Glasses for lithography and lithography for glasses

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Goals of IMI-NFG:
• International Collaboration with Research Trust on 6 new Functionalities
• Multimedia Glass Education delivered across the boundaries
• Outreach/Networking

Glass Lecture Series: prepared for and produced by the International Material Institute for New Functionality in Glass
An NSF sponsored program – material herein not for sale
Available at www.lehigh.edu/imi
Questions

• What is lithography? What is glass?

• Can glass be photosensitive?

• Can glass be selectively etched/featured? If yes, how and what is the resolution limit?

• Can a glass be applied in lithographic process and vice versa can lithography be applied to structure glasses?
Lithography – what does it mean?

in ancient Greek: lithos = stones graphia = to write

discovered by Alois Senefelder (Prague, Bohemia currently Czech Republic) in 1796

• oil-based image painted on the smooth surface of limestone

• nitric acid (HNO₃) emulsified with gum arabic burns the image only where surface unpainted and gum arabic sticks to the resulting etched area.

• printing – water adheres to the gum arabic surface and avoids the oily parts, oily ink used for printing is doing exactly opposite, positive image is transferred on paper

http://sweb.cz/galerie.litografie/
“Technical understanding of term lithography these days: formation of 3-D relief images in a film on the substrate with the aim of transferring them subsequently to the substrate

**Microlithography** – pattering method which allows features smaller than 10 μm to be fabricated

**Nanolithography** – pattering on a scale smaller than 100 nm

**Contact and/or proximity lithography** – photomask in direct contact with structurised resist-coated substrate and/or small gap between them

**Maskless lithography** - no mask is required to generate the final pattern – examples:
- **electron beam lithography** – final patterns are created from digital representation, computer controls scan of an electron beam across a resist-coated substrate
- **interference lithography**
What lithography involves?

- an exposure (irradiation) source

- a mask and/or computer controled scan of suitable beam across resist-coated substrate

- a resist itself

- know how of a series of fabrication steps that would accomplish pattern transfer from the mask to resist and subsequently to substrate on which device is fabricated
How resists work?

Resist – radiation sensitive material, where chemical reactivity of exposed parts is modified relative to unexposed parts.

Etchant – agent (solvent, gas) which preferentially etches.

The exposed parts
- Positive etching

The unexposed parts
- Negative etching

Original patterns are thus transferred into the resist after that substrate is patterned in resist-not-covered regions only. All resist removed from corrugated substrate.
positive etching

negative etching

exposure

etching of resist

etching of SiO₂

resist removal

resist

SiO₂

Si

mask
Most important parameters of any resist

Sufficient sensitivity to some radiation and proper technology of selective etching (simpler is better)

Resistent to agents applied for substrate etching

High resolution – nano better

Easy to be deposited – homogenous in properties and thickness
What is glass?

Glass – solid matter which is produced when the viscous molten material cools very rapidly to below its glass transition temperature and there is not sufficient time for atoms to form regular crystal lattice.

_Silica based glasses – most common type of glasses_

- about 70 % by weight of SiO$_2$
- soda-lime glass ($\approx$ 30 % Na$_2$O + CaO)
- borosilicate glass ($\approx$ 10 % B$_2$O$_3$)
- lead crystal (at least 24 % of PbO)

brittle, under compression can withstand a great force, chemically quite resistant, stable

3D compact structure, strong Si-O bonds

obsidian – natural glass

http://www.galleries.com/minerals/mineralo/obsidian/obsidian.htm
chandelier in Capital, Washington

New York – Trump Tower and Times Square
But go back a little bit to science
Chalcogenide glasses - nonoxide glasses

- O replaced by S, Se or Te
- significantly lower T_g than oxide glasses
- transmission in IR
- high refractive index (≈ 1.8 – 3.2)
- !!! sensitive to different radiation!!!
Tailoring the properties

Adopted from A. Feltz: Amorphous Inorganic Materials and Glasses, VCH, 1993, Berlin, Germany

Tailoring the properties

Fig. 5. a Absorption coefficient as a function of the photon energy for the three chalcogenide glassy compositions, \( \text{As}_{40}\text{S}_{40}\text{Se}_{20} \) (this work), \( \text{As}_{40}\text{S}_{60} \) and \( \text{As}_{40}\text{Se}_{60} \). b Determination of the optical gap, \( E_{g}^{\text{opt}} \), in terms of the Tauc law

!!! CHG sensitive to different radiation!!!

What is the reason of sensitivity of CHG?

generally – all amorphous materials - thermodynamically metastable

exposure to suitable radiation can cause transformation in their structure or reaction with the environment (O₂, metal, ....) → optical and physico-chemical properties including chemical resistance are influenced
Classification of radiation induced processes in amorphous chalcogenides

Structural changes:
- changes of local atomic configuration
- polymerization – creating new bonds
- phase changes, including crystallization

Physico-chemical changes:
- decomposition
- photo-vaporization
- photo-dissolution of certain metals
- thermoplastic changes

All these processes can result in changes of optical and physico-chemical properties
exposure with suitable radiation can change optical properties (T, R, n, α ...)

Fig. 1. Spectral dependence of optical transmissivity of Ge$_{30}$Sb$_{10}$S$_{60}$ thin film.

Exposure with suitable radiation can change chemical resistance

What does it mean „suitable radiation“?
band gap light (≈ 1 – 2.3 eV)
UV or even visible light
e - beam
flux of ions
X –ray....

both dry and wet etching can be applied

*Wet etching – all photoinduced processes can be applied*

*Dry etching – usually photo-dissolution of certain metals is applied*
DRY ETCHING
Plasma of ionized gases used to blast away atoms from the surface of the sample. (Also known as plasma etching)

www2.ece.jhu.edu/faculty/andreou/495/2003/LectureNotes/DryEtching.pdf

Certain metals usually added to CHG photoresist – Why?
combine photostructural and compositional changes from photodiffusion of metal (mainly Ag) in ChG is the solution !!!

harsh conditions in plasma requires hard photoresist!
including:
• high contrast of patterning
• resistance to aggressive, ionied gases
• High contrast of resist patterning wanted
  Ag diffuses transversally only, no lateral diffusion

• resistant to plasma etching gas
• resistance increases due to formation ternary
  Ag-As-S glass but in exposed parts only

Ag diffuses into As-S step like
- depth of diffusion - function of exposure dose

Drawbacks – two more steps:
• deposition of Ag
• removal of excess Ag from unexposed
All Dry Process or combined process

- deposition of As-S
- deposition of Ag
- exposure (vertical transfer of Ag into As-S)
- removal of excess Ag from unexposed parts by dry/wet etching
- dry/wet etching of As-S
- dry/wet etching of substrate
- dry/wet removal of Ag-As-S layer from exposed parts
bilayer photoresist Ag + As (and/or Ge) based chalcogenide glass exhibit excellent resolution, high contrast and good resistance to dry etching by CF$_4$ (+ O$_2$)

<table>
<thead>
<tr>
<th>Materials</th>
<th>Etch Gases</th>
<th>Etch Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si, SiO$_2$, Si$_3$N$_4$</td>
<td>CF$_4$, SF$_6$, NF$_3$</td>
<td>SiF$_4$</td>
</tr>
<tr>
<td>Si</td>
<td>C$_2$H$_2$, CCl$_2$F$_2$</td>
<td>SiCl$_2$, SiCl$_4$</td>
</tr>
<tr>
<td>Al</td>
<td>BC$_3$, CCl$_4$, SiCl$_4$, C$_2$H$_2$</td>
<td>AlCl$_3$, Al$_2$Cl$_6$</td>
</tr>
<tr>
<td>Organics</td>
<td>O$_2$, O$_2$ + CF$_4$</td>
<td>CO, CO$_2$, H$_2$O, HF</td>
</tr>
<tr>
<td>Other: (W, Ta, Mo, ..)</td>
<td>CF$_4$</td>
<td>WF$_6$, ..</td>
</tr>
</tbody>
</table>

Sensitization - evaporation of Ag 200 W Hg lamp, 60 mW/cm$^2$ excess Ag removed in HNO$_3$-HCl-H$_2$O 0.5 Torr CF$_4$ gas, 100 W rf power etching rates: undoped 55 nm/sec Ag photodoped 0.15 nm/sec

A. Yoshikawa Appl.Phys.Lett. 36(1) 107

www.ece.jhu.edu/faculty/andreou/495/2003/LectureNotes/DryEtching.pdf
Patterning Options for dry etching

Different sources !!!

UV or visible light

e - beam

X - ray beam

Electron-beam exposure characteristics of Ag-Se$_{65}$Ge$_{15}$ system. Remaining film thickness is normalized in the terms of the initial 280 nm thickness


X-ray lithography utilizing inorganic resist - 0.2 μm line/space pattern

Dry etching

Negative dry etching of Ag-As$_2$S$_3$ bilayer resist by CF$_4$/O$_2$

Dry etching of shaped structures

- Ag diffuses into As-S glass in step like fashion
- depth of diffusion - function of exposure dose

Optical Profiler image demonstrating the possibility of smooth shaping with lens-like mask by photoinduced Ag diffusion into As$_2$S$_3$ film with following dry etching (reverse image, depth of etching 200 nm). CF$_4$ as the etchant gas, with pressure of 100 mTorr, an electrode power of 110 W, CF$_4$ flow rate of 100 sccm and an etching time of 2 min

Profilogram demonstrating the change of etching depth with gradual variation of transparency of mask fragments.

Photodoping Phenomenon for Enhanced Selectivity

- (a) Deposition of chalcogenide layer
- (b) Deposition of silver layer
- (c) Exposure through mask
- (d) Silver diffusion
- (e) Removal of remaining silver
- (f) Removal of chalcogenide regions to create photoresist
Photodiffusion enhanced lithography – when to use it???

hard resists applications

Bilayer photoresist ⇒ more complicated technology

BUT

higher sensitivity and selectivity for both, wet and dry etching

combine photostructural and compositional changes from photodiffusion of metal (mainly Ag) in ChG
Dry etching of pure CHG possible too

Fig. 10. Micrographs of the As$_2$S$_3$ waveguides obtained using different etching conditions: (a) O$_2$/CF$_4$=1/1, $P=600$ W, and $V_s=-120$ V; (b) O$_2$/CF$_4$=7/3, $P=1000$ W, and $V_s=-120$ V; (c) O$_2$/CF$_4$=7/3, $P=600$ W, and $V_b=-50$ V; (d) O$_2$/CF$_4$=7/3, $P=600$ W, and $V_b=-120$ V. The processing pressure was 10 mTorr for all samples.

Table I. Etch rate of As$_2$S$_3$ films floated in different plasma with a power of 600 W.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Gas flow (sccm)</th>
<th>Etch time (min)</th>
<th>Etch rate (nm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>O$_2$=70</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Ar=70</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>CF$_4$=90</td>
<td>2</td>
<td>1500</td>
</tr>
<tr>
<td>4</td>
<td>CF$_4$/Ar=30/70</td>
<td>2</td>
<td>210</td>
</tr>
<tr>
<td>5</td>
<td>CF$_4$/O$_2$=30/70</td>
<td>2</td>
<td>130</td>
</tr>
<tr>
<td>6</td>
<td>CF$_4$/O$_2$=30/70</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>CF$_4$/O$_2$=30/70</td>
<td>2</td>
<td>100</td>
</tr>
</tbody>
</table>

*The sample surface was preoxidized in an O$_2$-plasma.

*The sample was positive biased with dc 60 V.

Diluted CF$_4$ must be applied.

WET ETCHING
amorphous chalcogenides

- insoluble in acid solutions
- relatively well soluble in alkaline solvents

Dissolution rate in alkaline solvents can be influenced by exposure. Both, positive and negative etching can be achieved (even without Ag diffusion).
Parameters influencing selectivity of wet etching

Sample composition, method and conditions of thin films preparation

Prehistory of sample – virgin vs annealed

Exposure conditions (I, λ, T, τ, environment...)

Etching conditions (composition of etching bath, pH, temperature..)
Method and conditions of thin films preparation

all amorphous materials - thermodynamically metastable
thin layers farther from the equilibrium than bulk

• vacuum evaporation
fast condensation of fragments that exist only in vapour state – final structure influenced by $v_{\text{dep}}$, $p$, substrate temperature, rotation of substrate..

• PE - CVD
deposited at low temperature, H$_2$ is incorporated in samples prepared by PE – CVD

• spin coating
deposited at low temperature, residual amount of the dissolver is „captured“ in the structure
Prehistory of the sample
 virgin vs annealed

Ge$_{30}$Sb$_{20}$In$_{10}$, 1, 2 – non-irradiated, 1’, 2’ – irradiated, 2, 2’ – previously annealed at 430 K
Etching bath

Aqueous base

Positive etching

Organic amine base

Negative etching
What is the fundamental cause of sensitivity and changes in chemical resistance?

Different CHG composition and different sources of radiation - different reason, let us discuss only most common case – band gap exposure photosensitivity of as-evaporated As-S thin films.

Vacuum evaporation - fast condensation of fragments that exist only in vapour state.

\[
\text{As}_2\text{S}_3 \quad \text{As}_4\text{S}_4
\]

\[
\text{orpiment} \quad \text{realgar}
\]

\[
\text{cages} \quad \text{chains}
\]

\[
\text{As}_2\text{S}_3 \quad \text{As}_4\text{S}_4
\]

\[
\text{pyramids}
\]

\[
\text{crystal} \quad \text{amorphous}
\]
What is the fundamental cause of sensitivity and changes in chemical resistance?

Vacuum evaporation - fast condensation of fragments that exist only in vapour state

\[
\text{As}_4\text{S}_{58} \rightarrow \text{As}_3 + \text{S-S} \rightarrow 2 \text{As-S}
\]

Photoinduced changes of homopolar bonds concentration

In general:
- Aqueous base solvents - positive etching
- Non-aqueous solvents - negative etching

Fig. 1. Raman spectra of \(\text{As}_4\text{S}_{58}\) thin layers as-evaporated (a) and exposed (b) and of bulk sample (c). Exposure time 30 min, halogen lamp with 20 mW/cm².

M. Vlček, S. Schroeter, J. Čech, T. Wagner, T. Glaser
Mechanism of selective POSITIVE etching in aqueous solvents

Dissolution of \( \text{As}_2\text{S}_3 \) and \( \text{As}_4\text{S}_4 \) crystals:

\[
\text{As}_2\text{S}_3 + 6 \text{OH}^- = \text{AsO}_3^{3-} + \text{AsS}_3^{3-} + 3 \text{H}_2\text{O}
\]
well soluble

\[
3 \text{As}_4\text{S}_4 + 24 \text{OH}^- = 4 \text{AsO}_3^{3-} + 4 \text{AsS}_3^{3-} + 4 \text{As} + 12 \text{H}_2\text{O}
\]
low dissolution rate due to protective As film; insoluble in solutions with low concentration of \( \text{OH}^- \)

**Glassy samples:**
\( \text{As}_4\text{S}_4, \text{As}_4\text{S}_3 \) fragments present together with \( \text{S}_n \) fragments in the structure of virgin samples

Exposure or annealing – chemical homogenisation, etching rate increases due to decrease of activation energy of dissolution
Activation energy of dissolution in aqueous K$_2$CO$_3$ solution

- $1,1'$ - As$_{28}$S$_{72}$
- $2,2'$ - As$_{40}$S$_{60}$
- $3,3'$ - As$_{42}$S$_{58}$
- $4,4'$ - As$_{45}$S$_{55}$
- $X$ - virgin
- $X'$ - exposed by halogen lamp, 14 mW.cm$^{-2}$

$\Delta E \approx 90$ kJ/mol for $x \geq 40$ virgin and exposed
$\Delta E \approx 40-50$ kJ/mol for $x < 40$

As$_x$S$_{100-x}$ films

M. Vlček, M. Frumar, M. Kubový, V. Nevšímalová

aqueous solvents - positive etching of As rich films
Negative selective etching in non-aqueous base

As$_{2}$S$_{3}$, triethylamine, halogen lamp

As$_{50}$Se$_{50}$, ethanolamine, HeNe laser 10 mW, ArF laser (193 nm) 0.5-0.45 mJ single pulses, pulse width 16 ns,
Mechanism of NEGATIVE selective etching in non-aqueous amine based solvents

Kinetically controlled process - the ultimate composition of the products is a function of the rate of elementary stages of a process.

Amines can promote the cleavage of sulfur rings (or chains):

\[ R_3N + S_8 = R_3N^+S_8^- \]

Exposed parts – ammonolysis of heteropolar bonds (slow process):

\[ As_2S_3 + 6 (C_2H_5)_2NH = [(C_2H_5)_2NH_2]_3AsS_3 + As[(C_2H_5)_2N]_3 \]

Unexposed part – breaking of polymeric network through homopolar bonds (faster process):

\[ (C_2H_5)_2NH + S_n = (C_2H_5)_2NH^+S_n^- \]

\[ (C_2H_5)_2NH^+S_n^- + As_{2S_{4/2}} = (C_2H_5)_2NH_2^+S^-AsS_{2/2} + (C_2H_5)_2NAsS_{2/2} \]

cage type

Raman spectra of As$_{35}$S$_{65}$ thin film

**virgin**

**exposed 3 min**

As$_2$S$_3$ - orpiment  
As$_4$S$_4$ cages - realgar

As-As bonds containing species present even in the structure of S rich As-S films due to nanoscale phase separation of cages
Understanding the selective etching mechanism -
first step to achieve extremely high selectivity
Etching bath

Aqueous base
Positive etching

Organic amine base
Negative etching

!!!LOW SELECTIVITY!!!
How to achieve high selectivity of etching?

Proper glass composition, proper conditions of deposition, proper exposure ……………

Modification of composition of etching bath

- addition of redox agent into etching bath

- addition of surface active substance (SAS) into etching bath
Selectivity improvement - addition of reducing agent

As$_2$S$_3$ film, etched in Na$_2$CO$_3$/Na$_3$PO$_4$+ metol, pH = 12.
Concentration of metol (g/l): 1,1’ - 0; 2,2’ - 0,1; 3,3’ – 0,2; 4,4’ - 0,3;
1’ - 4’ exposure with mercury lamp $I = 14$ mW/cm$^2$


\[ \text{As}_2\text{S}_3 + 6 \text{OH}^- = \text{AsO}_3^{3-} + \text{AsS}_3^{3-} + 3 \text{H}_2\text{O} \]

\[ 3 \text{As}_4\text{S}_4 + 24 \text{OH}^- = 4 \text{AsO}_3^{3-} + 4 \text{AsS}_3^{3-} + 4 \text{As} + 12 \text{H}_2\text{O} \]
Selectivity improvement - addition of surface active substances (SAS)

Anion-active SAS – sodium p-dodecylbenzenesulphite
disodium bis-2-ethylhexylsuccinic disulphite

Non-ionic SAS - oxyethyl derivates of monoethanolaminesters

Cation-active SAS - cetyltrimethylammonium bromide
benzenedodecyldimethylammonium bromide
carboxypentadecyl-trimethylammonium chloride
Addition of anion-active and/or non-ionic SAS

no selectivity of etching improvement – only slower rate for both
Addition of cation-active SAS

stopped fully!

N\textsubscript{a}\textsubscript{2}CO\textsubscript{3} + N\textsubscript{a}\textsubscript{2}PO\textsubscript{4} + cation-active SAS
exposure 5 min

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure.png}
\caption{As\textsubscript{40}S\textsubscript{60} 300 nm layer}
\end{figure}

cetyltrimethylammonium bromide


It works!!! But how???
How it works? What is function of cation-active SAS?

Structure of SAS: quaternary ammonium salts with long hydrophobic chain

Preferably sorbed at the surface of unexposed samples, hydrophobic chain repulse OH⁻ ions, etching rate decreases significantly
Conclusion - positive wet lithography

exploit photostructural change in ChG and application of SAS produce extremally high positive selective etching in aqueous alkaline solvents

![Diagram of lithography process]

- deposition of ChG
- exposure
- etching by aqueous alkaline solution
- substrate (Cr, SiO₂, Si₃N₄,...)
- etching
- ChG layer removal
Selectivity improvement – proper composition of CHG and proper exposure source

As$_{33}$S$_{67}$

d$_0$ = 3.7 μm

UV lamp
Exposure in air (sec)
1 – 0
2 – 30
3 – 60
4 – 90
5 – 120

TEA based solvent

postponing in etching proportional to exposure dose
even shaped structures can be etched

Micro-lens Array
made by exposure with Halogen Lamp through Grey Mask

12 μm
Conclusion - negative wet lithography

exploit photostructural change in ChG extremally high negative selective etching in non-aqueous alkaline solvents can be achieved

**Microlithography with gray scale mask**

- deposition of ChG
- exposure
- etching by amine based alkaline solution
- substrate (Cr, SiO₂, Si₃N₄…)
- etching
- ChG layer removal

microlens arrays (12 μm diameter) in a thin As₃₅S₆₅ film, fabricated using a gray Cr mask. The focusing action of light by the lenses is clearly seen.
Wet microlithography example – direct laser writing

Fig. 1. SEM picture of a gold coated binary grating with a period of 1.26 μm and a ridge width of 750 nm etched 550 nm deep into As$_{35}$S$_{65}$
Electron beam wet nanolithography

SEM pictures of pillar arrays in quadratic arrangement etched into As$_{35}$S$_{65}$. (a): diameter 122 nm, depth 410 nm, and period 400 nm (b): diameter 100 nm, depth 410 nm, and period 300 nm (c,d): diameter less than 100 nm, depth 300 nm, and period 350 nm, displayed at different magnifications

!!!Wet macrolithography!!!

Green tower, Pardubice, Czech Republic

in real  in chromium

http://www.pardubice.cz/
What is the resolution limit of CHG etching?
Resolution capability
Resolution limit – 7 nm???

or less????

SEM picture of a nanograting fabricated in As-S film by electron beam exposure followed by development in amine based solvent. Stage tilt of 45° at 15 kV. Grooves width 14 nm.


Figure 2(a) shows various vertical lines that are 27 nm wide and have gap separations of only 7 nm. In Figure 2(b) a tilted SEM image shows the topography of the grating structure. Heights of the individual lines ~80-90 nm tall.

Some examples of micro and nanostructuring of CHG and/or their exploitation to transfer patterns into other materials
Direct laser writing at 442 nm, wet etching
Holographic exposure
Fig. 3. Spectral distribution of the diffraction efficiency $\eta$ for the grating with spatial frequency $1350$ mm$^{-1}$. (1) P-polarization; (2) S-polarization; (3) non-polarized light.

Fig. 4. AFM image of polymer copy of master grating with spatial frequency $1600$ mm$^{-1}$.

A.V. Stronski, M. Vlcek, A. Sklenar, P.E. Shepeljavi, S.A. Kostyukevich, T. Wagner
DLW of 3D photonic crystal structures

Figure 3. Scanning electron microscopy images of As$_2$S$_3$ woodpiles. a) Woodpile with rod distance $a = 2 \ \mu m$ to illustrate the construction principle of the rods. Each rod is made from eight parallel subrods to yield a rod aspect ratio of almost 1.0 (see inset). b) Top view of a woodpile with rod distance $a = 1 \ \mu m$. Note the perfectly straight rods. c) Focused-ion-beam cross section of the woodpile in (b). d) Close up of (b). Note the smoothness of the rod surfaces. e) Top view of a woodpile similar to the one shown in (b) but with a 40 $\mu m \times 40 \ \mu m$ footprint and twelve layers. f) Side view of the woodpile shown in (e). The walls merely serve as a support for the woodpile, which is intentionally raised off the substrate.
Direct microstructuring
(no etching best etching)
Photoinduced local oxidation

\[ 2 \text{As}_2\text{S}_3 + 3 \text{O}_2 \xrightarrow{h\nu} \text{As}_4\text{O}_6 \uparrow + 3 \text{S}_2 \uparrow \]
Photoinduced local corrugation by high energy high intensity beam

Local heating close to $T_g$

Corrugated result

Surface corrugation power threshold

Corrugation Depth

Optical Power
Laser writer DWL 66-UV, 244 nm – doubled Ar laser

Grating in As$_{35}$S$_{65}$ layer with period of 1.28 μm, and grooves of 160 nm bottom width and 640 nm depth, written with beam power of 400 mW at a scanning speed of 30 mm/s
SEM pictures of 2D gratings fabricated by direct DUV laser writing technique and consisting of a trigonal air hole pattern written with a period of 2.2 \( \mu m \) designed to exhibit hexagonal holes of 1.6 \( \mu m \) width across flats in a 700 nm thick layer of As\(_{35}\)S\(_{65}\) written at 0.4 mW (up), 0.5 mW (left) and 0.8 mW (right) imaged at 75°. For 0.5 mW the exposed power intensity and dose are 0.7 MW/cm\(^2\) and 2.6 J/cm\(^2\).

Laser writer DWL 66-UV, 244 nm – doubled Ar laser

Fig. 4. Transmission mode microscope picture of the square lattice of air holes in As$_{35}$S$_{65}$ with a period of 0.8 μm and a hole diameter of 0.48 μm (a) and diffraction pattern at a wavelength of 633 nm at normal incidence (b).
Summary

Glasses, mainly some chalcogenide glasses, can be applied as highly sensitive resists with extraordinary resolution going down to nanometers size

both, positive and negative resists can be achieved

Easy to prepare large array films with controllable thickness, good adhesion to Si, SiO₂, Si₃N₄ ..., and strong resistance to HF, H₂SO₄, H₃PO₄, HCl...and or gases as CF₄

direct structuring using high energy high intensity beam

3D nanostructures can be fabricated in CHG using UVDLW and/or electron beam lithography down to 100 nm and 10 nm, respectively
Do you know now the answers?

• What is lithography? What is glass?

• Can glass be photosensitive?

• Can glass be selectively etched/featured? If yes, how and what is the resolution limit?

• Can a glass be applied in lithographic process and vice versa can lithography be applied to structure glasses?
And still something pleasant before I say you GOODBYE
Prof. Himanshu Jain – winner of Otto Schott Research Award – 2007
Director of IMI

- outstanding work towards advancing fundamental understanding of the movements of atoms inside glass
- research into unique light-induced phenomena in glass
- studies of the corrosion of glass in nuclear environments
- studies in the field of sensors, infrared optics, waveguides, photolithography, nanolithography and other photonic applications of glass
Thank you for your attention

Your feedback highly appreciated at:

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or

MiroslavVlcek@yahoo.com
GOODBYE!!!