The measurement of viscosity of thin polymer films

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1. Introduction

The development of nanotechnology faces many problems, one of which is lack of a fast and cheap method for fabricating structures whose dimensions are less than 0.1 μm. One method to solve this problem is nanoimprint lithography (NIL). The method of fabricating nanometer scale patterns by NIL was first proposed by Chou1,2 in 1995. Nanoimprint lithography creates patterns by the mechanical deformation of imprint resist and has many advantages, such as low cost and high resolution. Unfortunately, in spite of the simplicity of the idea and significant development of the method, there are many problems which must be overcome. One of which is the proper valuer of viscosity. The viscosity is a very important property of resists used in NIL and many methods to measure viscosity in thin films have been developed. In this paper we present the innovative method which allows the measurement of the viscosity of thin film as a function of temperature and indentation depth. It is then possible to investigate the influence of substrate on the rheological properties of thin films. Thickness of the measured films was reduced to 30 nm whereas resolution of the indentation depth was reduced to 5 nm.

2. Experimental

The viscosity is evaluated from the response of the oscillating piezoelectric cantilever at the end of which an indentation probe is mounted (Fig. 1a). When a polymer film is indented, the resonant frequency of the oscillations is changed and the parameters of used model (i.e. Maxwell model) can be identified. The frequency of the oscillations is equal to tens of kilohertz therefore the influence of extremely high deformation velocities can be investigated by means of this method. It is also possible to conduct the experiments in elevated temperature (up to 150°C). The oscillations direction can be parallel as well as perpendicular to the film's surface.

a) b)

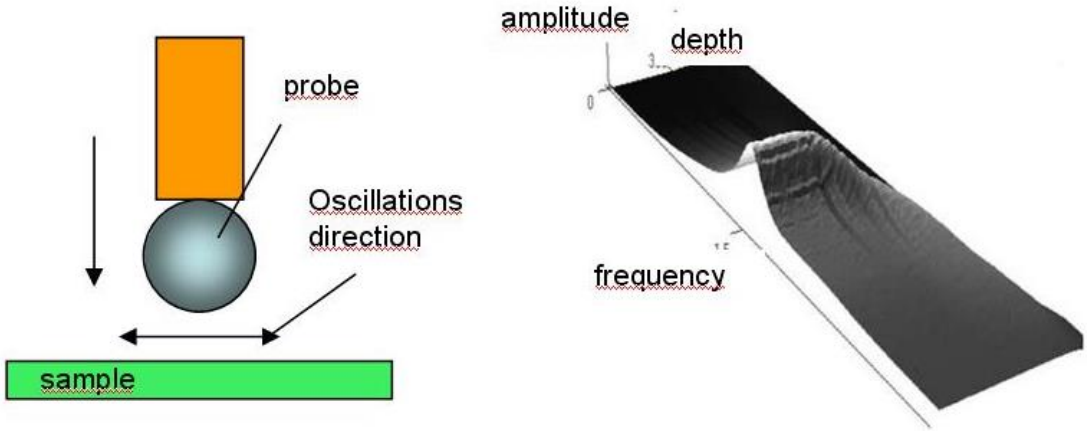

Figure 1. The scheme of the method.

The investigated films were made of PMMA. Their thickness ranges from a few nanometers up to 1 micrometer.

3. The evaluation of viscosity

During the measurement, the probe is partially inserted into the sample film so the damping coefficient of the film should be added to the damping coefficient of the air. In this case the equation, which describes the probe movement, is:

$$m\frac{d^2x}{dt^2} + (c_p + c_s)\frac{dx}{dt} + kx = F_0 \sin(\Omega t) \qquad \textbf{(1)}$$

where m stands for the effective mass of the probe, x is its position, c_p and c_s are the damping coefficients of air and of sample, respectively, F_0 is the force amplitude and X is the angular frequency.

The damping coefficient, cs, is dependent upon the geometrical parameters of the measurement system and it may be used to calculate the complex viscosity using the equation:

$$\eta = \frac{c_s}{\Gamma} \qquad \textbf{(2)}$$

where Γ is a geometric coefficient.

4. Results

Examples of the results are shown in Fig. 2. In every case the viscosity increase by a small amount with the indentation depth.

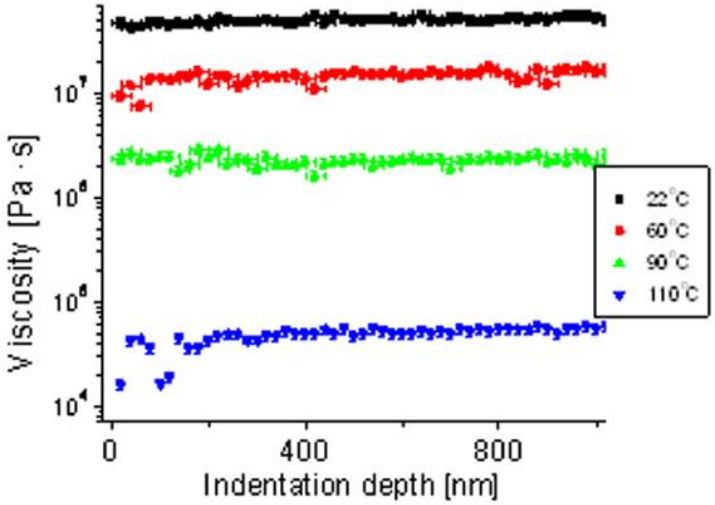

Figure 2. The example results. The graph shows the results for the PMMA sample, 1 µm thick.

5. Acknowledgments

The present research was funded by Foundation for Polish Science grant 68/UD/SKILLS/2015, IMPULS prize within the SKILLS project. The SKILLS project was cofounded by European Social Found.

5. References

[1] D.M. Jarząbek, Z. Rymuza, A. Horiba, Y. Hirai (2011). Development of an experimental technique for testing rheological properties of ultrathin polymer films used in nanoimprint lithography, Journal of Vacuum Science and Technology B, **6**, 061603-1-6