Self-deploying structures and polymer materials with shape memory

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1. Introduction

For the aims of investigations of space the necessity arises in the using of the self-deploying light, unwieldy space constructions which contain the forms during the maneuvers. This construction has to be enough technological. That is it can be folded for minimizing the physical envelope and accurately self-deployed taking the origin shape, which it has at the manufacturing stage, after removal a mechanical load. The structure has to self-deploy without using inflation by gas, sticking and destruction, contains this form during many thousands days and gets the form during minutes.

Now in spite of a progress in the creation of inflatable structures [1] there are no the investigations on self-deploying structures and corresponding materials which have the memory of shape properties. This material has to be enough light. For this purpose a polymer material or a corresponding composite material can be allowed. The material is used on the fast (during minutes) and sharp (on temperature from – 70 to 200 C) change of exploitation conditions. Besides that the material has to characterize by enough light-, radiation-, thermo- and heat- stability. Therefore the elaboration of a technology of creation of self-deploying structures and corresponding materials with shape memory represents the complicated scientific problems for our aims.

The examples of self-deploying structures can be the following: a framework of solar sail, a reflector for a heating of a space structure part, a space optical systems, mirrors etc.

The well-known variant of Sun sail structure shows by Figure 1. As a variant the Sun sail consists of triangular "petals" with sides 10 and 15 m which are located around a center. The thin polymer tubes form a framework of "petals". Obviously it is impossible to deliver the deployed Sun sail in space and it is necessary to fold it to decrease the dimensions. It is possible to deploy the folded sail framework in space by inflation system but gas will flow out from the framework because of micro-destroying, diffusion etc. In this case Sun sail doesn't carry out the maneuvers. Therefore the polymer material with shape memory has to be used for framework of sail in this case. Analogously this material can be used for a reflector framework which can have a diameter about few meters. Polymer material with shape memory may also be used for unwieldy optical systems.

Thus the intensification of the studies of self-deploying space structures dictates by logic of development of space investigations [2].

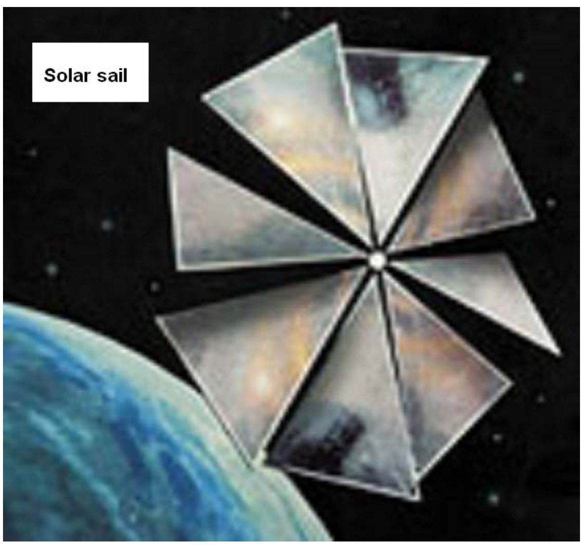

FIG. 1. Petal variant of solar sail

2. Polymer material with shape memory

2.1. Liquid Photo Polymerized Composition

At present time, polymeric products are produced using a two-stage scheme: synthesis of the polymeric material and further - mechanical treatment, pressure molding, pressing etc. The main advantage of the proposed technology of self-deploying structure creation (besides shape memory) is combining of the polymer synthesis and forming of the product at the same stage under the UV- radiation. The technology allows manufacture the products with the memory of shape. This one-stage technology provides optical accuracy of dimensions without any further treatment. For taking the given shape of product at the operation stage from folded product it is necessary to obtain the temperature of the glass-transition of polymer lower than operation temperature.

The polymer synthesis and forming of a product are performed (e.g. in the special forms) by photo polymerization of a liquid photo-polymerized composition. Liquid photo-polymerized compositions apply as a raw material and based on oligomers of metacrile row. As a rule poly-functional monomers polymerized by radical mechanism are used for a LPP-composition receipt [3].

For example, the LPP-composition can be the following: liquid photo polymerized composition receipt based on oligo-carbonat-metacrilat

**CH_2=C(CH_3)-COO-(CH_2)$_2$O-[COO(CH_2)$_2$O(CH_2)$_2$O]$_n$-
-COO-(CH_2)$_2$-OCC-C(CH_3)=CH_2**

Photo-initiator: 2,2 - dimetoxy – 2 –fenil-aceto-fenon

2.2. Comparison of performance of shape memory polymer material with analog

Let us consider the properties of polymer material with shape memory in detail. To avoid the shrinkage of LPP-composition on a part production a front photo-polymerization method is proposed [3,4]. The method characterized by thin transitional layer between liquid PPC and polymer and resembles the molecular crystal growth process. Ultra – violet (UV) lamps use as the radiation sources. This method allows produce space-sewing and stable polymer materials. The structure of polymer material ensures the property of shape memory. The propitious conditions for removal of polymer free volume which creates on monomer polymerization are produced by FPP-method. The free volume is a main cause for internal stresses and corresponding destruction of a polymer.

An initiation of a polymerization occurs by the action of light with wave-length 360 nm. The polymerization process takes place during minutes. The thermo-sets create as a result of a polymerization processes [3,4]. The comparative data of polymer materials are presented on Tables 1,2. The data reached with usage of standard samples, methods and available equipment.

These data show the advantage of material with shape memory over poly-metil-methacrilat (PMMA) and other polymer materials. Polymer with shape memory has high surface quality, shock strength and doesn't have an internal stresses and double refraction. The absence of double refraction is important optical property which allows use the material as optical material.

	Front Photo-polymerization Method	***Traditional Technology PMMA***
Memory of shape	**Yes**	**No**
Surface quality	**Roughness 3nm**	**Roughness 35nm**
Shock strength	**High**	**Low**
Double refraction	**No**	**Yes**
Internal stress	**No**	**Yes**

TAB. 1. Properties of polymer with memory of shape

The investigations show the high chemical and biological stability of material in comparison with PMMA

	Front Photo-polymerization Method	*Traditional Technology PMMA*
Chemical stability (biology active ambience)	No change discovered during 10 years, Stable in solvents, microorganisms and moisture Typical thermo-set	No change discovered during 3 years, Dissolve in solvents Typical thermo-plastic

TAB. 2. Chemical properties of polymer with memory of shape

The material demonstrates high light, stability in comparison with PMMA and other polymers and can therefore be used as optical material

	Front Photo-polymerization Method	*Traditional Technology PMMA*
Light stability Radiation Stability Laser radiation stability	Stable to UV-light, radiation and powerful laser radiation	Low radiation stability Light destruction, toxic monomer production

TAB. 3. Stability properties of polymer with memory of shape

A wide range of composites has been defined. It allows obtain polymeric materials with different physical-mechanical properties from solid to elastic (with the temperature of glass transition -50C + 100C, hydrophilic or hydrophobic materials). This technology allows improve many parameters of polymer material (strength, transparence, chemical stability etc.) as consequence of the absence of defect formation. The mechanical properties presents below.

Young modulus 37,2 - 800 kg/cm²
Poisson coefficient 0,3
Rupture stress 40 – 800 kg/cm²
Elongation of rupture 2 – 30 %
Optical properties conservation interval - 70C - +250C
Mechanical properties conservation interval - 70C - +200C

The data show a wide region of mechanical and optical properties stability on temperature.

3. Production of polymer parts with shape memory

3.1.Forming of polymer tubes

A one-stage FPP-method will be used for elaboration of technology of creation of self-deployed structure (and elements: tubes, spheres etc). It is possibly to distinguish continuous and “scrappy” FPP-methods for production of polymer parts with shape memory. Continuous method can be applied for production of simple parts and fragments of structures: tubes, small lenses, films etc. The production of polymer parts by continuous method can be realized by different manners (with and without using of special forms).

Let us consider the method of forming of polymer tubes with shape memory without usage of special forms described on Figure 2. The method of inflation (like the method of production of poly- ethylene tubes) has been developed to improve the one-stage FPP-method. The tube supposes create by extruding manner: LPP-composition gives in a top part of a cylindrical limiter, this composition blows on walls of limiter by inert gas feed, given "stoking" moves with constant speed and hardening under action of light sources and then gets into a receptacle. The thickness of tube regulates by an intensity of gas feed. The speed of stoking has to correspond to speed of hardening. The limiter creates from transparent for light and non-adhesive material.

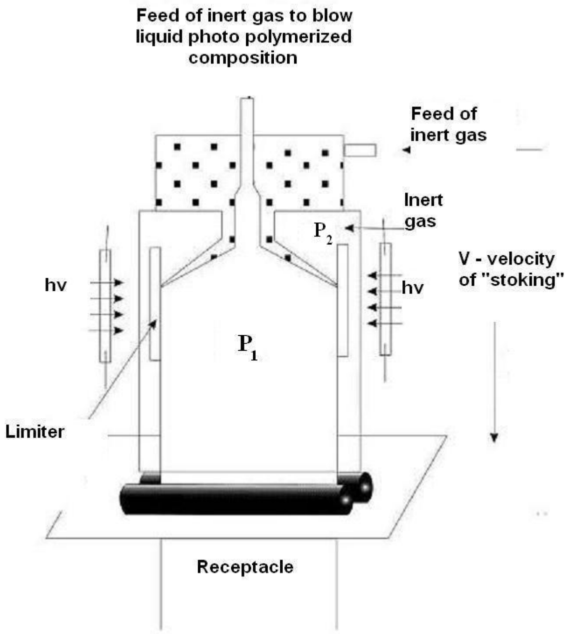

FIG. 2. The method of inflation for tube production

3.2. Precise polymeric parts

The other continue way (see Figure3) using the special forms can be applied when we need the optical precise of polymeric parts with shape memory. The liquid PP-composition gives in special precise forms (A or B) where is hardening by FPP-method to avoid the shrinkage (for this purpose liquid PPC adds in the form). The polymerization front moves up and liquid PPC moves down. This way applies to produce lenses, bases of reflectors and mirrors and other parts and fragments of precise form.

The difficulty in this case connects with the creating of corresponding precise forms of different dimension (from meter up to hundred μm) from transparent for light and non-adhesive material.

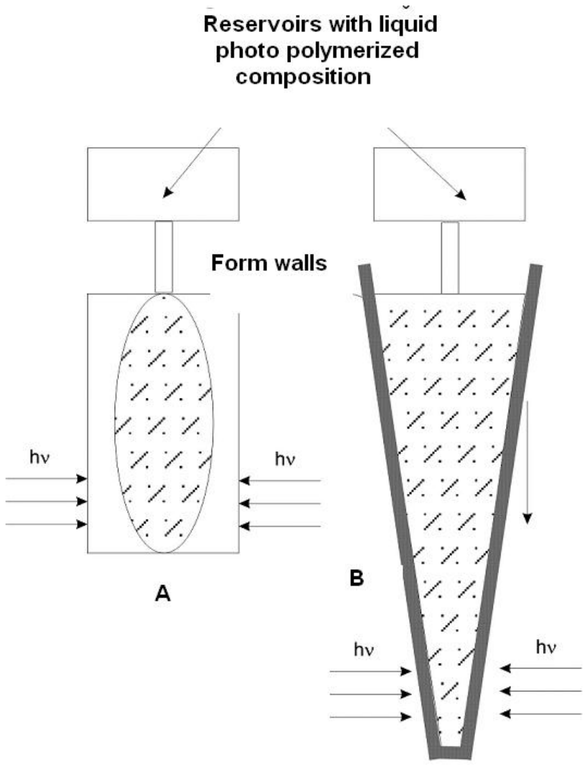

FIG. 3. The method of production precise polymeric parts

3.3 "Scrappy" technology

To produce the polymer product of complex form or cumbersome constructions with shape memory the using of scrappy method is offered. According to this method (see Figure 4) the fragments- "scraps" of parts are initially produced in the corresponding limiters using the special photo stencils by FPP-method. The scrap topology is calculated as pattern of any part. In this case the fragment borders have non-polymerized zones. Then the scraps are joined by borders and "welded" by FPP-method using non-polymerized zones and adding the liquid photo polymerized composition. This "photo-chemical welding" uses the special mandrels. By this way we get practically monolith product with shape memory. For example these patterns (see below) can be used for the tube production. The scraps are joined and welded along X-line to produce the tape of any length. The tube (cylinder) can be received by roll around X-line and corresponding welding.

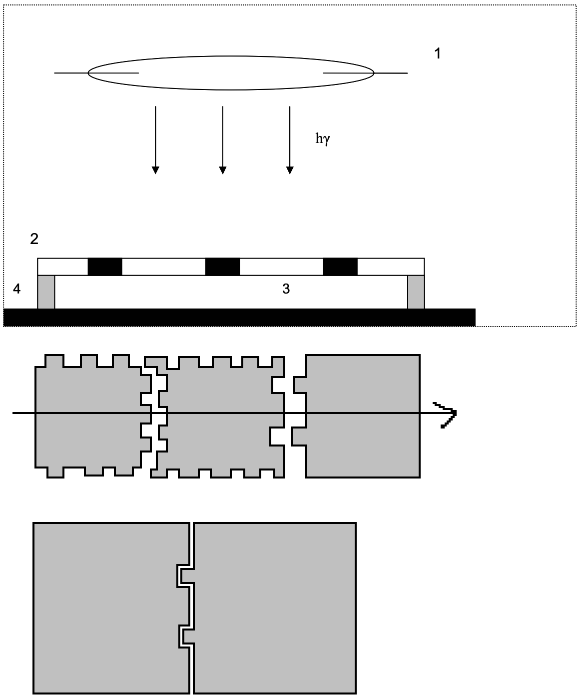

FIG. 4. Description of "scrappy" method:
1- light source, 2- photo stencil, 3-liquid PPC, 4-limiter

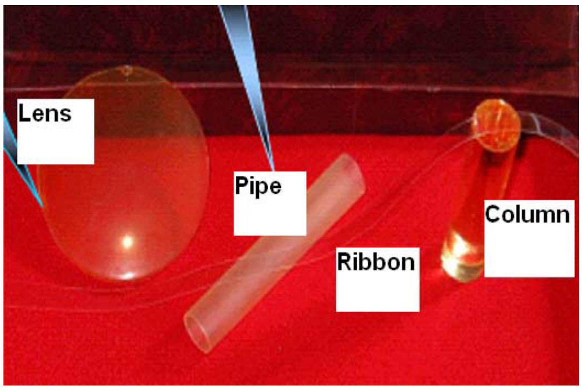

FIG. 5. Polymer parts with shape memory

The small parts from polymer material with shape memory are presented on Figure5.

4. X-ray refractive lenses

4.1. Principle of hard X-rays optic

Besides of polymer shape memory optical systems in visible range: reflectors, mirrors etc, space devices using the hard X-rays for investigations, for example Sun, can be offered. This device is cumbersome because of long focal length, therefore the using of polymer with shape memory for framework creation is necessary (see Figure 7).

In the X-rays region the refractive lenses are characterized by refractive coefficient less then unity and can be produced from polymer with shape memory by method of production of precise polymeric parts (see Figure3). The Figure 6 shows the principle of action of bundle of refractive lenses in the region of X-rays. One refractive lens has a long focal distance but a bundle of refractive lenses has a relatively shot focal distance [5, 6].

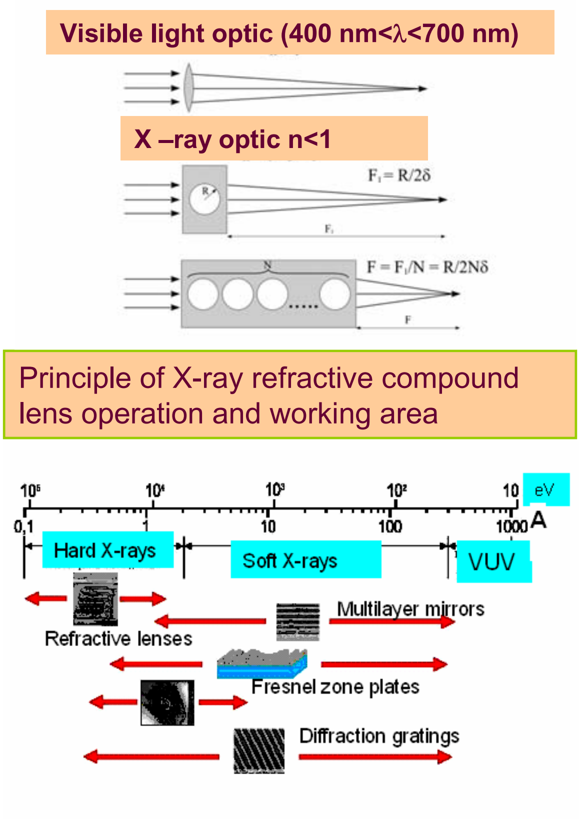

FIG. 6. Principle of hard X-ray optic

Based on this principle it is interesting to produce the set of compound lenses. The characteristics of the parabolic lens and bundle of lenses presents below (for PMMA).

Parabolic lens calculated data (PMMA)

Optical aperture A =1000 µm (1mm)
Lens outer diameter D = 1,5 mm
Length of single lens L = 2.2 mm
Number of lenses in compound set 15

Overall length of compound lenses
33 mm
Curvature radius in the parabola apex for single lens Rc = 57 mm
Focal distance (X-ray energy 32,2 keV)
F = 7,26 m
Focal distance (X-ray energy 8,05 keV)
F = 0,45 m

Usage of the self-deploying material gives better characteristics in comparison with PMMA characteristics presented above.

4.2. Hard X-rays device

A variant of X-ray refractive radiometer/telescope (which can be folded and self-deployed) for observations of integral flux from Sun in the region of hard X-rays (energies over 10-100 KeV) is presented on Figure7. In this variant polymer material with shape memory is used. The telescope can be folded to deliver in space where it self –deploys into origin shape.

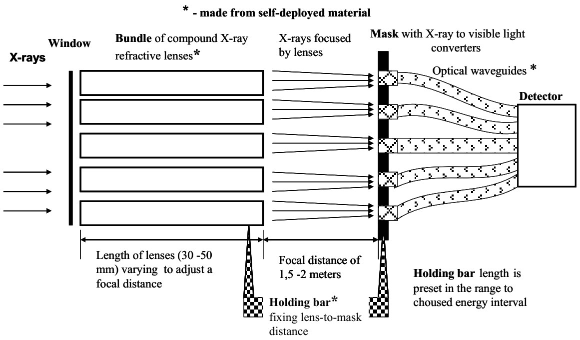

FIG. 7. Hard X-rays refractive radiometer/ telescope

The radiometer principle scheme is the following. X-rays are focused by a bundle of refractive lenses with entrance area up to 1-4 cm^2. Length of lenses (30-50 mm, about 20 lenses) can be varying to adjust a focal distance. Self-deploying lens material allows changing focal distance in chosen X-ray energy range. A set of focal spots produced by the bundles converts X-rays into visible light which are collected by waveguides from self-deploying material. Thus integral flux of X-rays focused by lenses is delivered by waveguides to detectors without losses. Self-deploying material is used for manufacturing of holding bar which fixes lens-to-mask distance in the range of focal distance 1.5-2 meters.

5. Conclusions and opportunities

Thus the set of technologies created to produce the self - deploying space structures. The investigations executed to get polymer materials with shape memory properties of which are necessary for space exploitation. Experimental and technological equipment are supposed for production of carried polymer construction, polymer base of reflectors, mirrors and polymer optical elements with shape memory. The methods of computer simulation for testing of these structures are elaborated.

Therefore the set of opportunities arises for collaboration. Firstly, the investigations and elaboration of polymeric materials with shape memory properties of which allow use in different space projects. Secondly, the projection and production of experimental and technological equipment for creation of various polymer construction and elements of construction with shape memory and different accuracy by FPP-method which can be folded and self-deployed: antennae, Solar cell, Solar sail structure etc. Thirdly, the projection and production of experimental and technological equipment which makes coating some layers of metal and other materials of different thickness on polymeric base with shape memory. The layers of coating allow exclude an internal stresses in the structure because of temperature gradients and temperature oscillations in space. At last, the projection and creation of device with shape memory for investigations of space objects in hard X-rays region which can be folded and self-deployed.

6. References

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