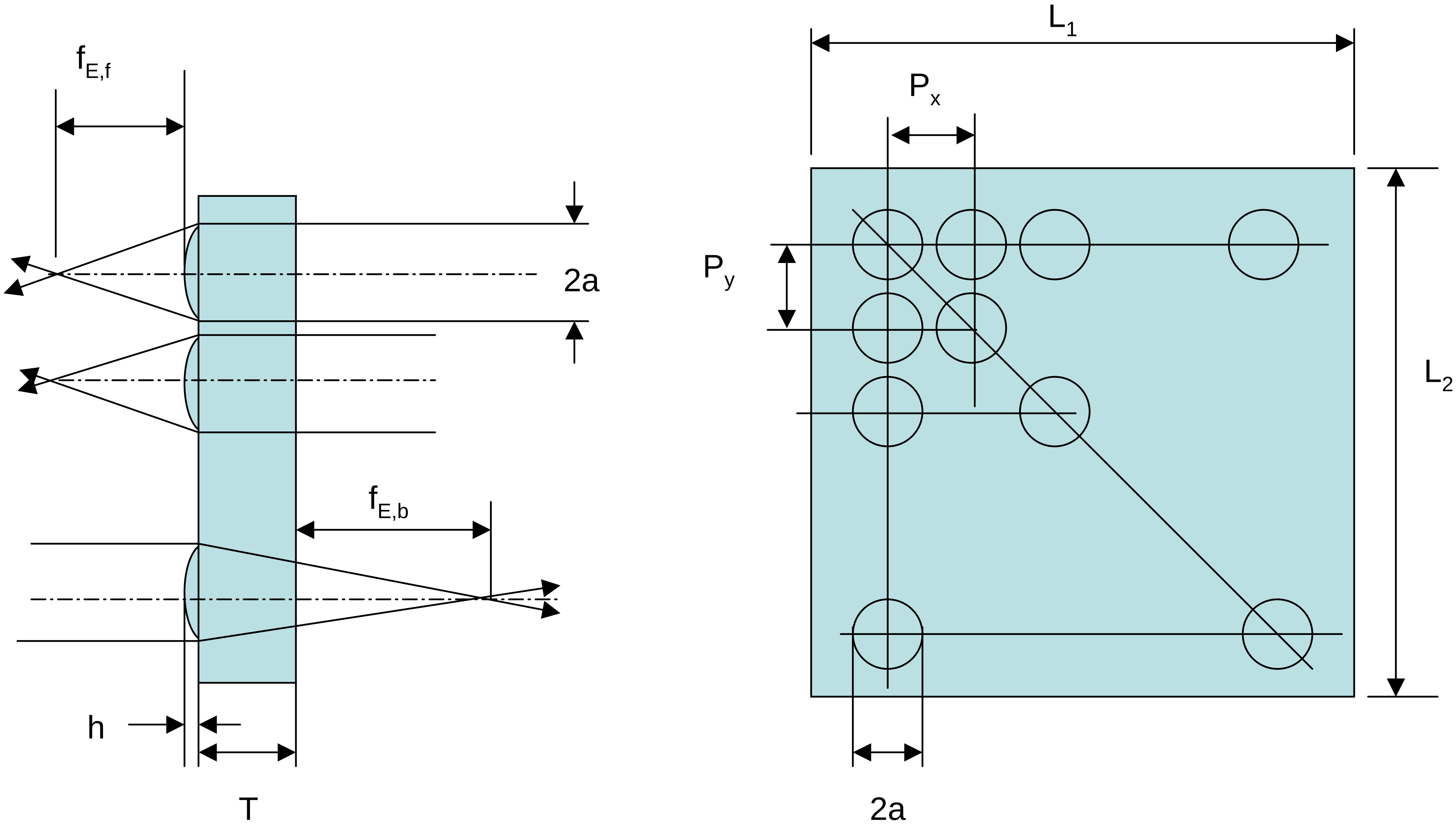
Typical parameters:

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

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

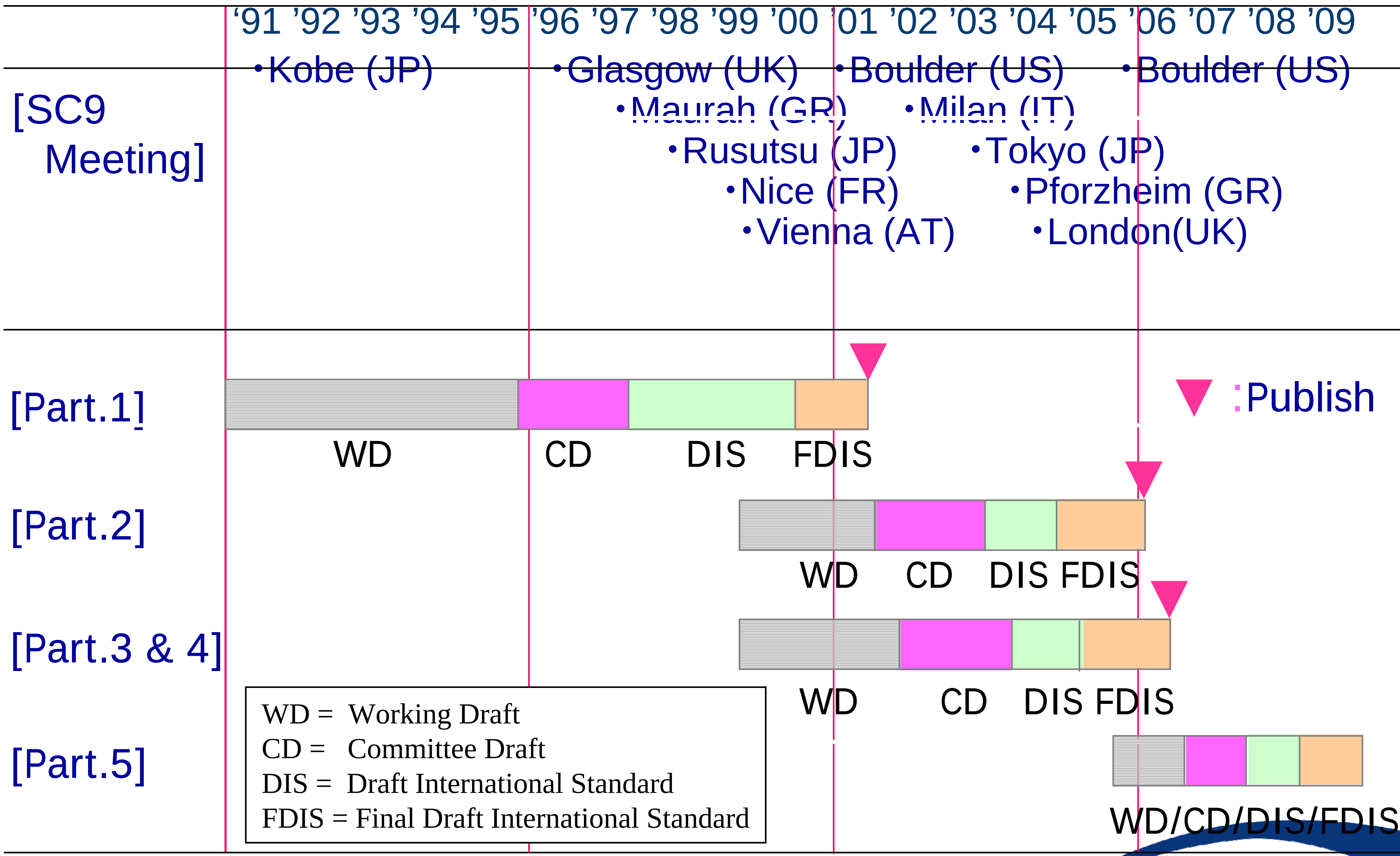
- **BS EN ISO 14880-3:2005 Microlens arrays** – part 3 Test methods for optical properties other than wavefront aberrations

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

Miyashita T. "Standardization for Microlens and Microlens Arrays", Japanese Journal of Applied Physics(JJAP), Vol. 46, No. 8B (2007) pp. 5391-5396.

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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.

Acknowledgements:

Department for Innovation, Universities & Skills (DIUS)

Takaaki MIYASHITA, project leader for ISO 14880 microlens standards, Ricoh Company Ltd, Japan.

References:

1) Miyashita T. Standardisation for microlenses and microlens arrays. Jap. Jnl. of Appl. Phys. vol 46, no8B, 2007, pp 5391-5396

2) BS EN ISO 14880 series Microlens arrays parts 1–4. 2005, 2006.

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