USING LIQUID CHEMICAL ETCHING TO MANUFACTURE TECHNOLOGICAL STRUCTURES OF MINIMUM SIZE

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We consider the effect of the electric field on the pulling of an etching liquid through holes in a thin insulating protective mask and the possibility of achieving high-resolution liquid etching for manufacturing LSI components of minimum size.

Liquid chemical etching is one of the key processes in modern microelectronic technology, and it is relevant to estimate the maximum attainable resolution of this method. The problem is to study the effect of the electric field on the pulling of the etching liquid through holes in the protective mask and the possibility of increasing the resolution in this way.

We consider the following model problem. A layer of viscous incompressible liquid of height $h$ is placed on a horizontal insulating base of thickness $b$ with round holes of radius $r_0$ (Fig. 1). Contrary to [2], we assume a wetting liquid with wetting angle $\theta$ ($\theta < \pi/2$). A plane electrode (the plate to be etched) is located on the other side of the base, under the hole. A certain potential difference $U$ is maintained between the electrode and the liquid. Without loss of generality, we assume that the potential of the plane electrode is zero and the potential of the liquid is $\varphi = U$. Thus, each hole functions as a microcapacitor: its bottom winding is the bottom of the hole, and its top winding is the free surface of the liquid forming a meniscus.

In the space between the capacitor windings, the potential of the electrostatic field $E$ satisfies the Laplace equation in cylindrical coordinates in the axisymmetric case:

$$
\frac{\partial^2 \varphi}{\partial r^2} + \frac{1}{r} \frac{\partial \varphi}{\partial r} + \frac{\partial^2 \varphi}{\partial z^2} = 0
$$

with the boundary conditions

$$
\varphi(0, r) = 0, \quad \varphi(f(r), r) = U,
$$

where $x = f(r)$ is the equation of the free surface of the liquid in the hole.

Equation (1) has particular solutions of the form

$$
\varphi = k \sin \lambda x I_0(\lambda r),
$$

where $k$ and $\lambda$ are the integration constant obtained from boundary conditions; $I_0(\lambda)$ is the modified Bessel function; $\lambda > 0$, $k > 0$ [4].

The relationship

$$
F(x, r) = \sin \lambda x I_0(\lambda r) - \gamma = 0
$$

Fig. 1 describes a whole family of equipotential surfaces with the constant $\gamma$ ($\gamma > 0$).

We rewrite Eq. (3) in explicit form:

$$x = \frac{1}{\lambda} \arcsin \left[ \gamma I_0(\lambda x) \right].$$

(5)

We know that the surface of the liquid in microholes can be approximated with sufficient accuracy by the surface of a sphere of radius $R = r_0/\cos \Theta$ [5]. The coordinate $x_0$ of the intersection point of the meniscus with the Ox-axis is defined as the sum of the height of the spherical segment forming the meniscus and the distance $l$ from the bottom capacitor winding to the lower edge of the meniscus (the point A),

$$x_0 = l + r_0 \frac{1 - \sin \Theta}{\cos \Theta}.$$  

(6)

We assume that for certain values of the parameters $\lambda$ and $\gamma$ the equipotential surface from (5) approximates with acceptable accuracy the shape of the liquid surface in the given region. As the wetting angle $\Theta$ increases, the accuracy of approximation of the liquid surface by the curve (5) improves. The sought surface can be determined from the condition that it passes through the points $A(l_0, r_0)$ and $C(x_c, 0)$, while preserving the natural wetting angle $\Theta$ for the given material and the liquid.

Substituting the coordinates of the point $C$ in (4), we obtain $\gamma = \sin \lambda x_c$, where $x_c$ is given by (6). Assuming that the parameter $l_0$ is known, we obtain from (4) the following transcendental equation for the coefficient $\lambda$:

$$F(\lambda) = I_0(\lambda r_0) - \sin \lambda x_0/\sin \lambda l = 0,$$

(7)

The approximate roots of this equation are obtained by one of the standard methods, e.g., by Newton's method [3]. The initial approximation for $l$ can be obtained from the condition of static equilibrium of the liquid in the hole in the absence of an electric field:

$$P_o + P_a + P_s - P_g = 0,$$

(8)

where $P_o$ is the pressure above the liquid layer, which is set equal to atmospheric pressure; $P_g = \rho g(h + b - l)$ is the pressure of a liquid column of height $h + b - l$; $\rho$ is the liquid density; $g$ is the free-fall acceleration; $P_s = \sigma k$ is the pressure due to surface tension; $k = 1/R_1 + 1/R_2$ is the mean curvature of the liquid surface; $R_1$ and $R_2$ are the principal radii of curvature; $\sigma$ is the coefficient of surface tension; $P_{tr}$ is the unknown pressure of the gas trapped in the hole.

We write the expression for the internal volume of the hole $V_o$ and for the trapped gas volume $V_{tr}$:

$$V_o = \pi r_o^2 b,$$

$$V_{tr} = \pi r_o^2 l_o + \frac{\pi}{6} \eta (3r_o^2 + \eta^2) =$$

$$= \pi \eta_0^2 l_o + r_o (1 - \sin \Theta)^2 (2 + \sin \Theta)/3 \cos^3 \Theta,$$