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CHARACTERIZATION OF NANOMATERIAL-BASED CONTACT LENSES BY ATOMIC FORCE MICROSCOPY

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Abstract: In this paper the comparative studies were conducted of the surface areas of nanophotonic contact lens and contact lens made from base material, measured by Nanoprobe Atomic Force Microscope. Nanoprobe atomic force microscopy (AFM) provides information on the size structure on nano scale level, the form of recorded structures (cavities), their distribution of the surface, and the total roughness of the scanned area. The atomic force microscope used in this study is a SPM-5200 of JEOL, Japan. AFM consists of a cantilever with a sharp tip (probe) at its end that is used to scan the specimen surface. Images of the specimen surface are created by measuring the deflection of the cantilever. The cantilever used in this study is produced by MikroMasch (Estonia) by trade name NCS18/Co-Cr. This AFM probe is silicon etched probe tip that has conical shape. It is coated with Co and Cr layers. Images of surface topography were obtained for each type of contact lenses. The base material of contact lens was made from PMMA and the nanophotonic contact lens was made of fullerene doped PMMA. Fullerenes were used because of their good transitive characteristics in ultraviolet, visible and near infrared light spectrums. Measurements were done at room temperature. Results of topography for both materials are presented and compared.

Keywords: PMMA, Fullerene, Nanophotonic contact lens, Cantilever, AFM.

1. INTRODUCTION

This paper shows the comparative studies of the surface areas of photonic contact lens and contact lens made from base material, measured by Nanoprobe Atomic Force Microscopy. The images of surface topography were obtained for both contact lenses. The base material of contact lens was made from PMMA, and the photonic contact lens was made of fullerene-doped PMMA. Fullerenes were used because of their good transitive characteristics in ultra-violet, visible and near infrared spectrums of light. The atomic force microscope used in this study is a SPM-5200 of JEOL, Japan (Figure 1). The cantilever used in this study is produced by MikroMasch (Estonia) by trade name NCS18/Co-Cr. This AFM probe is silicon etched probe tip that has conical shape. It is coated with Co and Cr layers. Atomic force microscopy (AFM) or scanning force microscopy (SFM) is a very high-resolution type of scanning probe microscopy. AFM consists of a microscale cantilever with a sharp tip (probe) at its end that is used to scan the specimen surface. Images of the specimen surface are created by measuring the deflection of the cantilever. Images of surface topography were obtained for each type of contact lenses. Measurements were done at room temperature. The imaging area was 2μm x 2μm. [1] Results of topography for both materials are presented and compared.

2. MATERIAL

PMMA is a commonly used base material for rigid contact lenses. It is produced by adopting the polymerization of MMA with a free radical initiation system to form "buttons" from which a contact lens can be obtained by lathing and polishing. It is cheap, easy to fabricate, durable, with acceptable

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surface wettability, excellent dimensional stability, also resistant to tear deposition. The only problem is that PMMA presents an oxygen barrier, which is of extreme importance for the human cornea because it is avascular. In order to change this, another polymer – silicone rubber (highly oxygen permeable) was added to PMMA and a new type of rigid contact lenses (RGP) material, siloxane acrylate was produced. This material is a commercial material used in this study as a referent material with working name SP40 (SP40™). SP40™ was produced by Soleko (Milan, Italy). Transmittance of this material in visible spectrum is less than 90% while in UV-VIS spectrum it is less than 60%. The material has a refractive index of 1.472 with oxygen permeability (Dk) of 13.7. [2,3]

The new, photonic nanomaterial for contact lenses is based on PMMA, but C_{60} molecule was added during polymerization. Molecule C_{60} was synthesized in 1985 by Kroto and Smalley research team (Kroto et al, 1985). The first production of C_{60} was done at the University of Arizona in 1990 by Kratschmer/ Hoffman team (Kratschmer at al, 1990) and its first image with atomic resolution was done at the University of Belgrade in 1992 by Koruga-Hameroff research team (Koruga et al, 1993a) [4,5]

The process of polymerization was done by adding 1g of C_{60} to the base material SP40™. This compound, a new material, has the working name A. Polymerization was homogeneous and the photonic nanomaterial has slightly less than 0.33% of fullerenes in it. Thin plates, from which contact lenses can be produced, were made from this material. Polymers containing fullerenes, particularly C_{60}, offer opportunities for production of new optical and electro active materials that can be processed into shaped objects and thin films.

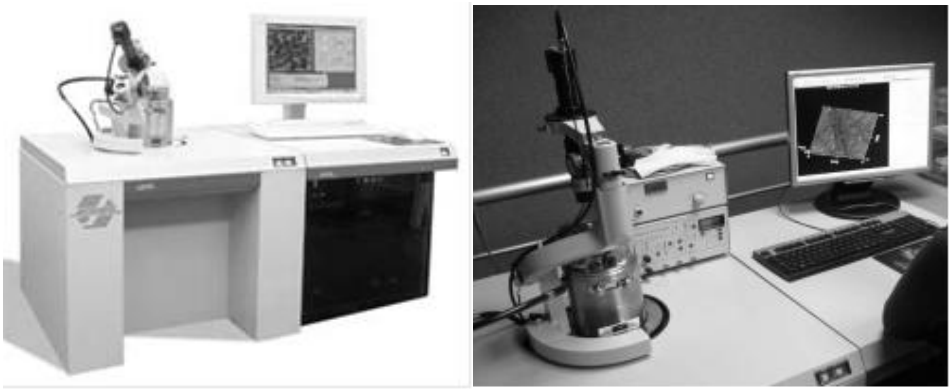

Figure 1. Atomic force microscope used in this study, SPM-5200 from JEOL, Japan [1]

3. METHOD

The SPM-5200 is a multipurpose, high resolution scanning probe microscope offering ease of use with diverse measurement and sample environments. The AFM consists of a cantilever with a sharp tip (probe) at its end that is used to scan the specimen surface. The cantilever is typically silicon or silicon nitride with a tip radius of curvature on the order of nanometers. When the tip is brought into the proximity of a sample surface, forces between the tip and the sample lead to a deflection of the cantilever according to Hooke's law. Typically, the deflection is measured using a laser spot reflected from the top surface of the cantilever into an array of photodiodes. There are many different imaging modes available for AFM, providing different information about the sample surfaces being examined. In this study was used the so-called Tapping mode of AFM. Tapping Mode of AFM is an imaging mode in which the probe is vertically oscillated at or near the resonant frequency of the cantilever. Electromechanical feedback maintains the oscillation at constant amplitude during scanning. The image is produced by mapping the distance when scanner moves vertically, to maintain the constant oscillation amplitude at each lateral data point. The key advantage of Tapping Mode is in the elimination of the lateral shear forces present in contact mode, which, on many specimens, can damage the structure being imaged. Tapping Mode AFM can be conducted in an air or liquid environment. [6]

AFM probe (NCS18/ Co-Cr, by MicroMasch, Estonia) used in this study is silicon-etched probe tip that has conical shape. It is coated with Co and Cr layers, so the resulting tip radius with the coating is 90nm. Full tip cone angle is 40°.

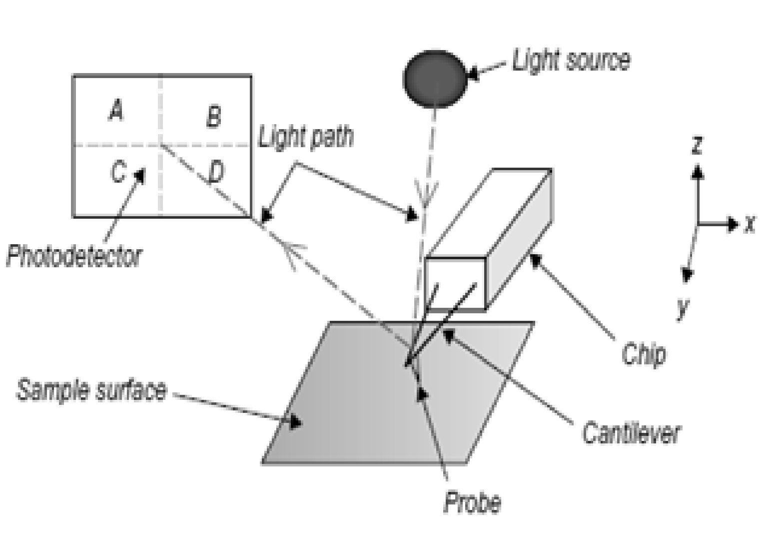

Figure 2. Schematic assembly of an AFM [6]

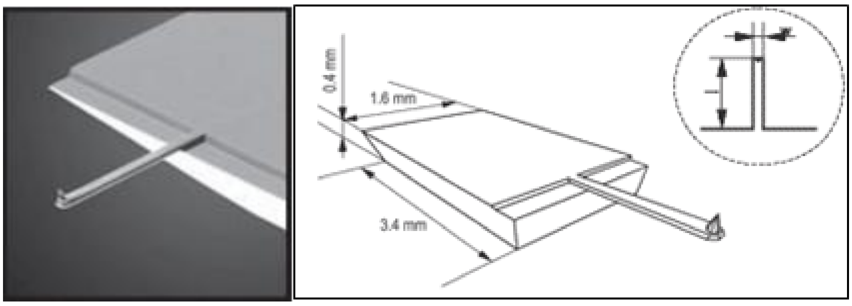

Figure 3. AFM Cantilevers and Tips

4. RESULTS

All images are done by tapping mode of AFM in resolution of 256x256 pixels in the scan area of 2x2μm.

Tapping mode was used in order to prevent mechanical damage to the surface. All measurements were performed at room temperature in protected space of measuring device. After scanning, all data were transferred to WinSPM software package that allows further analysis of images.

5. DISCUSSION

The base material and the material with incorporated C_{60} molecules (photonic nanomaterial), exhibit similar mechanical properties. Looking at the topographies of both materials we can see that photonic nanomaterial has better characteristics for contact lenses manufacturing than the base material (Figures 4,5,6) This can be concluded from the structure of the surface, that has no unequal peaks, but the whole rough surface is rather uniform. This is appropriate because contact lenses should have some roughness, in order to have adhesive forces with the tear film.

WinSPM software package has the ability to execute multiple cross section (profile) analyses on an image and to obtain the roughness information of the whole image or a specific region. The maximum number of profile lines is five. This software can display a three-dimensional image (bird's eye view) of the surface structure from the topography image of the AFM, which is very important for better visualization of topographic characteristic of sample.

The software displays analysis results regarding the profile. The height z at the position d along the line is defined as:

$$z=f(s) \quad (1)$$

The height Zo of the centerline is defined as:

$$Z_0 = \frac{1}{L}\int_0^L f(s)ds \quad (2)$$

Roughness parameters that can be displayed are:

Average of roughness (R_a):

$$R_a = \frac{1}{L}\int_0^L |f(s) - Z_0|\, ds \qquad (3)$$

Root mean square roughness (Rq):

$$Rq = \sqrt{\frac{1}{L}\int_0^L (f(s) - Z_0)^2\, ds} \qquad (4)$$

This is defined by a root mean square of deviation of f(s) from the centerline. [7]

10-point average roughness (Rzijs):

$$Rzijs = \frac{|z_{p1} + z_{p2} + z_{p3} + z_{p4} + z_{p5}| + |z_{v1} + z_{v2} + z_{v3} + z_{v4} + z_{v5}|}{10} \qquad (5)$$

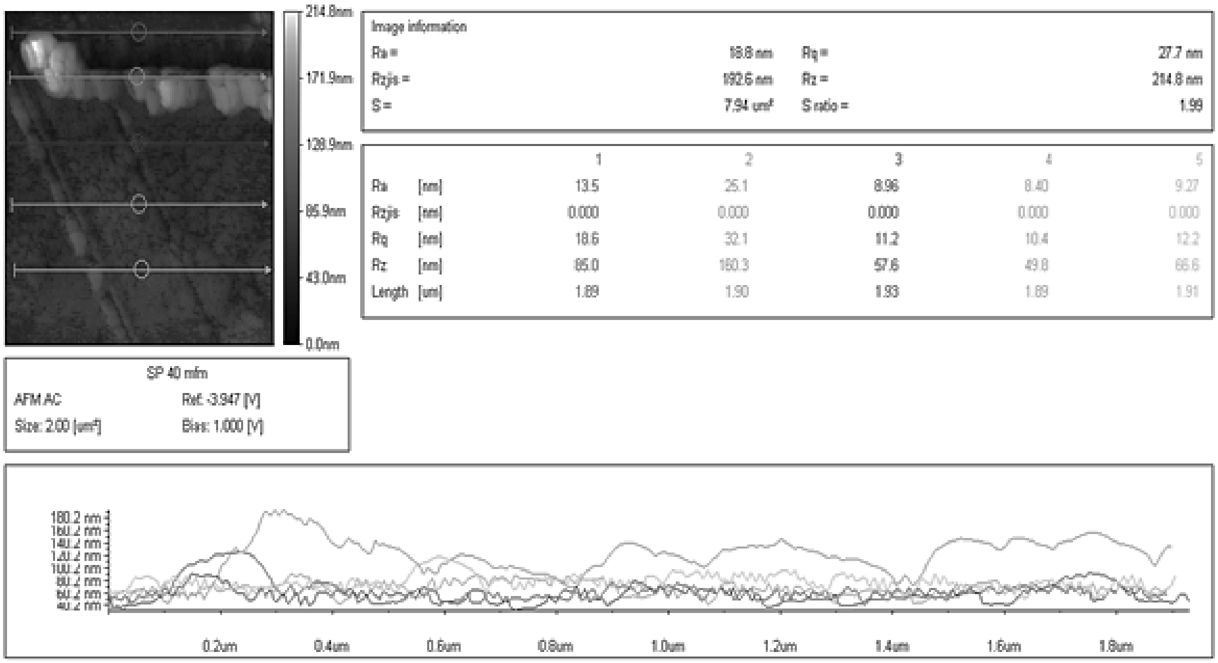

Figure 4. Base material, SP40, topography

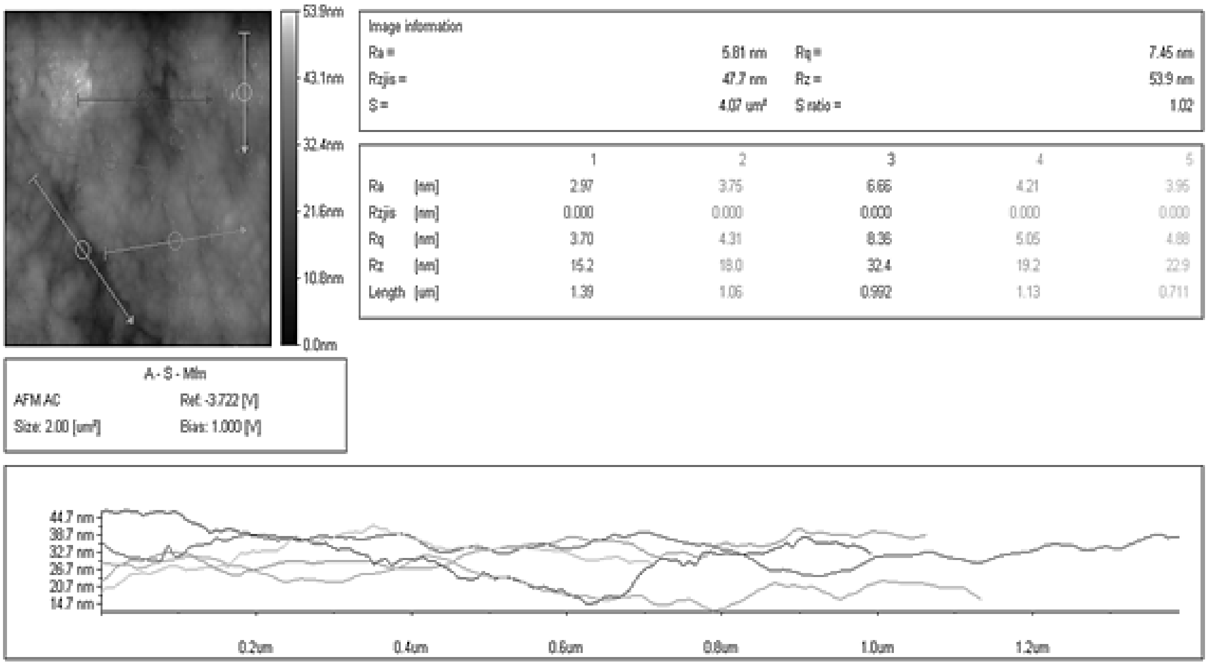

Figure 5. Topography of photonic nanomaterial, SP40+C_{60}, with working name A

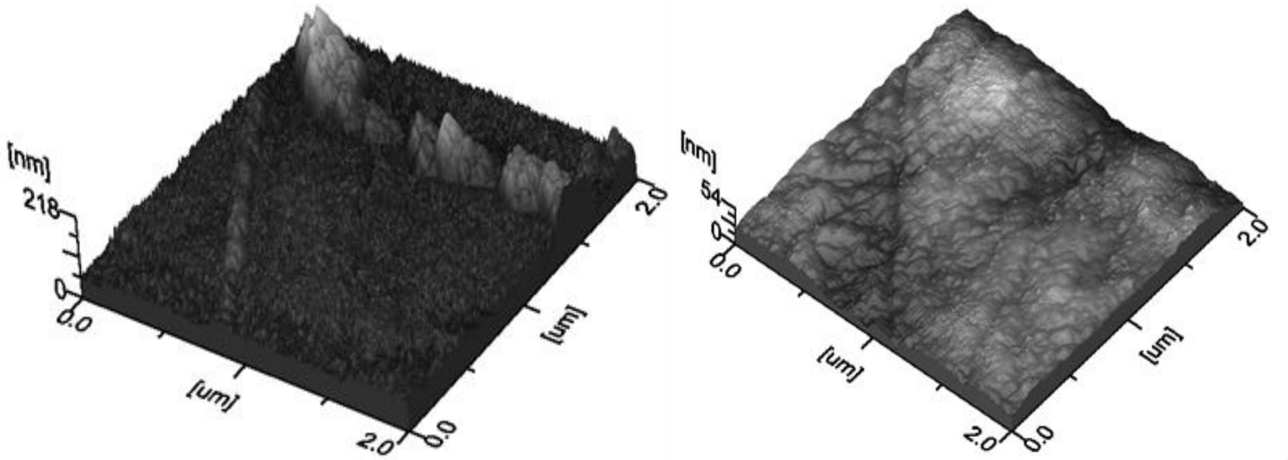

Figure 6. 3D topography images of SP40 (right) and photonic nanomaterial (left)

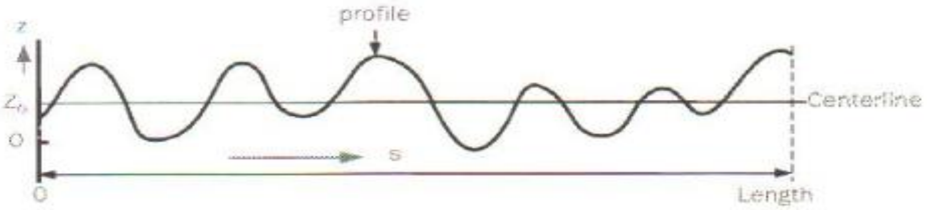

Figure 7. Profile with central line Z_0 [7]

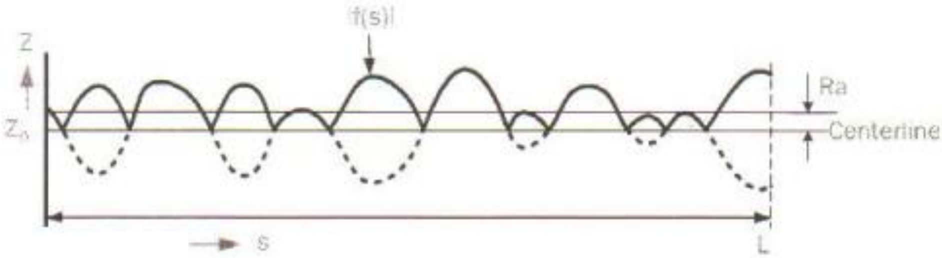

Figure 8. Average of roughness [7]

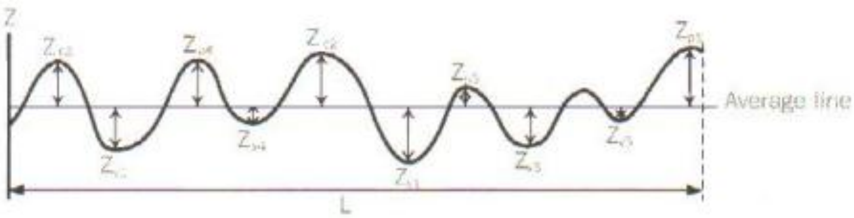

Figure 9. 10-point average roughness [7]

The 10-point average roughness is defined as the "sum of the average value of the absolute values of the deviation from the centerline between the largest deviation and the fifth deviation, and the average value of the absolute values of the deviation between the smallest deviation and the fifth deviation" [7].

Maximum difference between high (maximum value Z) and low (minimum max value Z_{min}) (R_z):

$$R_z = R_{max} - R_{min} \quad (6)$$

Table 1. Roughness parameters for both materials

Base material SP40			**Photonic nanomaterial SP40+C_{60} (material A)**		
Ra(nm)	Rq(nm)	Rz(nm)	Ra(nm)	Rq(nm)	Rz(nm)
31,60	42,1	303,1	5, 81	7,45	53,9

6. CONCLUSION

Photonic nanomaterial has more uniform structures of the surface compared to the base material; at the same time it has necessary roughness that will ensure the creation of adhesive force between the lens and the tear film.

Fullerene in photonic contact lenses gives the material better electro-magnetic characteristics of transmitted light. The potential applications of this sort of contact lenses can include everyday wearing for better UV protection of the retina, with lower intensity of light at wavelengths to which the eye is sensitive, as well as potential depression treatment. [2,3,6]

ACKNOWLEDGEMENTS

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7. REFERENCES

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КАРАКТЕРИЗАЦИЈА КОНТАКТНИХ СОЧИВА НА БАЗИ НАНОМАТЕРИЈАЛА ПОМОЋУ НАНОПРОБ МИКРОСКОПА АТОМСКИХ СИЛА

Сажетак: У овом раду представљено је компаративно испитивање топографских карактеристика потенцијалног новог, фотоничног наноматеријала за израду контактних сочива и комерцијалног материјала контактних сочива. Испитивање је рађено микроскопијом атомских сила (енг. Atomic Force Microscopy, AFM) која омогућава увид у површинске структуре испитиваног материјала на нанонивоу. Коришћен је микроскоп атомских сила, SPM-5200, фирме JEOL из Јапана. За скенирање површине узорка АФМ користи посебно дизајниране физичке сонде које се састоје од шиљка постављеног на микроносач (кантилевер). Скенирање површине заснива се на превлачењу сонде по површини узорка и праћења њене деформације у циљу добијања слика топографије. Сонда коришћена у овом раду носи назив NCS18/Co-Cr и производ је фирме MikroMasch (Естонија). NCS18/Co-Cr је силицијумска сонда, са врхом у облику конуса. Силицијумски врх обложен је превлаком од легуре кобалтхрома. Базни, комерцијални, материјал контактних сочива у основи је израђен од полиметилметакрилата (PMMA), док је фотонични наноматеријал комбинација базног материјала и фулерена C_{60}. Фулерени су употребљени због њихових добрих трансмисионих особина у ултраљубичастом, видљивом и блиском инфрацрвеном спектру. Сва снимања су обављена на собној температури. Резултати испитивања и компарације топографије оба материјала приказани су у раду.

Кључне речи: PMMA, фулерен, нанофотонично контактно сочиво, кантилевер, AFM.