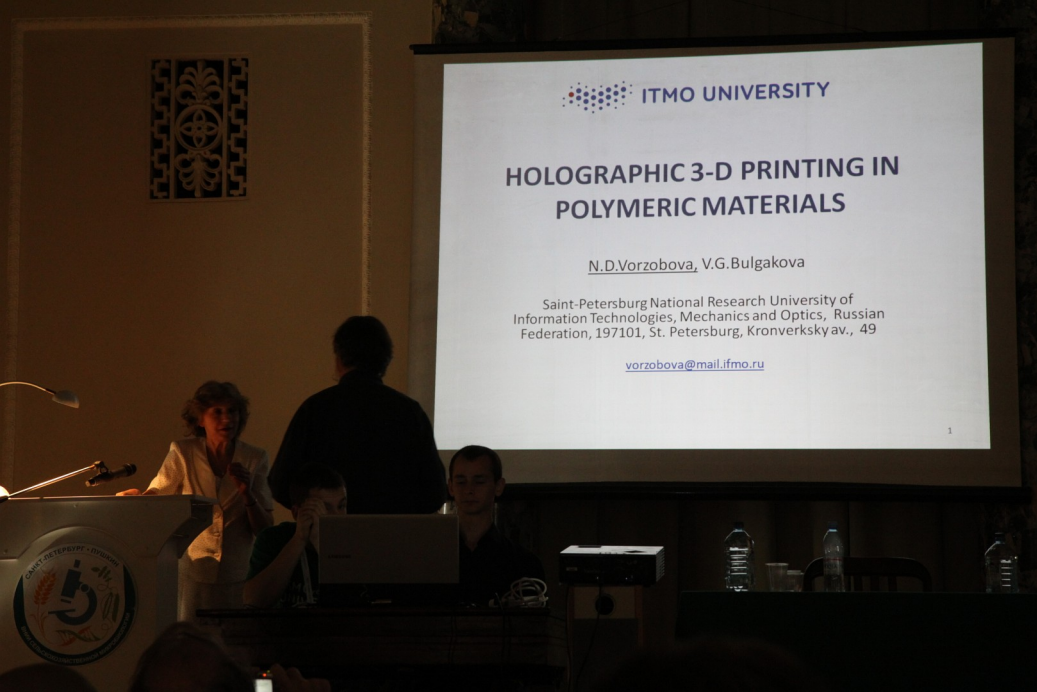
ITMO UNIVERSITY
HOLOGRAPHIC 3-D PRINTING IN POLYMERIC MATERIALS
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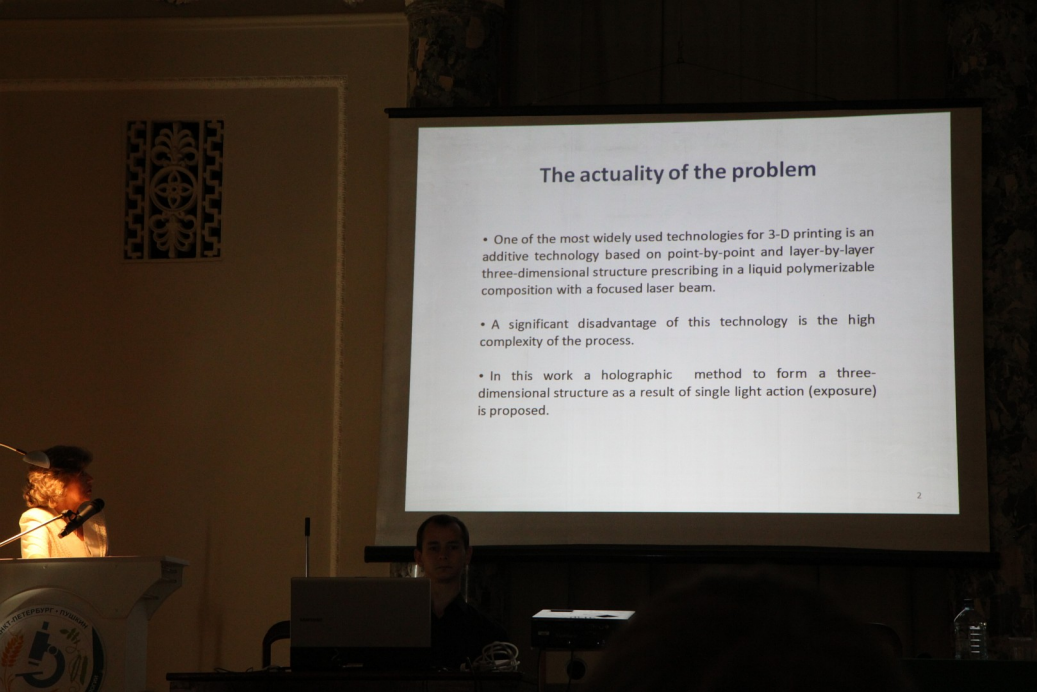
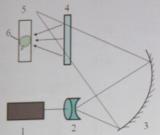

The actuality of the problem
• One of the most widely used technologies for 3-D printing is an additive technology based on point-by-point and layer-by-layer three-dimensional structure prescribing in a liquid polymerizable composition with a focused laser beam.
• A significant disadvantage of this technology is the high complexity of the process.
• In this work a holographic method to form a three-dimensional structure as a result of single light action (exposure) is proposed.
2

The essence of the method



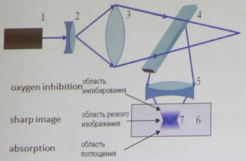
The principle scheme of a holographic projection.

1 – laser, 2 - lens, 3-spherical mirror, 4-hologram, 5- reconstructed real image, 6-photocurable material.

The method consists in the projection of three-dimensional intensity distribution of the laser radiation, forming by the hologram, to the volume of the polymerizable composition and displaying of holographic image in the thickness of material.

The main problem with the display of the projected intensity distribution in the volume of material is the depth of curing. We need obtain curing only in the areas of greatest brightness (sharpness) of the projected image, that is, we should to limit the polymerization in the fields before and after the area of sharpness - in the upper and lower parts of the beam that forms the reconstructed image.

Principles the depth of curing limiting



The scheme used in experiments.

1-laser, 2 – microobjective, 3 – lens, 4 – hologram, 5 – objective, 6 – photocurable material, 7 – reconstructed real image

- using of photocurable material with low exposure contrast and radical polymerization;
- exposure by the oxygen accessibility to layer and at the optimal exposure parameters - as a result of oxygen inhibition limit the photopolymerization in the upper part of forming light beam;
- providing the corresponding radiation absorption in the layer (to limit the polymerization in the lower part of the projecting beam);
- introduction of the objective (for increasing the aperture of the light beam, forming a reconstructed image, reducing the image size and depth of sharp image).

Experiment

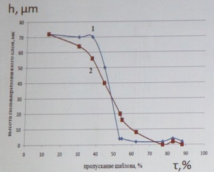
Holographic real images were formed by transmission holograms, which were recorded with pulse radiation at a wavelength of 532 nm using the technology developed by us previously.
As radiation sources DPSS laser with a wavelength of 532 nm and a helium-cadmium laser with a wavelength of 442 nm with output power of 100 mW and 50 mW respectively were used .
In the light beam forming the image the objective with a focal length of 5 cm and a relative aperture of 1: 3.5 was entered.

The process of a polymeric element formation consisted of three steps:
- preparation of photopolymerizable layer,
- exposure,
- removing the uncured material.

Photopolymerizable composition, liquid in the initial state, was poured into a cuvette, the greatest thickness of the layer was 3 mm.

Experiment

Optimal material



To find the optimal material dependence of the height of the cured layer from exposure when applying the gradient amplitude mask was investigated.

The best material is a monomeric composition with the lowest exposure contrast.

The dependence of the height of the cured layer on the transmittance of the amplitude mask.

1 - nanocomposite, 2- monomeric composition*.

*Burunkova Yu. E., Semjina S. A., Kaporsky L. N., Levichev V.V. Nanomodified optical acrylate composites // Optical journal, 2008, V. 75, No. 10, P. 54-58.

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Experiment

Layers transmission

Transmission of layers with different thickness

№	Layer thickness, μm	Transmission, %			
		442 nm		532 nm	
		Initiator concentration, w.%			
		0.5	5	0.5	5
1	20	99	72	99	96
2	100	85	20	96	82
3	500	45	$3 \cdot 10^{-4}$	83	37
4	1000	19	$1 \cdot 10^{-7}$	68	13

- The increase of absorption with initiator concentration increasing.
- The advantage of the wavelength 442 nm - increase of the absorption coefficient.

Exposure parameters

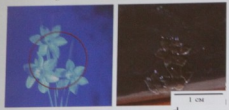
Exposure with ingress of oxygen has specific requirements for power density and exposure duration as a result of two competing processes- photoradical generation and oxygen inhibition. When power density is small can dominate the oxygen inhibition and increasing of exposure duration is not effective.

The optimal parameters (were found experimentally):

- $3 \cdot 10^{-2}$ W /см^2 at a wavelength of 532 nm
- $1 \cdot 10^{-1}$ W /см^2 at a wavelength of 442 nm,
- exposure duration of 5 sec – 5 min (depending on the size of formed field)

Results

a b



c d

When exposure in normal conditions, the layer is cured on all depth.

The elements can be formed on glass and film and separated from the substrate.

View of holographic images and polymeric elements on the glass (when proposed principles depth of curing limiting are realized).

Displaying of intensity gradations in the reconstructed image and configuration of the wave front (simultaneously).

Results

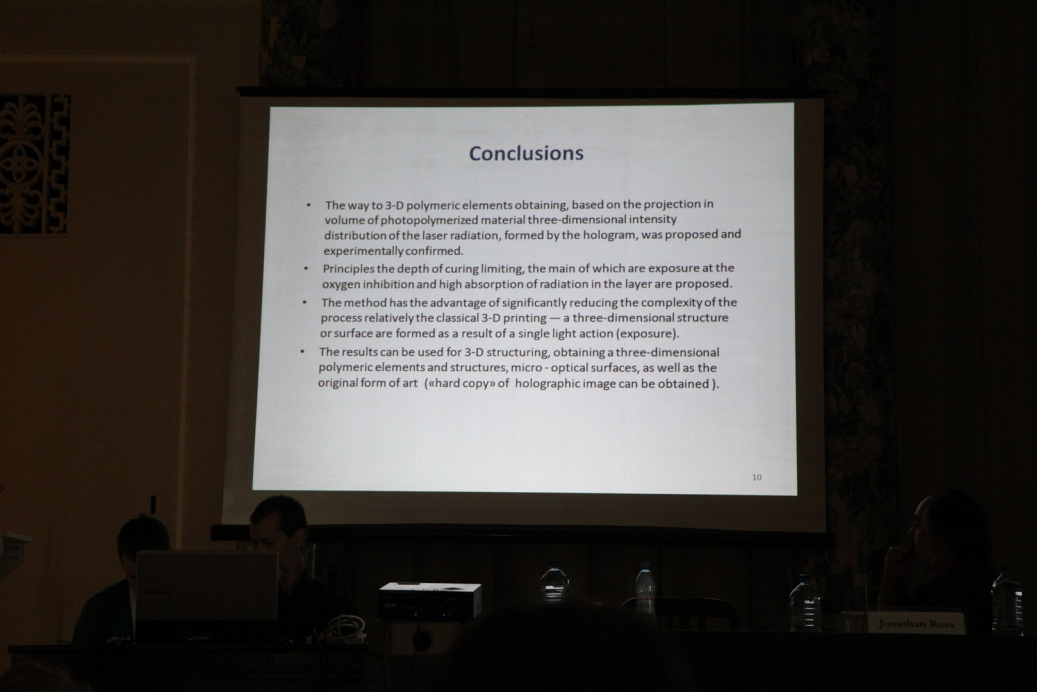
Model objects with planar, spherical, slanted and stepped surfaces.

Polymeric elements on the glass. Configuration correspond to a model surfaces.

The results of experiments showing the possibility of three-dimensional elements obtaining by display the configuration of the wave front.

Special model objects with a planar, spherical, slanted and stepped surfaces were manufactured and transmission hologram was recorded. Reconstructed real image was projected in a volume material with a thickness of 2 mm.

The result - display the surfaces of equal intensity, that is the configuration of the wave front.


Conclusions
The way to 3-D polymeric elements obtaining, based on the projection in volume of photopolymerized material three-dimensional intensity distribution of the laser radiation, formed by the hologram, was proposed and experimentally confirmed.
Principles the depth of curing limiting, the main of which are exposure at the oxygen inhibition and high absorption of radiation in the layer are proposed.
The method has the advantage of significantly reducing the complexity of the process relatively the classical 3-D printing — a three-dimensional structure or surface are formed as a result of a single light action (exposure).
The results can be used for 3-D structuring, obtaining a three-dimensional polymeric elements and structures, micro - optical surfaces, as well as the original form of art («hard copy» of holographic image can be obtained).
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