



Replicated Optical MEMS in Sol-Gel Materials



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2.3.1 The Lithographic Process (1)



- ▼ The pattern-transfer process is accomplished by using a lithographic exposure tool that emits radiation
- ▼ Resolution is defined as the minimum feature size that can be transferred with high fidelity to a resist film on the surface of wafer
- ▼ Registration is a measure of how accurately patterns of successive masks can be aligned with respect to the previously defined patterns on a wafer
- ▼ Throughput is the number of wafers that can be exposed per hour for a given mask level.
- ▼ Depending on the resolution, several types of radiation, including electromagnetic (e.g. UV and X rays) and particulate (e.g. electrons and

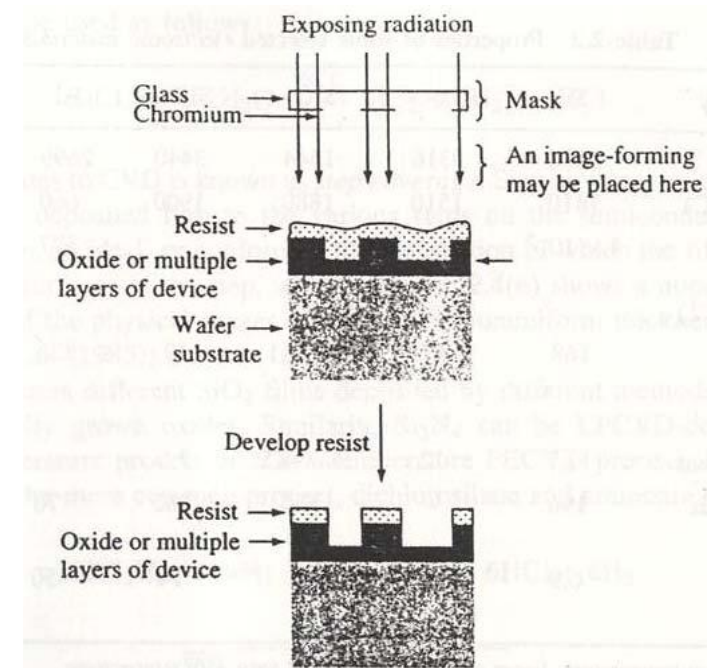


Fig 2.5 Basic steps in a lithograph used to fabricate a device



2.3.1 The Lithographic Process (2)



- ▼ UV($0.2-0.4\mu\text{m}$)
 - : $1\mu\text{m}$ resolution, $0.5\mu\text{m}$ registration, throughput 50 to 100 wafers per hour
- ▼ Electron-beam lithography
 - : $0.5\mu\text{m}$ resolution with $0.2\mu\text{m}$ registration
- ▼ X-ray lithography
 - : $0.5\mu\text{m}$ resolution with $0.2\mu\text{m}$ registration
- ▼ Two method for imprinting the desired pattern on the photoresist
 1. Shadow printing
 2. Projection printing

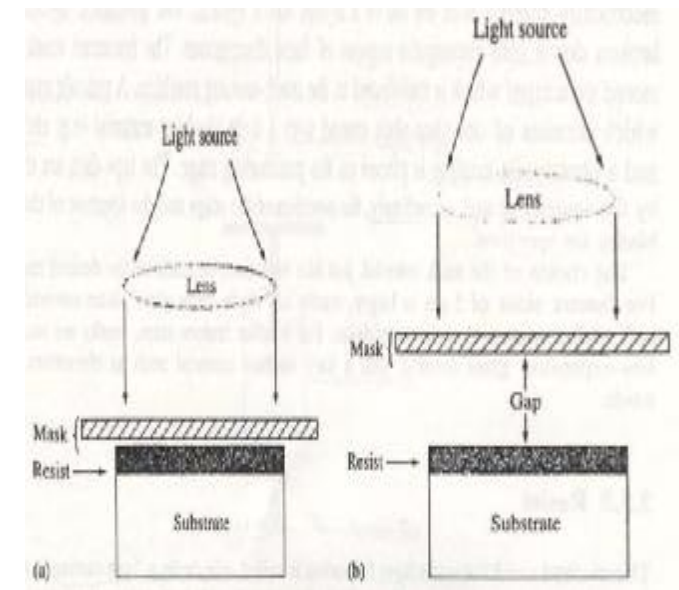


Fig 2.6 Basic lithographic mask arrangement : (a) shadow printing and (b) projection printing (not to scale as chrome layer on glass exaggerated)





2.3.2 Mask Formation



- It consists of the UV light source, a motorised x-y stage sitting on a vibration-isolated table and optical accessories.
- The information that contains the geometric features corresponding to a particular mask is electrically entered with the aid of a layout editor system.
- Geometric layout is then stored on a tape, which is transferred to the mask-making machine.
- A reticule mask plate (one glass plate coated with a light-blocking material (chromium), photoresist) is placed on the positioning stage.
- Tape data are then read by the equipment and, accordingly, the position of the stage and the aperture of the shutter blades are specified.

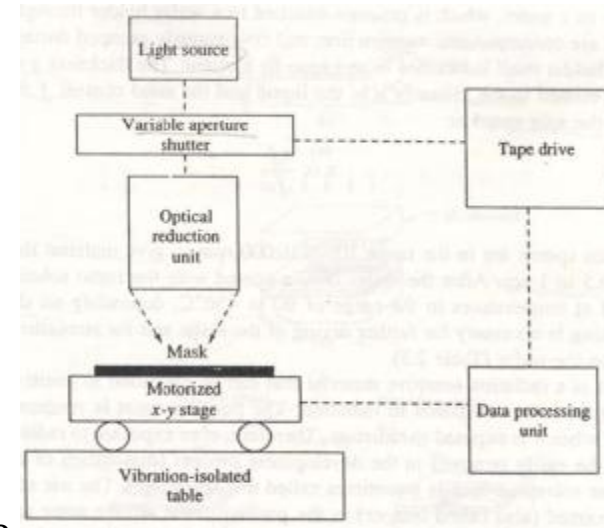


Fig 2.8 Typical arrangement a mask-making machine

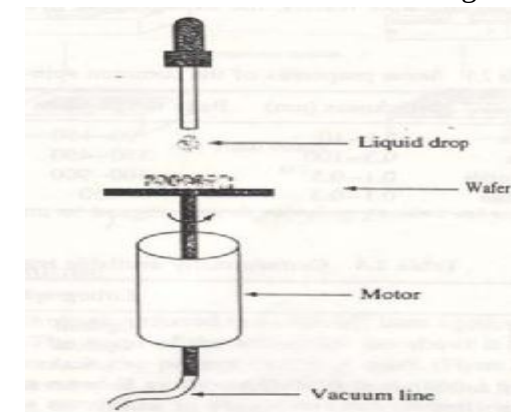


Fig 2.9 Basic setup for the spin coating a photoresist layer onto a wafer



2.3.3 Resist



v Table 2.3 Some properties of the common spin-on materials

material	Thickness	Bake temperature	Solvent
Photoresist	0.1-10 (μm)	90-150 ($^{\circ}\text{C}$)	Weak base
Polyimide	0.3-100	350-450	Weak base
Silicon dioxide	0.1-0.5	500-900	HF
	0.1-0.3	650	HNO_3

v Table 2.4 Commercially available resists

Resist	Lithography	Type
Kodak 747	Optical	Negative
AZ-1350J	Optical	Positive
PR102	Optical	Positive
Poly(methyl methacrylate) (PMMA)	E-beam & X ray	Positive
Poly[(glycidyl methacrylate)-co-ethylacrylate] (COP)	E-beam & X ray	Negative
Dichloropropyl acrylate and glycidyl methacrylate-co-ethyl acrylate (DCOPA)	X ray	Negative

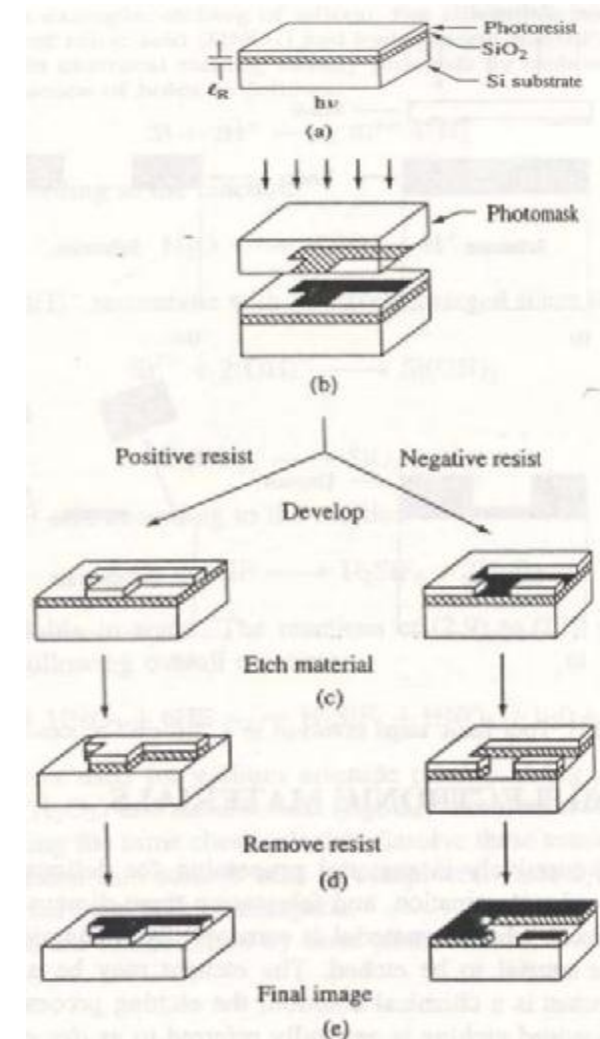


Fig 2.10 Formation of images after development for positive and negative resists (Sze)

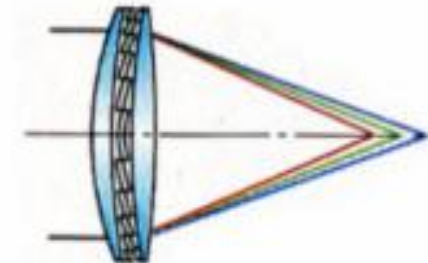


Abstract



- ▼ Replication technology using sol-gel materials offers an interesting alternative to the current approach to optical MEMS fabricated in silicon using lithographic and micromachining technologies
- ▼ The use of UV-curable sol-gel materials enables optical features (micro-lense and diffractive optical elements) to be fabricated in the same process step as the MEMS structures
- ▼ The use of UV-curable sol-gel materials has the potential of low-cost high-resolution production technology.

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introduction



- v MEMS lithographic () etching .
- v Replication technology
 - compact discs(injection moulding), security holograms (hot embossing)
- v
 - 1) Fewer processing steps: continuous-relief and binary microstructures and nanostructures can be replicated in a single processing step
 - 2) Very high resolution, in the nanometer regime for typical material and processes described here.
 - 3) Lower production costs for mass production-many copies are made from a single mould.
- v For MEMS application, the material must be durable, stable, withstand considerable mechanical flexing without undergoing fatigue or permanent deformation. à Sol-gels
- v Sol-gel ultraviolet (UV)/ thermal treatment



Material (1)



v

1. solvent-free liquid with a viscosity suitable for the moulding process (preferably $<10 \text{ Pa} \cdot \text{s}$)
2. Curable by exposure to UV radiation and compatibility with semiconductor mask aligner equipment
3. Uncured material selectively removable using a suitable solvent (lithographic processing)
4. Optical transparency at visible and near infrared wavelengths
5. Hard, glass-like properties of the cured material
6. Good stability and lifetime properties of the cured material





Material (2)



- ▼ ORMOCER (organically modified ceramics)
inorganic-organic hybrid polymer family
- Fraunhofer ISC
- ▼ ORMOCOMP(ORMOCER US-S4) with Lucirin TPO initiator
 - optically transparent (wave length 400~1600nm)
 - Refractive index 1.52 at 588nm

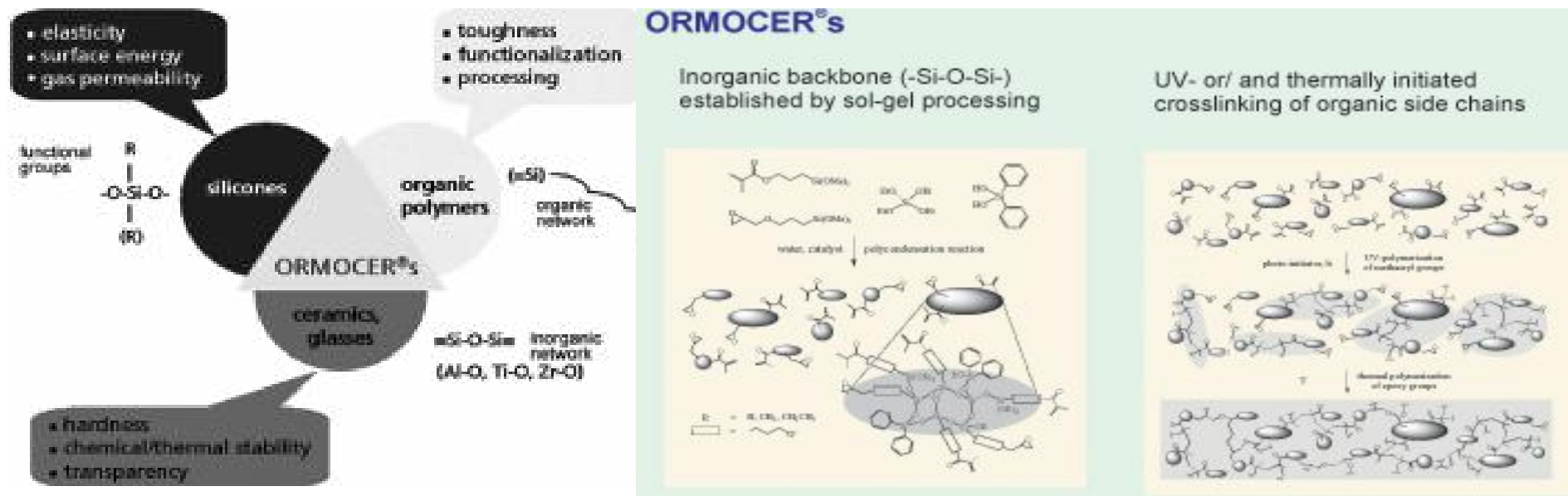


Fig 1. ORMOCER materials used in this paper are chemically tailored inorganic hybrid polymers, for in replicated microoptics (diagram courtesy of ISC, Fraunhofer Gesellschaft Germany)



Processing (1)



v Photolithography

(Photo resist)

PR

pattern mask
mask pattern

pattern

- v Fig 3. example of the replication of a cantilever beam with superimposed micro-lenses (for simple replicated microstructures, the sacrificial layer processing is not required)

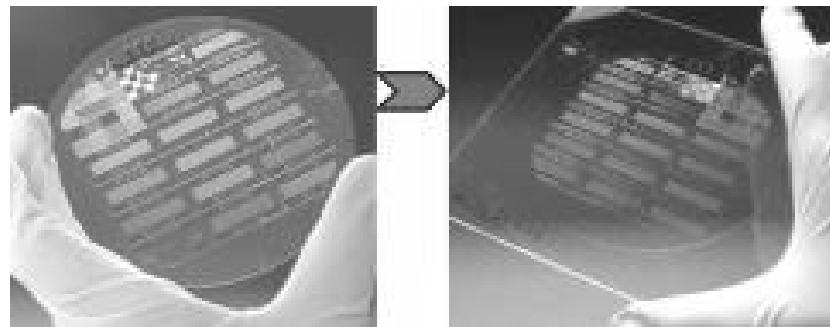


Fig 2. Fabrication of the replication mould. The original microstructure is fabricated in photoresist and then moulded onto a glass substrate which can optionally already contain a chrome masking pattern



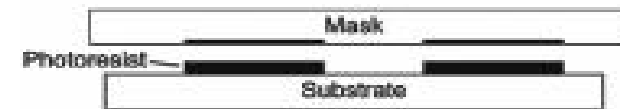


Processing (2)



- v** Following are the basic steps involved
- 1) Lithographic patterning of a sacrificial layer (photoresist) using a conventional chrome mask.
 - 2) Dispensing of the liquid sol-gel between the substrate and the mould, consisting of a chrome substrate with an additional transparent surface relief layer.
 - 3) Pressing the mould into the liquid to a predefined gap and curing by exposure to UV light (i-Line 365nm). The dose for these structures is around 1 J/cm^2
 - 4) Demoulding, removal of the uncured liquid as well as the sacrificial layer by immersion in solvent (Methyl isobutyl

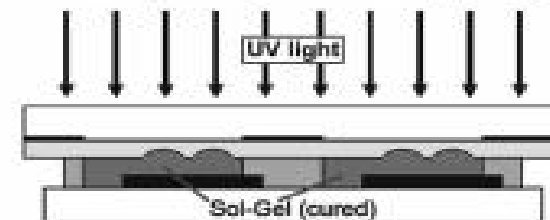
Sacrificial layer photolithography



Dispensing and casting



Molding and photolithography



Development and hardbake



Fig 3. Process steps for the fabrication of replicated
The example shown is for a cantilever with mi



Processing (3)



- ▼ The process is carried out at 4-in wafer scale using a Suss Ma6 Mask Aligner modified to accept a replication mould instead of the chrome mask and the deposition of liquid sol-gel material onto the wafer substrate.



Fig 4. Modified mask aligner for implementing the wafer scale sol-gel on Glass replication process.

- ▼ mask aligner()

- ▼ Fig 4. the machine

- ▼ Fig 5. example of a replicated sol-gel microstructure on glass substrate

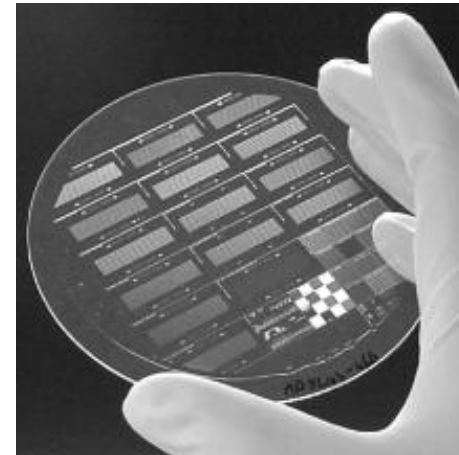


Fig 5. Fabricated sol-gel optical microstructures on a glass wafer substrate



Micro-optics (1)



- Fig 6. replicated micro-lense form a full 4-in wafer fabricated in the modified aligner
- Diameter(120 μ m), sag(relief height:27 μ m), Lenslets up about 100 μ m sag
- Fig 7. mechanical alignment microstructures.

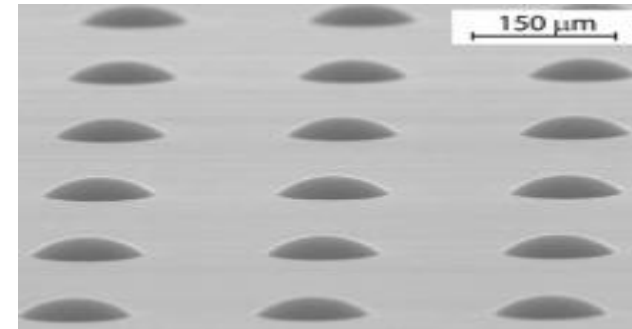


Fig 6. SEM of replicated micro-lenses in sol-gel material.

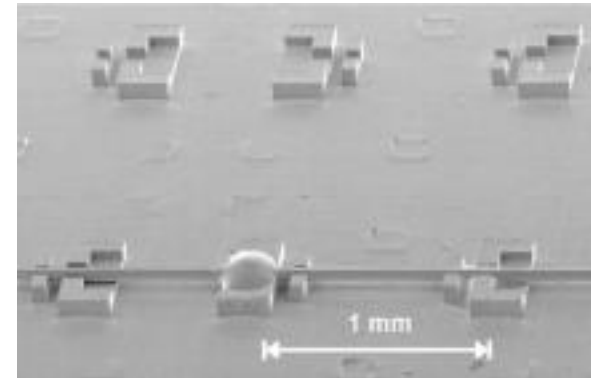


Fig 7. SEM of replicated mechanical alignment microstructures in sol-gel material (collaboration with Leica Geosystems, Heerbrugg, Switzerland)





Micro-optics (2)



- v Fig 8(a) lithographic processing, surface of a III-V wafer with fabricated vertical-cavity surface-emitting laser (VCSEL) devices.
- v Each with a replicated refractive micro-lens for VCSEL to fiber optical coupling
- v VCSEL
-
- LD IRLED
- v ORMOCER material
- wide spectrum of transmittance (400~1600nm)
- Low material loss (<1%) in visible (VIS) and near infrared response (NIR)

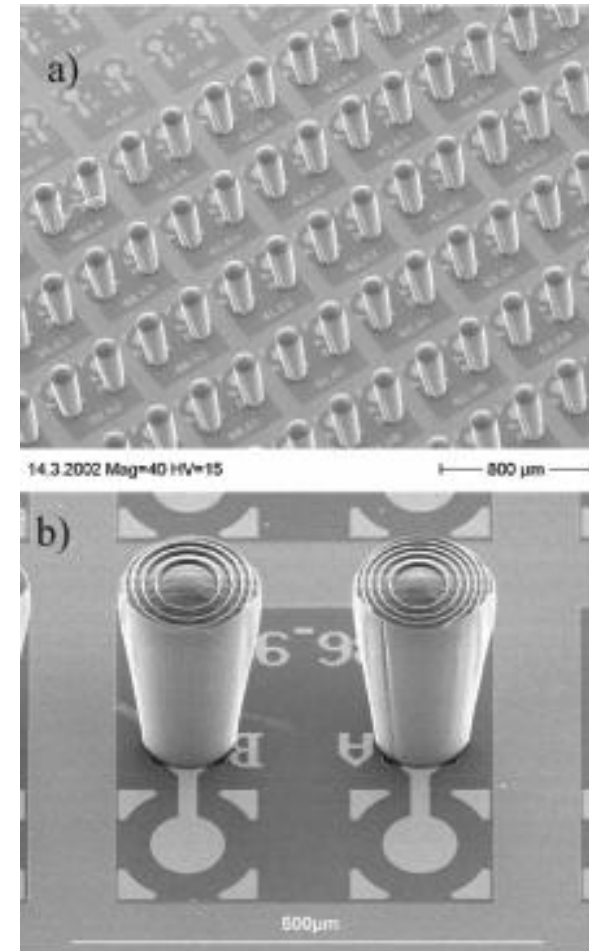


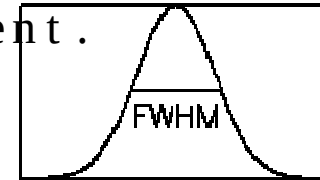
Fig 8. (a) SEM of replicated sol-gel micro-lenses on a VCSEL wafer surface. (b) Diffractive lenslet pair replicated on a VCSEL device.



Micro-optics (3)



- ▼ Wafer-scale fabrication of refractive micro-lenses on multimode VCSEL has been carried out for reducing the divergence of the VCSEL output
- ▼ The full-width half-maximum (FWHM) far-field angle $2\theta = 16^\circ$ and 24° depending on the driving current.



- ▼ Equipped with a replicated spherical lens, the measured FWHM angles were reduced to $2\theta = 8^\circ$ for 8mA and $2\theta = 7^\circ$ at 5-mA driving current.





Optical MEMS (1)



- v After demolding, the unexposed sol-gel material as well as the sacrificial layer are removed in same developer solution.
- v The structures are hard-baked (150°C, 8h)
 - à thermal, mechanical, chemical stability.
- v Shrinkage of about 6% in volume occurs,
 - à
- .
- v Fig 9. fabricated cantilever beams with refractive lenslet.
- v The curvature below the beams toward the socket is given by the photoresist used as sacrificial layer. Structures with relief heights up to 300 μm have been fabricated thus far

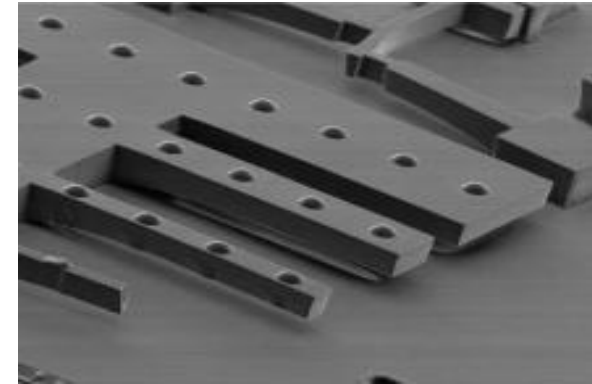


Fig 9. Replicated sol-gel cantilever beams with micro-lense on top. The beam are 1mm in length, 50 μm in height and 500, 200, 100 μm in width. The gap under the beams is 30 μm .



Fig 10. Beam fixed at both ends. The beam is 1mm in length, 100 μm in height, and 50 μm in width.



Optical MEMS (2)



- ✓ The effect of the shrinkage of the ORMOCER material during curing (ca. 6%) has been analyzed using freestanding ring structures with a center beam.
- ✓ The structure convert tensile strain into compressive strain and the buckling of the center beam can be used to estimate the strain
- ✓ Beams (< 20 μm in width) are buckled; beams (> 50 μm) remain stable

$$e_0 = \frac{\pi^2 \cdot b_b^2}{12 \cdot g(R) \cdot R^2}$$

- ✓ For a very slender ring, the tensile strain in the sol-gel film is

- ✓ b_b : width of the center beam
- ✓ R : radius of the ring
- ✓ $g(R)$: conversion efficiency of tensile strain into compressive strain
- ✓ For ideal ring $g(R)=0.918$

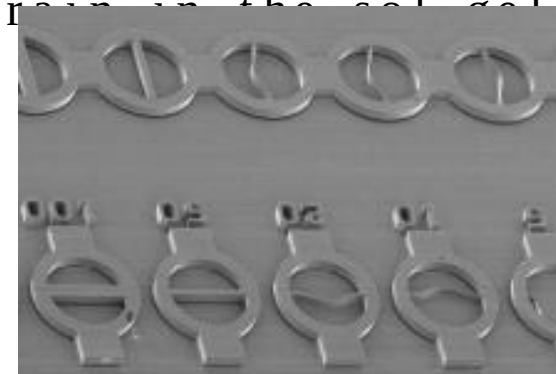


Fig 11. Measurement of strain in free ring structures with center



Conclusion



- ▼ Feasibility of fabricating optical MEMS structures, including cantilevers, micro-lenses and other optical elements, using an ORMOCER sol-gel replication approach.
- ▼ The fabrication is carried out at wafer-scale using a modified commercial mask aligner.
- ▼ The process is highly attractive because of ability to fabricate very precise, high resolution micro-optical elements together with MEMS structures in a single replication step.
- ▼ The integration of electrode structures and realization of MEMS function is underway.

