

Investigation of the properties of different surfaces used in evaporation systems

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Abstract. This paper presents a study of the properties of surfaces with nanocoatings of two types: NOA 81 photoresist with silanization and NOA 65 photoresist. These surfaces are resistant to thermal and mechanical loads. The structure of the surfaces was investigated by scanning electron microscopy. The contact angle hysteresis for these surfaces was determined by the standard DSA-100 KRÜSS procedure, in which the advancing and receding contact angles are measured, and also by a second method – measuring the contact angle under isothermal droplet evaporation. The contact angle hysteresis values measured by the two different methods are in satisfactory agreement. The contact angle hysteresis was about 20° for the NOA 81 substrate and about 50° for NOA 65.

1. Introduction

The rapid development of electronic technology and the miniaturization of various devices have necessitated a substantial increase in the performance of heat-exchange devices and the use of new materials. Nano- and micro-structured surfaces are promising for use in microfluidics and microsystems. One of the major problems today is the cooling of microelectronics, where the change in the surface chemical composition, morphology, and properties can play a key role. For example, at present, there is a transition in the production of processors from 14 nm topology to 7 nm technology. This transition was made possible by the use of a silicon-germanium alloy in the transistor design instead of pure silicon, the traditional material for microchip manufacture. The new technology has led to a decrease in the size of the microprocessor building block, an increase in transistor switching speed, and a reduction in power consumption. Next-generation devices may have higher heat fluxes and pulsed loads [1]. Knowledge of the morphology and contact angle hysteresis of these surfaces is required to determine their possible applications [2].

The objectives of this work were to study the morphology and determine the contact angle hysteresis (CAH) for surfaces with different coatings. Coatings were chosen so as to be resistant to thermal and mechanical loads and hold promise for use in various evaporator cooling systems. We study glass surfaces with two different types of nanocoating: surfaces obtained by coating with NOA 81 photoresist and silanization and surfaces obtained by coating with NOA 65 photoresist. The type of applied coating affects the properties of the surface.



2. Types of coatings and contact angle hysteresis

NOA 81 (Norland Optical Adhesive 81) is a single-component liquid adhesive which, when exposed to ultraviolet light, hardens in a few seconds to form a hard solid polymer. NOA 81 forms a solid film without becoming brittle. The film has low elasticity, providing vibration or thermal relaxation and long-term performance of the adhesive bond. The solidified film withstands temperatures from -150 °C to 125 °C.

Silanization is the treatment of a glass or quartz surface with silanizing agents such as trimethylchlorosilane, dimethyldichlorosilane, disilazane, etc. The silanol groups (-Si-OH) present on the glass surface react with the silanizing agent to form a chemically sewn hydrophobic siloxane film.

These surfaces were examined with a Hitachi S3400N scanning electron microscope. A photograph of a glass substrate with a NOA 81 photoresist coating and silanization is shown in Fig. 1. Inclusions are uniformly distributed across the surface, which is typical of the absorption of trichlorooctadecylsilane on silica or glass surfaces. The typical size of the inclusions is found to be 0.5–1 µm, as seen in Figure 1b.

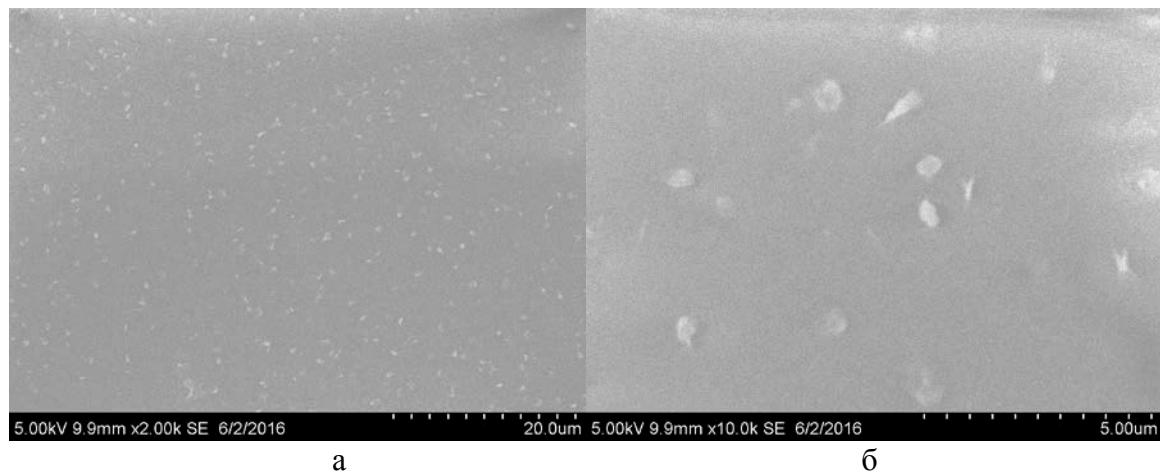


Figure 1. SEM on Hitachi S3400N, NOA 81 with silane. a - scale 20 µm : 10, b - scale 5 µm : 10.

NOA 65 is a clear, colorless liquid photopolymer, which also hardens when exposed to ultraviolet light. It has good elasticity, temperature range from -15 to 60 °C.

On the test surfaces, the contact angle and the contact angle hysteresis were measured. The difference between the advancing and receding contact angles is the contact angle hysteresis [3]. The advancing contact angle is measured when the solid/liquid contact area increases, and the receding contact angle is observed when this area decreases. The interval may be 10° or more if the surfaces are not specially treated. The hysteresis value is affected by the main three factors: surface roughness [4, 5], chemical impurities or inhomogeneities in the structure of the solid surface, and substances (surfactants, polymers, etc.) dissolved in the liquid [6].

3. Experimental setup and methods

The DSA-100E (KRÜSS GmbH, Hamburg) drop shape analyzer can be used to measure the contact angle by the sessile drop method. The contact angle is measured in the range 1–180° with a measurement error of ± 0.1°. The DSA-100E includes an automatic carousel-type liquid supply system (step 0.1 µl), an optical system (7x zoom, field of view 3.7x2.7 - 23.2x17.2 mm), a digital camera (up to 311 frames/s with a maximum resolution of 780 x 580 / 780 x 60 pixels), and a computer-controlled table with motorized axes for samples.

Contact angle hysteresis was determined using two different methods. In the first method, the advancing and receding contact angles were measured (the standard KRUSS procedure, Fig. 2). A 10 μl drop is dosed onto the surface at a constant rate of 0.05 $\mu\text{l}/\text{min}$, and the advancing contact angle is measured. After the maximum volume is reached, the liquid is pumped, and the receding contact angle is measured. The difference between the advancing and receding contact angles is the contact angle hysteresis. As the second method we studied isothermal droplet evaporation. The evaporation of a 5 μl water droplet into the atmosphere is considered, and the change in the contact angle throughout the evaporation of the droplet is determined. In both cases, the hysteresis is determined in the vicinity of the zero contact-line speed.

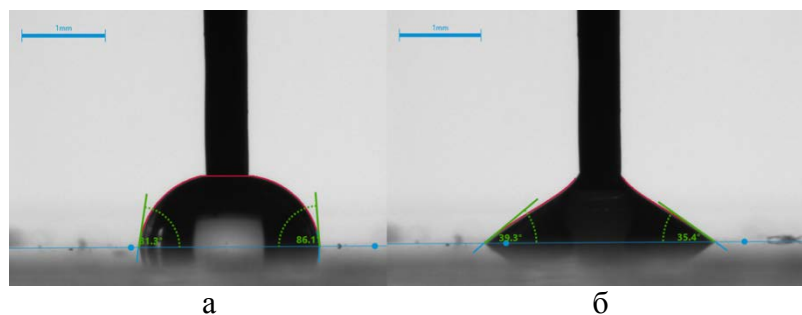


Figure 2. Advancing (a) and receding (b) contact angles on a substrate coated with NOA 65.

4. Results

On the NOA 81 surface, the contact angle was 110°, and on the NOA 65 surface, it was 82°. Figure 3 shows the dependence of the contact angle on the contact line speed on a substrate with a NOA 81 photoresist coating and silanization. Hysteresis is determined in the vicinity of the zero contact line speed, and on this surface, it is 20° (Fig. 3).

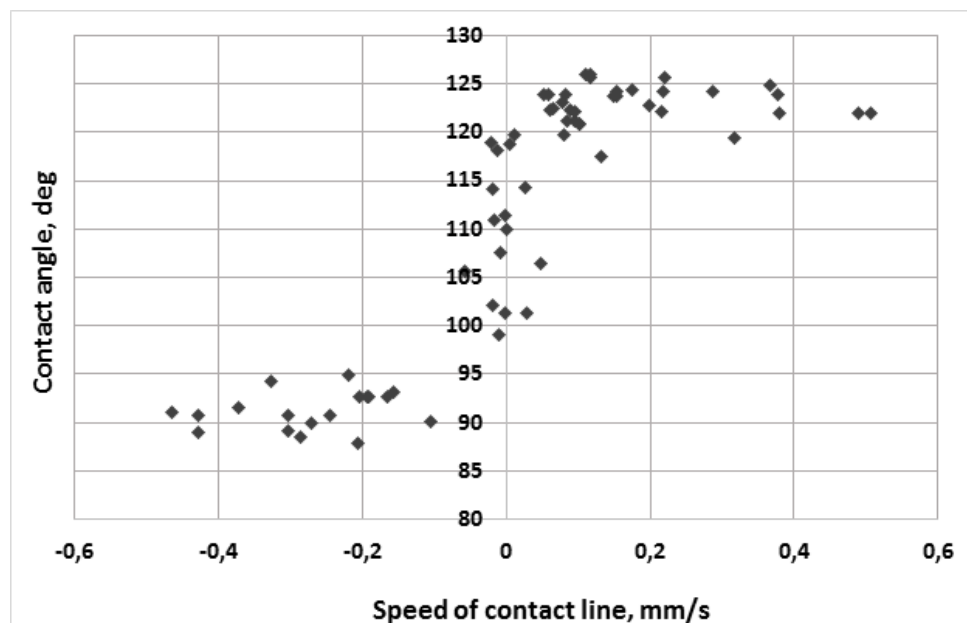


Figure 3. Contact line speed versus contact angle on a substrate coated with NOA 81 and silane.

Figure 4 shows the dependence of the contact angle on the contact line speed on a substrate coated with NOA65 photoresist. For this surface, the hysteresis is found to be about 50° .

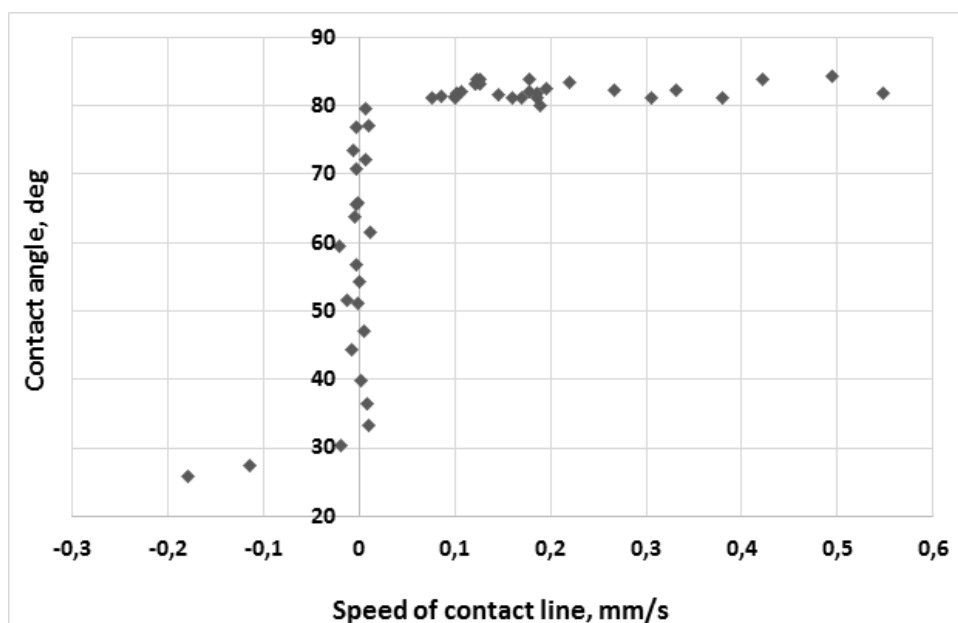


Figure 4. Contact line speed versus contact angle on a substrate coated with NOA 65.

It is shown that the contact angle hysteresis depends on the type of coating applied. The contact angle hysteresis values obtained by the method of isothermal droplet evaporation into the atmosphere are in agreement with the results of the first method and are about 20° and 50° for NOA81 substrates with silanization and NOA65 substrates, respectively. The test surfaces can be used to produce controlled flows. Surfaces obtained by applying NOA65 photoresist can provide evaporation under pinning conditions ($CAH=50^\circ$). Surfaces obtained by applying NOA81 photoresist and silanization can be used to produce flows with a constant contact angle.

5. Conclusions

Glass surfaces with nanocoatings of two different types — a NOA 65 coating and a NOA 81 coating with silanization — were studied. These coatings are sufficiently resistant to thermal and mechanical loads. The characteristic sizes of the inclusions present in the NOA 81 coating with silanization were measured with a scanning electron microscope to be $0.5\text{--}1\text{ }\mu\text{m}$. The contact angle hysteresis was studied by two methods on a KRUSS DSA-100 apparatus. The contact angle hysteresis is about 20° for NOA 81 substrates with silanization and about 50° for NOA 65. The results obtained by the standard KRUSS procedures are in good agreement with the results obtained by isothermal droplet evaporation.

The authors gratefully acknowledge the support of this work by the Ministry of Education and Science of the Russian Federation (Agreement 14.616.21.0016, project identifier RFMEFI61614X0016).

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