

# **POLARIZATION HOLOGRAMS AND DIFFRACTION ANISOTROPY IN AMORPHOUS CHALCOGENIDES\***

**Andris Ozols<sup>1,2</sup> and Mara Reinfeldē<sup>2</sup>**

**<sup>1</sup>Institute of Technical Physics, Riga Technical University, LV-1048, Riga, Latvia**

**<sup>2</sup>Institute of Solid State Physics, University of Latvia, LV-1063, Riga, Latvia**



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# OUTLINE

- **Optics in Latvia – a short overview**
- **Introduction to the main topic**
- **Photoinduced anisotropy (PA)**
- **Polarization (vector) hologram recording basing on PA**
- **Experiments and their results in a-As-S-Se films**
- **Discussion**
- **Conclusions**

# OPTICS IN LATVIA

## FIRST STEPS

- **Theodor Grotthus** (1785–1822) – the first law of photochemistry in 1818 (Geduchi near Bauska)
- **August Toepler** (1836 –1912) –*schlieren* method in 1864, Riga Polytechnic School
- **Walter Zapp** (1905) and the State Factory *VEF* in Riga – the world's smallest camera *Minox* (1936-1942)
- **Ludvigs Jansons** (1909-2002) the founder of the Latvian school of optics after the Second World War (optical spectroscopy of color centers)

# CONTEMPORARY BRANCHES OF OPTICS IN LATVIA

- **OPTICAL SPECTROSCOPY OF SOLIDS** was developed in 1960ies by I.Vītols (1931-2000) and K.Schwartz (1930) (AHC with color centers). Now also ferroelectric crystals and ceramics (A.Sternberg, A.Krumins, D.Millers, L.Grigorjeva), nitrides, oxides, wolframates (I.Tale, D.Millers, B.Berzina), organic crystals (I.Muzikante), glasses (L.Skuja, A.Trukhin, A.Silins). Mainly in the Institute of Solid State Physics (ISSP), University of Latvia (<http://www.cfi.lu.lv>).
- **OPTICAL SPECTROSCOPY OF ATOMS AND MOLECULES** was started by E.Kraulina (1920-2002) in 1960ies. Now in the Institute of Atomic Physics and Spectroscopy (IAPS), University of Latvia (<http://www.lanet.lv/asi/~home>) led by M.Auzinsh.

Current research directions: laser spectroscopy of atoms and molecules focusing on angular momentum polarization, external field effects, collisions, intramolecular interactions . Book:

M.Auzinsh, R.Ferber. Optical Polarization of Molecules. Cambridge University Press, Cambridge, UK, 1995, 305 p.

Important recent result concerning LIGHT POLARIZATION:the fluorescence polarization of atoms and molecules can change from linear to circular in external **E** and **H** fields due to the angular momentum alignment orientation conversion (M.Auzinsh, J.Alnis, R.Ferber et al).

- **OPTICAL HOLOGRAPHY** was started by K.Schwartz (1930) and A.Ozols in 1972. Mainly used as the

- investigation method of photoinduced processes in:

-ISSP (alkali halide and electrooptic crystals, amorphous semiconductor films, PLZT ceramics, fullerenes, azobenzene oligomers – J.Teteris, A.Ozols, A.Krumins, M.Reinfelds)

- RTU (amorphous semiconductor films, azobenzene oligomers – A.Ozols)

- Daugavpils University (<http://www.dau.post.lv>) (amorphous semiconductor films- V.Pashkevich (Finland – 1987!), V.Gerbreder).

One of the most important results- the **hologram self-enhancement effect** was found in 1973 (KBr-F crystals, A.Ozols): under certain conditions diffraction efficiency increases during the readout or even in the dark. Takes place in many other materials (LiNbO<sub>3</sub>:Fe, ACh, ABO, etc.). Can be used itself for studies of photoinduced and thermoinduced processes and also for the production of embossed holograms (J.Teteris).

## □ Image holography

- ISSP (rainbow and reflection holograms, embossed holograms – J.Teteris, M.Reinfelde, J.Harja)

-Daugavpils University (embossed holograms – V.Gerbreder) .

Main results until 1993 are described in the book:

K.Schwartz. *The Physics of Holographic Recording*. Springer Verlag, Berlin, 1993, 191 p.

**NONLINEAR OPTICS** was started by G.Liberts in 1980ies at ISSP. G.Liberts and V.Zauls have studied SHG in various materials, have developed SHG methods for NL susceptibility and temperature measurements. Another direction – thermooptics. Important recent result: the first experimental observation of the giant thermo-optical mirror effect from the free surface of ferrofluid when irradiated by a He-Ne laser beam.

**ELECTROOPTICS** was pioneered by M.Ozolins and A.Sternberg in 1980ies again at ISSP using transparent ferroceramics (PLZT, PSN, etc.). M.Ozolins has made efficient PLZT ceramics modulators for YAG:Nd<sup>3+</sup> and YAG:Er<sup>3+</sup> infrared lasers.

**MEDICAL OPTICS** was started by I.Vītols (1931 – 2000) in 1990 at ISSP. M.Ozolins, I.Lacis, G.Papelba have developed different methods for eye characterization. J.Spigulis in IAPS has developed photoplethysmography ( non-invasive optical method for studies of blood volume pulsations)

**OPTICAL TECHNOLOGIES** were pioneered by J.Spigulis and D. Pfafrods in 1980ies (medical fibers for the laser beam transport, glowing fibers for entertainment,etc.)

# Optical production *Made in Latvia*

- ANDA OPTEC, Ltd. (<http://www.andaoptec.lv>) – silica-core optical fibres, bundles, laser delivery systems
- HOLOGRAMA, Ltd.; DARDEDZE HOLOGRAFIJA, Ltd.; DIFRAKS, Ltd. – Holography products
- ISP LATVIA, Ltd. (<http://www.ispoptics.com>) – optical crystals, optical components – prisms, lenses, mirrors
- OPTRON, Ltd. ([http://www.optron.lv/Frames\\_Index.htm](http://www.optron.lv/Frames_Index.htm)) – optical communication systems

# ***ANDA OPTEC: UV FIBRE BUNDLES***



# ***“LASERSNAKE” in Opera***



# ***Commercial holography in Latvia***

1. Laboratory of Optical Recording at the Institute of Solid State Physics

*RTD*

2. Hologramma Ltd.

*design, holographic recording, Ni shim growing*

3. Dardedze holography Ltd.

*mass replication of holographic stickers*

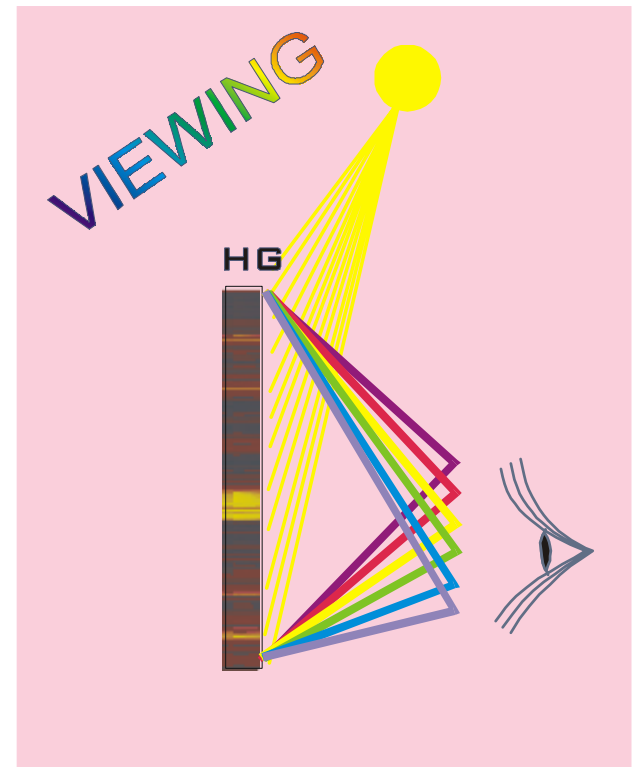
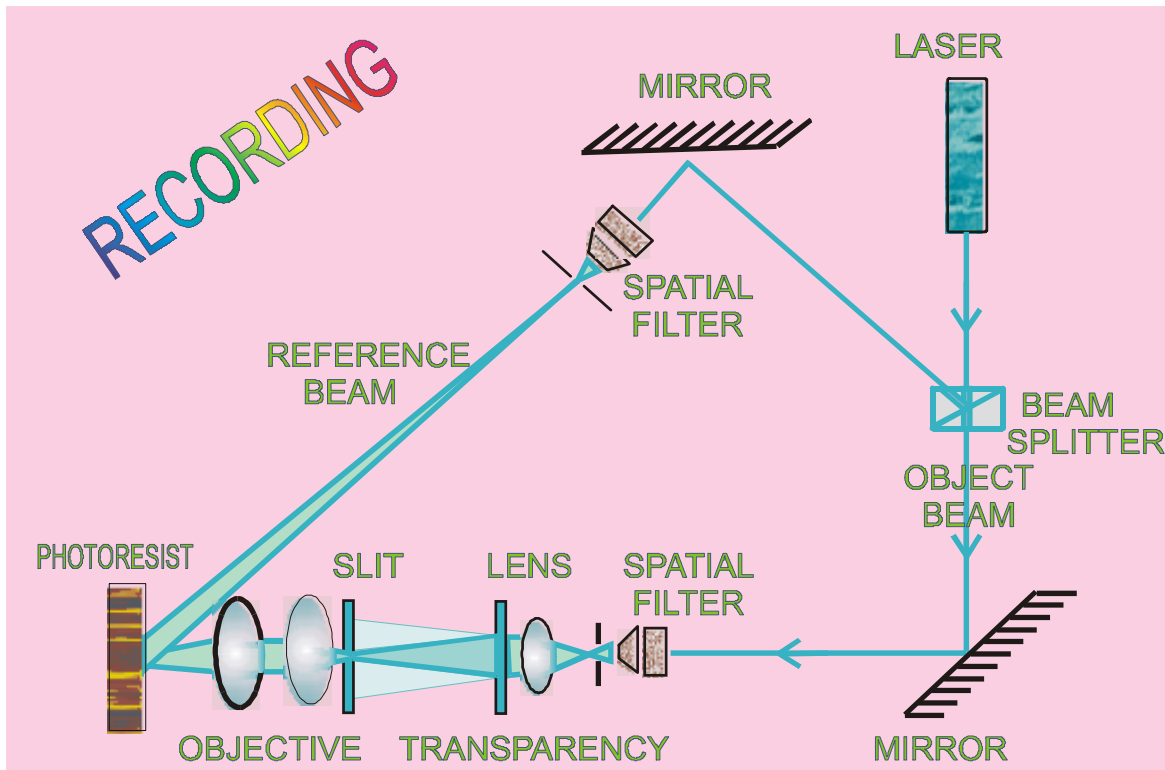
4. Difraks Ltd.

*mass replication of holographic stickers*

< about **2 000 000** stickers monthly >

## 2D/3D

# RAINBOW HOLOGRAMS



# ***SUMMARY: Optics in Latvia***

- Education and research on optics:
  - 3 universities, 5 institutes
- Industry:
  - ~ 10 SME's dealing with optical products
- 2 optical societies: SPIE/Baltics and ICO LC
- Total number of involved persons (scientists, teachers, students, SME employees):
  - ~ 200

# INTRODUCTION TO THE MAIN TOPIC

**MOTIVATION:** to study the properties of polarization holograms in ACh. Before only 2 papers with only DE and recording energies:

- C.H.Kwak, J.T.Kim, S.S.Lee. Opt. Lett, 1988, **13**, 437-439. (a-As<sub>2</sub>S<sub>3</sub> films)
- M.Mitkova, T.Petrova, P.Markovski, V.Mateev. J.Non-Cryst.Sol., 1993, **164-166**, 1203-1206. (a-Se<sub>70</sub>Ag<sub>15</sub>I<sub>15</sub> films)

**WHY ACh?** Numerous applications, outstanding optical properties, e.g.,  $\Delta n_{\max} = 0.73$  in As<sub>60</sub>Se<sub>40</sub> at 632.8 nm (J.Teteris, ISSP UL) due to PSC, **polarization sensitivity**.

Experience in production and scalar recording.

# PHOTOINDUCED ANISOTROPY (PA)

PA is the effect of elliptical birefringence and dichroism induced by a polarized light (when spatial dispersion neglected):

$$\varepsilon(\omega, \mathbf{k}) \rightarrow \varepsilon_{mn}(\omega, \mathbf{k}) = \varepsilon_{mn}(\omega) + i\gamma_{mnl}(\omega)k_l + \alpha_{mnlp}(\omega)k_l k_p \quad (1)$$

$$p_{ik} \sim |(\mathbf{d}_{ik} \cdot \mathbf{E}_{\text{light}})|^2 \quad (2)$$

1919 – linear PA discovered by F.Weigert in AgHal films.

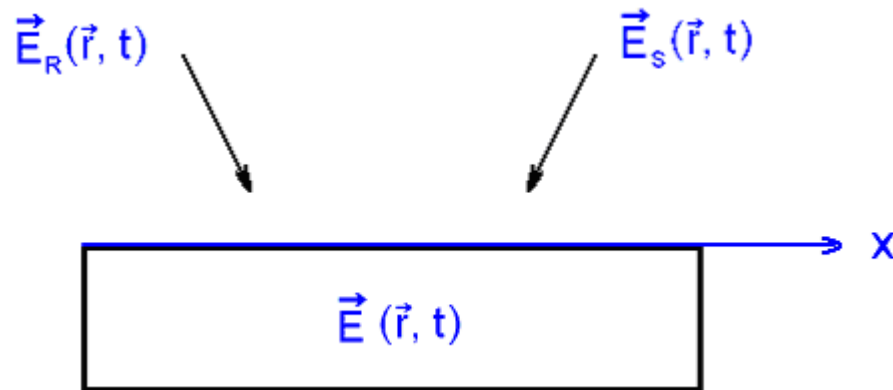
1928 – circular PA (photogyrotropy) discovered by H.Zocher and H.Coper. Helical structures appear.

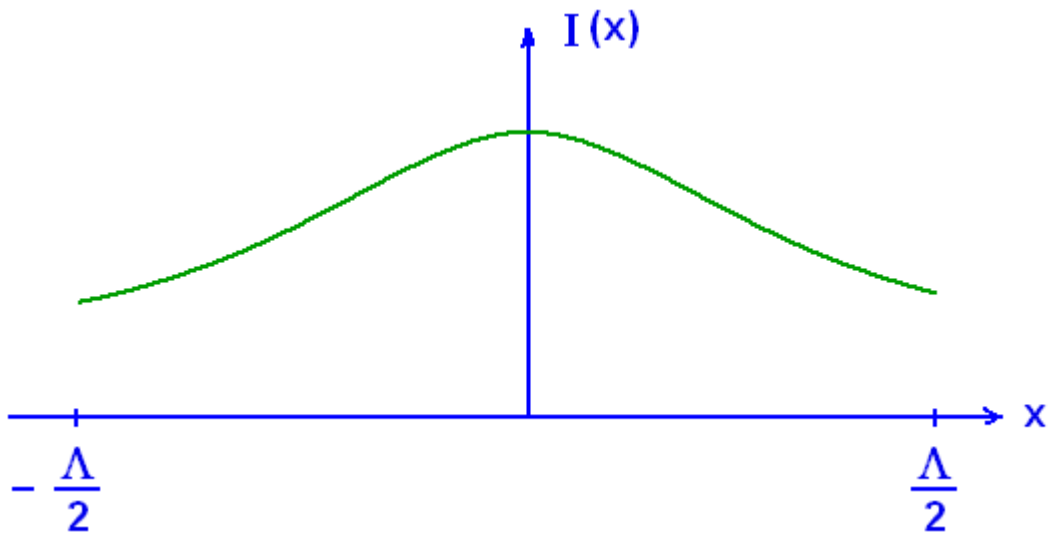
1977 – V.B.Zhdanov and V.K.Malinovsky: linear PA ( $\Delta n = 3 \cdot 10^{-3}$ ) in a-As<sub>2</sub>S<sub>3</sub> films by 514.5 nm light.

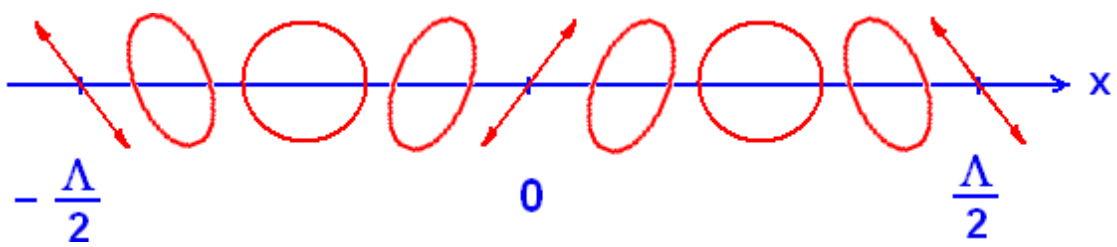
1990 – V.M.Lyubin and V.K.Tikhomirov: photogyrotropy in g-As<sub>2</sub>S<sub>3</sub> by 632.8 nm light. !!! Besides, **PA** ≠ **PSC**

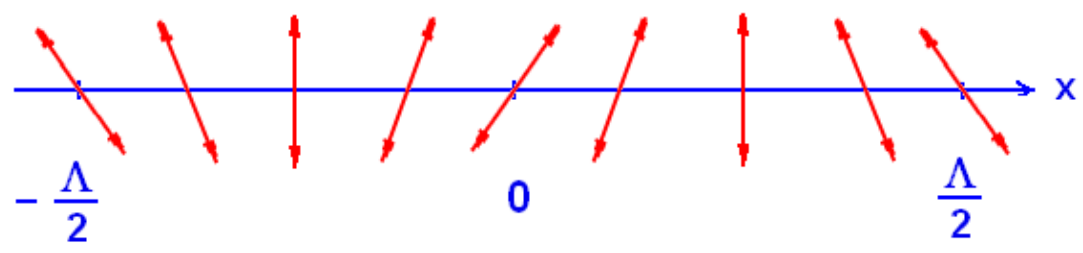
# POLARIZATION HOLOGRAM RECORDING BASING ON PA

**Polarization (vector) holograms** are holograms recorded by two arbitrary polarized waves containing **orthogonal** components.









Mixed field  $\mathbf{E}(\mathbf{r},t)$  creates PH:  $\Delta\epsilon_{mn}(\omega, \mathbf{k}, \mathbf{r}, \mathbf{E}_R, \mathbf{E}_S, t)$

$\Delta\epsilon_{mm}$  - scalar response from the intensity modulation

$\Delta\epsilon_{mn}, m \neq n$  - vector response from the polarization modulation

1975 – Sh.D.Kakitschashvili has recorded the first PH in g-AgCl

In 1978 – 2D PHG theory, in 1989 – 3D PHG theory (kinematic).

1999 – B.I.Sturman,...**E.Nippolainen, V.Prokofiev, A.A.Kamshilin:**

Theory of PhR vectorial wave coupling in cubic crystals .

Yet, there is **NO** CWT of PHG like Kogelnik's one for scalar HG

Kakitschashvili's theory: PA based PH generally does **not** fully reconstruct the signal wave polarization. To do this one should **match**,  $\mathbf{E}_R, \mathbf{E}_S$  and the photoanisotropic response  $\Delta\epsilon_{mn}$ .

Exception – lin. polarized  $\mathbf{E}_R$  when photogyrotropy is small.

# EXPERIMENTS AND THEIR RESULTS

Detailed studies of a-  $\text{As}_{40}\text{S}_{15}\text{Se}_{45}$  films ( $\text{As}_{40}\text{S}_{60}/3\text{As}_{40}\text{Se}_{60}$ )

$d = 4.2 \mu\text{m}$ , 2 years old, nonannealed, K8 glass substrate,  $7 \times 7 \text{ cm}^2$

$\lambda_1 = \lambda_2 = 632.8 \text{ nm}$ ,  $\Lambda = 0.7 - 10 \mu\text{m}$ ,  $I = 0.07 - 0.41 \text{ W/cm}^2$

Linear polarizations,  $\mathbf{E}_R \parallel \mathbf{E}_S$  and  $\mathbf{E}_R \perp \mathbf{E}_S$  cases compared

Verification of  $\mathbf{E}_R \perp \mathbf{E}_S$  :

- Absence of the magnified interference pattern
- Ellipticity=0 within  $\delta=5\%$  by measuring the Stokes parameters with Dubra-Ferrari method.

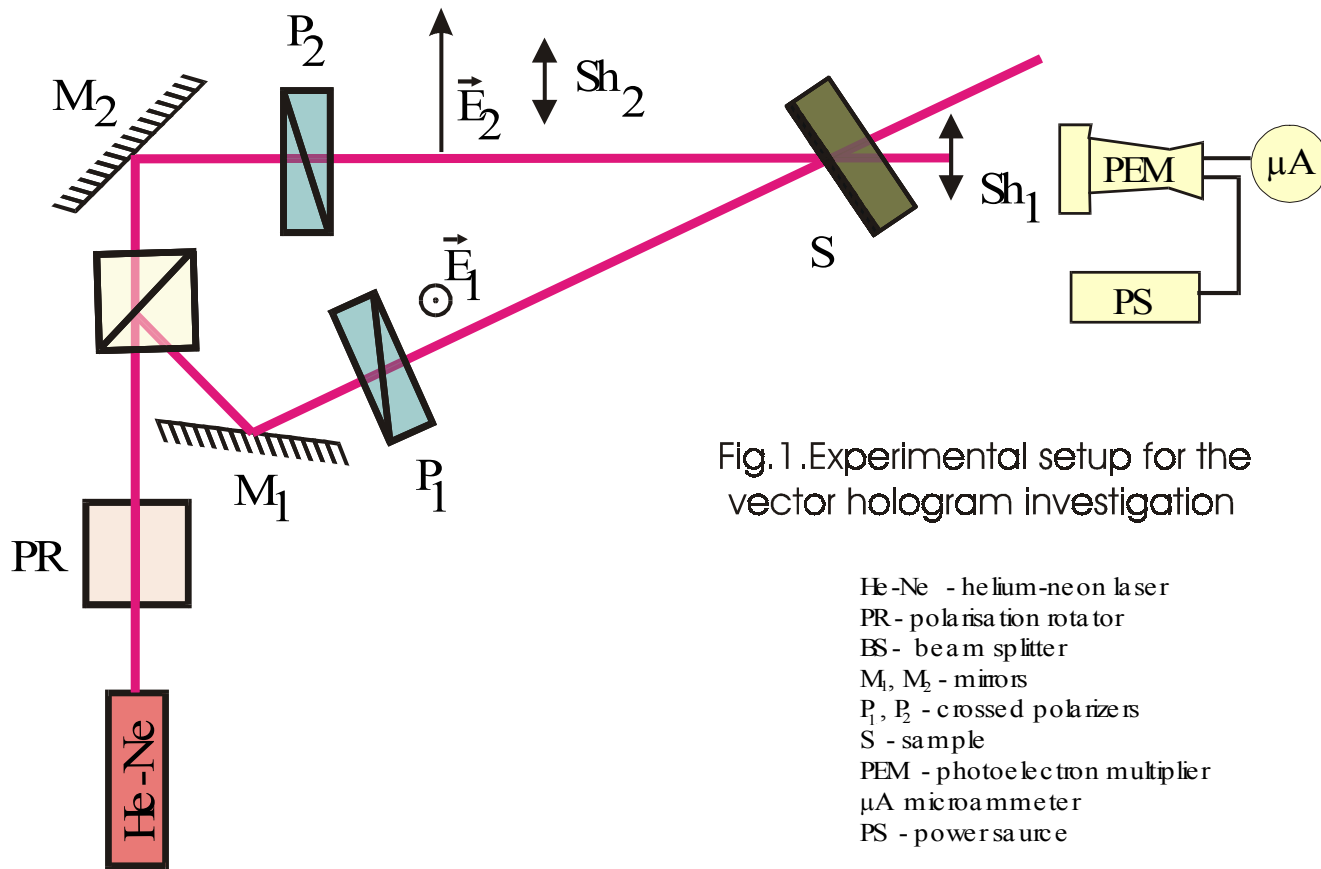


Fig. 1. Experimental setup for the vector hologram investigation

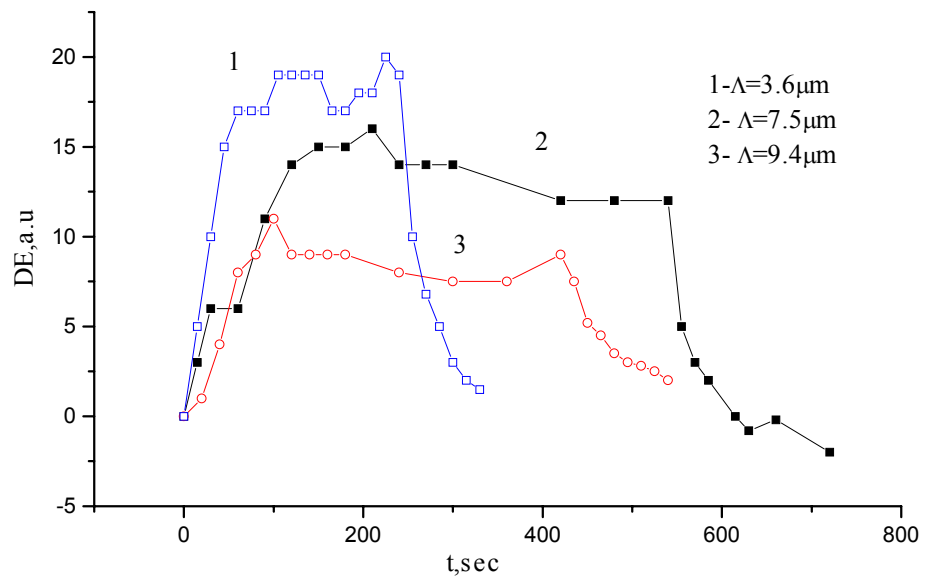


Fig.2. Diffraction efficiency exposure time dependence for different grating periods  $\Lambda$ .  
 Recording light intensity  $I = 0.17 \text{ W/cm}^2$ ,  $\lambda_1 = \lambda_2 = 632.8 \text{ nm}$ .  
 Readout with horizontal polarization.

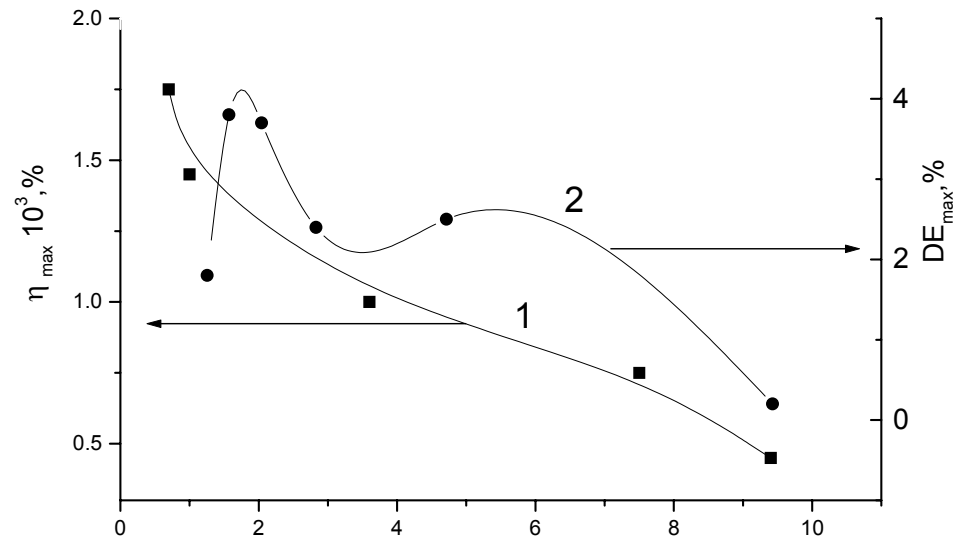


Fig.3. The grating period dependence of the maximal diffraction efficiency at  $I=0.17W/cm^2$ ; 1 - vector recording, 2 - scalar recording. Readout with horizontal polarization in both cases.

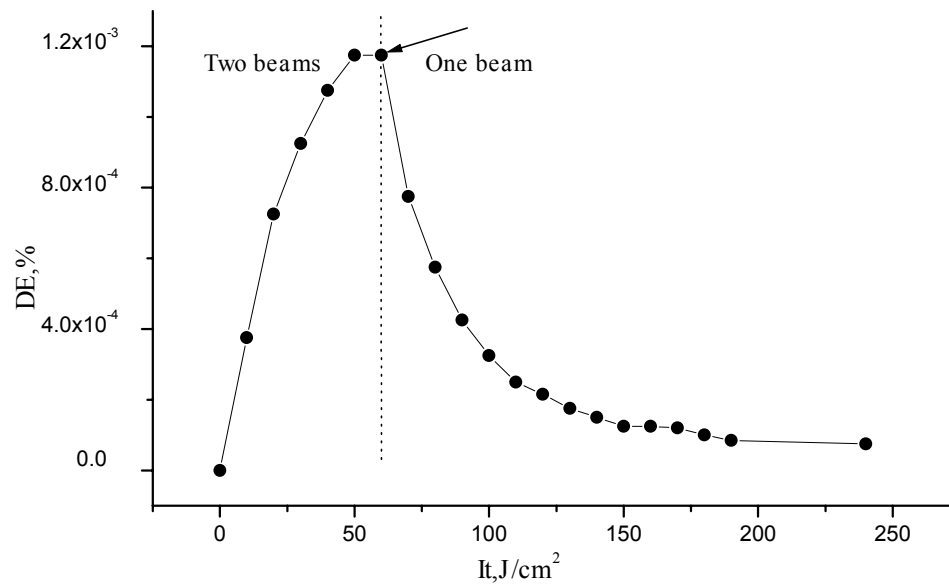


Fig.4. Diffraction efficiency exposure dependence during recording with two beams and during readout with vertically polarized beam;  
 $\Lambda=1.0\mu\text{m}$ ,  $I=0.17\text{ W/cm}^2$ .

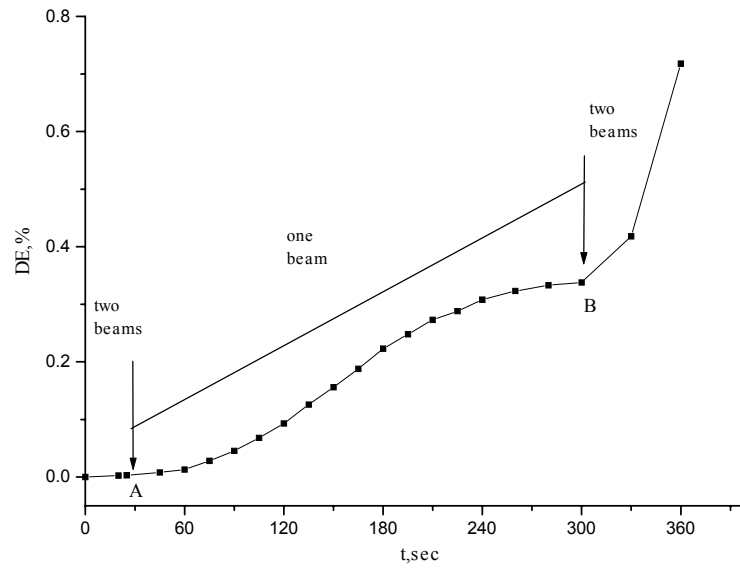


Fig.5. Diffraction efficiency time dependence during recording with two beams and during readout with one beam for scalar holographic grating.  
 $\Lambda=1.0\mu\text{m}$ ,  $I=0.069\text{ W/cm}^2$ . Vertical polarization for both beams.

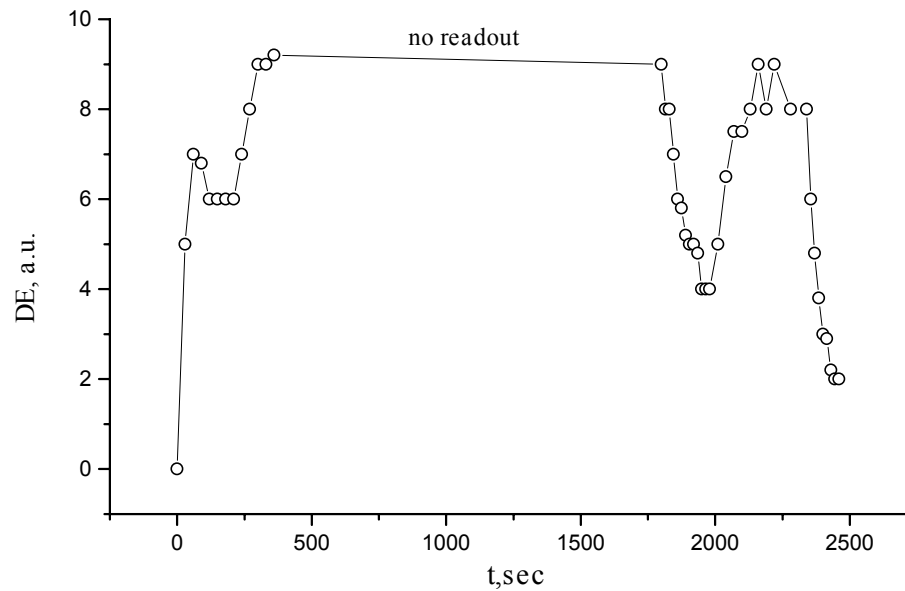


Fig.6. The stability of the diffraction efficiency saturation value and the influence of readout.  $\lambda=3.6\mu\text{m}$ ,  $I=0.17\text{ W/cm}^2$   
Readout with horizontal polarization.

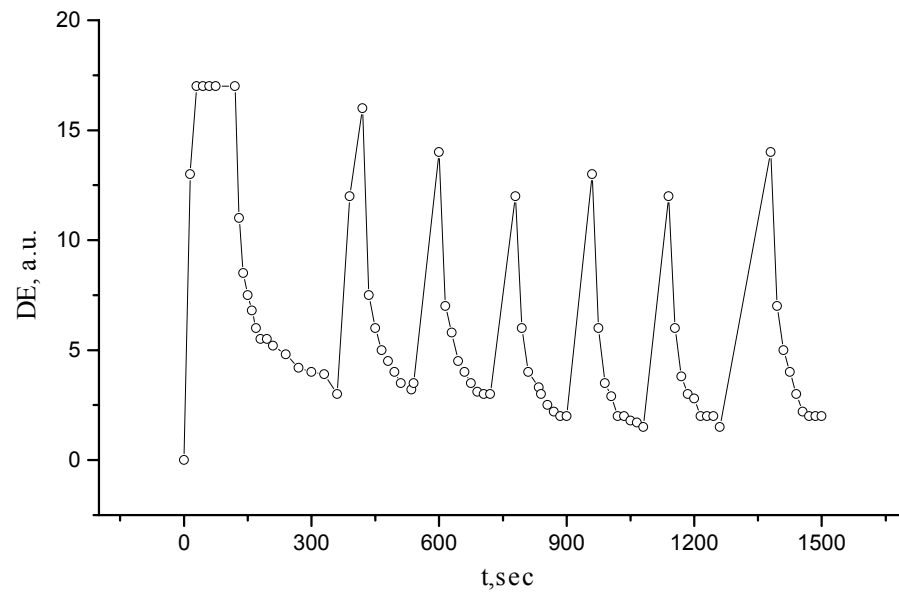


Fig.7. Diffraction efficiency time dependence during the seven repeating recording-readout cycles demonstrating a good reversibility of the vector recording;  $\Lambda = 1.0 \mu\text{m}$ ,  $I = 0.32 \text{ W/cm}^2$ . Readout with horizontal polarization.



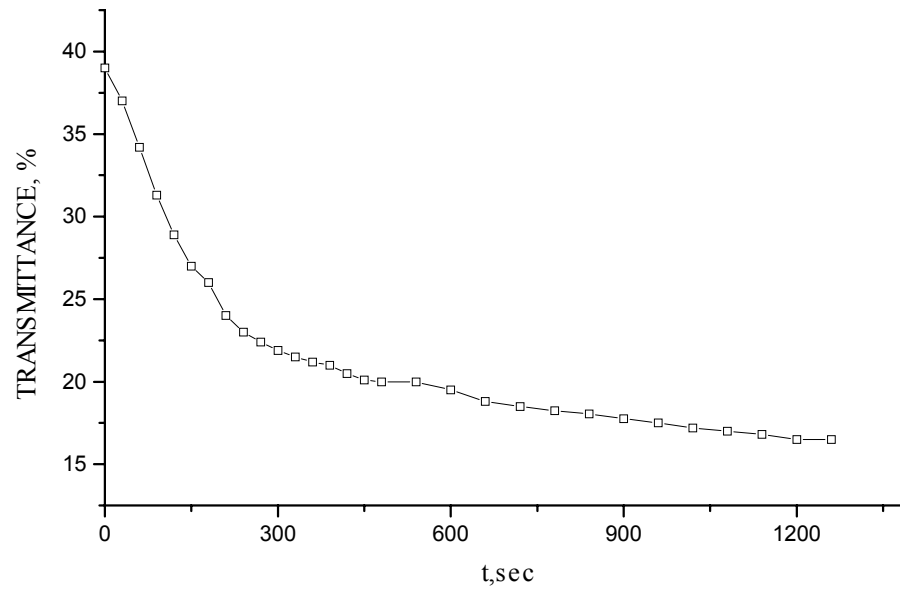
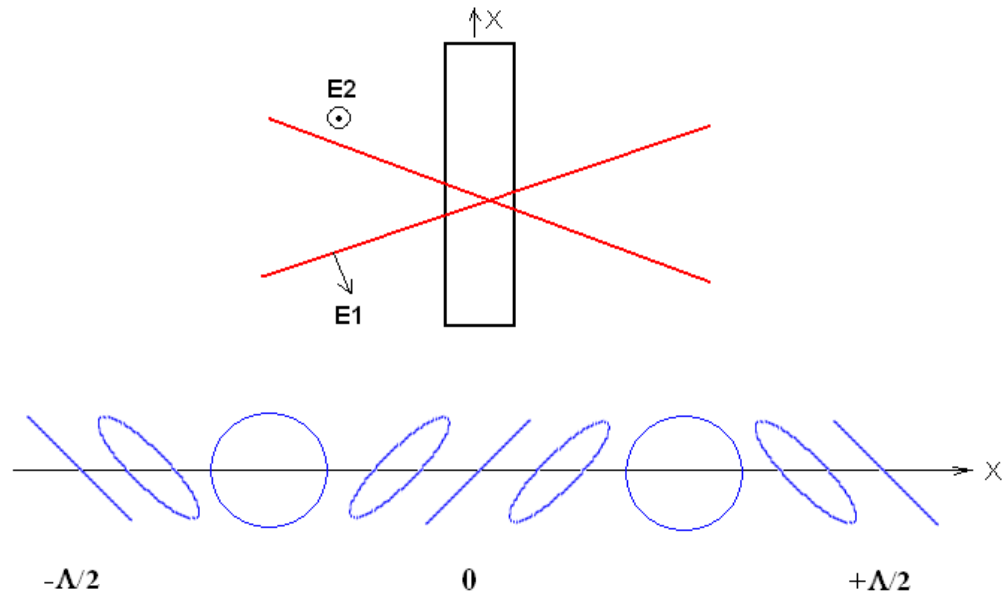


Fig.9. Transmittance of an As-S-Se film versus exposure time  
 $I = 0.13 \text{ W/cm}^2$ ,  $\lambda = 632.8 \text{ nm}$ .

## RECORDING



## READOUT

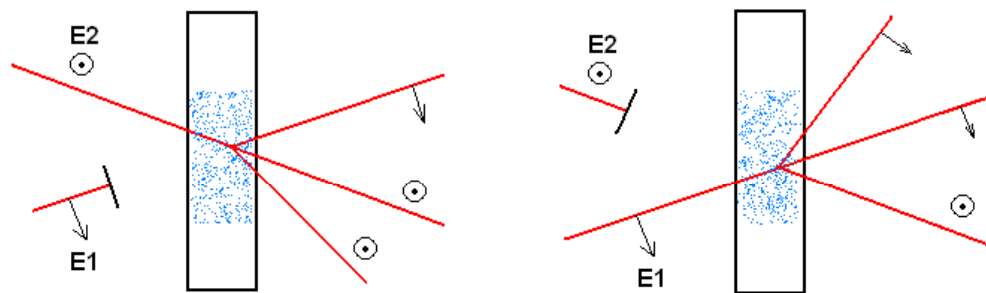


Fig. 10. Recording of the vector hologram and its anisotropic readout.

# DISCUSSION

PA  $\neq$  PSC

Mechanism? Most probably – D-center reorientation by light  
(V.K.Tikhomirov, S.R.Elliott, 1995). Why?

1) No correlation with PSC

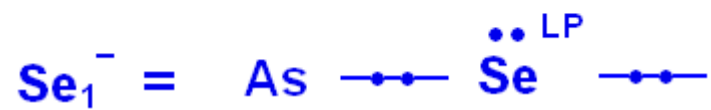
2) They can be easily reoriented by light

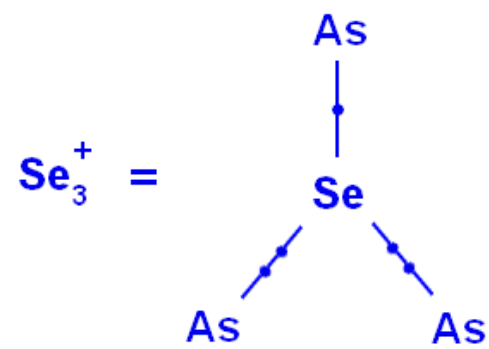
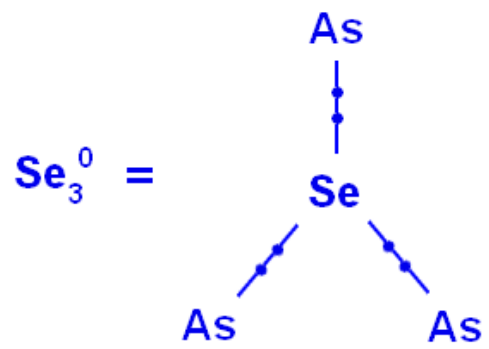
3) Relaxation time of 2 days  $\rightarrow$  activation energy of D-centers  $\approx 1$  eV

D-centers (VAP's) are anomalously coordinated chalcogen atoms:



( $D^+ + D^-$ )- dipoles are reoriented by light





Why the polarization recording in a-As-S-Se films is much less efficient than the scalar one?

Because  $N_D \approx 10^{17} \text{ cm}^{-3} \ll N_{\text{PSC}} \approx 10^{20} - 10^{21} \text{ cm}^{-3}$

Can it be improved?

**YES!**

- Take two circularly polarized waves instead of two linearly polarized ones.
- Take  $\lambda_1 < 632.8 \text{ nm}$  and  $\lambda_2 > 632.8 \text{ nm}$ .
- Optimize I, d, and chemical composition.

# CONCLUSIONS

- Polarized 632.8 nm light produces PA in a-As-S-Se films
- Properties of PH are established which are completely different from those of scalar ones in the same films
- Polarization holographic recording is a sensitive method for the testing of material properties

Thank you very much for your patience and attention!