

**Process Specification:
Measurement of the Positive
Photoresist Parameters A, B, and C**

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Abstract

A detailed description is given of the experimental procedure used to measure the photoresist parameters A, B, and C. These parameters are needed to model the behavior of positive optical photoresists.

Introduction

As semiconductor feature sizes grow smaller, optical lithography modeling is growing increasingly important. As with any process model, the ability of a lithography model to predict the behavior of a resist system is limited by the ability to measure the appropriate parameters needed to characterize that resist system. Three of the most important parameters needed to model positive optical photoresists are the A, B, and C parameters as described in this paper and in the references [1-3]. A theoretical basis for the use of these parameters is given and a technique for measuring them is described.

Theory

As light passes through a medium other than vacuum, some amount of that light is absorbed by the medium. The details of the absorption phenomenon have been given elsewhere [1] and only the applicable results will be given here. The Lambert Law of Absorption describes the change in light intensity as it passes through an absorbing medium:

$$\frac{dI}{dx} = -\alpha I \quad (1)$$

where I = light intensity

x = distance traveled in the medium

α = absorption coefficient of the medium.

The absorption coefficient can be expressed in terms of the chemical constituents of the resist using Beer's Law [1]. For a positive AZ-type photoresist,

$$\alpha = \alpha_M M + \alpha_R R + \alpha_S S + \alpha_P P \quad (2)$$

where M = concentration of the photoactive compound (PAC)

R = concentration of the resin

S = concentration of the solvent

P = concentration of the photoactive product (the PAC after it has been chemically changed by the exposure process)

$\alpha_M, \alpha_R, \alpha_S, \alpha_P$ = molar absorption coefficients of the respective photoresist components.

At the beginning of exposure there is no reaction product P and the PAC concentration takes the value M_0 , the initial PAC concentration. The stoichiometry of the reaction dictates that [2]

$$P = M_o - M \quad (3)$$

Substituting equation (3) into equation (2) and rearranging,

$$\alpha = (\alpha_M - \alpha_P)M + \alpha_R R + \alpha_S S + \alpha_P M_o \quad (4)$$

Let us define a relative PAC concentration m such that $m = M/M_o$. Equation (4) now becomes

$$\alpha = A m + B \quad (5)$$

where $A = (\alpha_M - \alpha_P)M_o$

$B = \alpha_R R + \alpha_S S + \alpha_P M_o$.

Equation (1) can now be rewritten.

$$\frac{\partial I(x,t)}{\partial x} = -I(x,t)[A m(x,t) + B] \quad (6)$$

By examining the kinetics of the photoresist exposure reaction, one can relate the PAC concentration as a function of exposure time to the intensity of the exposing radiation [2].

$$\frac{\partial m(x,t)}{\partial t} = -I(x,t)m(x,t)C \quad (7)$$

where C is the exposure rate constant. Thus, three parameters, A , B , and C , are needed to define the exposure reaction for the simple case of an absorbing photoresist film on a non-reflecting substrate.

Relating A , B , and C to measurable quantities

The three parameters A , B , and C can be measured by a single, simple experiment. This experiment was introduced by Dill, et. al., at IBM in their pioneering work on positive resist modeling [3] and will be summarized here. A photoresist film coated on a transparent substrate, which is chosen to minimize reflections, is exposed by monochromatic light. The light transmitted through the resist-substrate is measured as a function of time.

Given the defining equations (6) and (7), the parameters A , B , and C can be related to the internal transmittance of the photoresist film, T , by [3]

$$A = \frac{1}{d} \ln \left(\frac{T(\infty)}{T(0)} \right)$$

$$B = -\frac{1}{d} \ln(T(\infty))$$

$$C = \frac{A + B}{AI_0 T(0)\{1 - T(0)\}} \left. \frac{dT(0)}{dt} \right|_{t=0} \quad (8)$$

where d = resist thickness

$T(0)$ = transmittance of unexposed resist

$T(\infty)$ = transmittance of fully exposed resist

I_0 = light intensity at the top of the resist (i.e., $I(0,t)$).

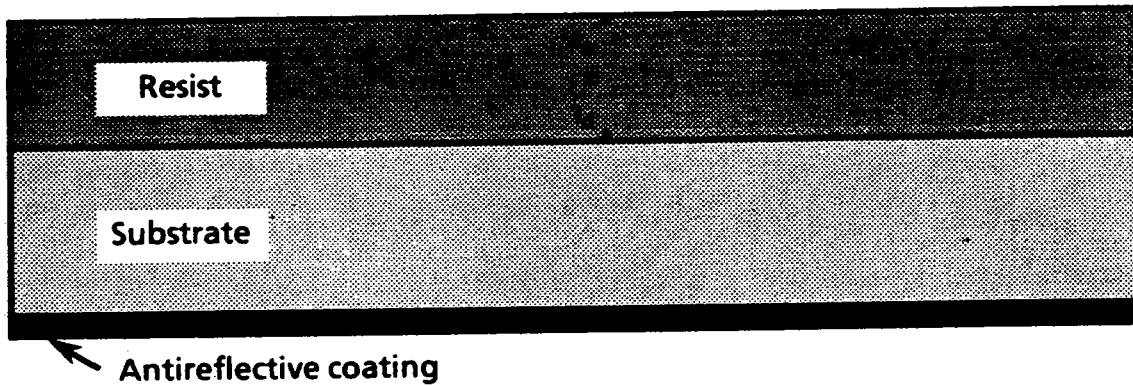


Figure 1 : Resist sample configuration for ABC measurement

The internal transmittance is defined as

$$T(t) = \frac{I(d,t)}{I(0,t)} \quad (9)$$

The intensity I_0 can be related to the incident intensity I_{inc} by

$$I_0 = I_{inc} \tau_{12} \quad (10)$$

$$\text{where } \tau_{12} = 1 - \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2$$

and n_1 and n_2 are the indices of refraction of air and the photoresist, respectively. The incident intensity is a measurable quantity. If the index of refraction of the photoresist is known, the transmission coefficient τ_{12} can be calculated. Thus, one must relate $I(d,t)$ to measurable quantities in order to use equation (9). Consider the resist coated substrate shown in Figure 1. If the resist and substrate are optically

matched (i.e., have the same index of refraction), there will be no reflections at the resist-substrate interface. If the bottom of the substrate is coated with an antireflective coating, there will be very little light which is reflected at the substrate-air interface. Thus, the light emanating from the substrate will be

$$I_m = I(d,t)T_g \tau_{AR} \quad (11)$$

where T_g = internal transmittance of the substrate (e.g., glass)

τ_{AR} = transmission of the antireflective coating.

Thus,

$$T(t) = \frac{I_m}{\tau_{12} I_{inc} T_g \tau_{AR}} \quad (12)$$

If one measures the light transmitted through the glass substrate without a resist film on top, the measured intensity will be

$$I_{mo} = \tau_{12} I_{inc} T_g \tau_{AR} \quad (13)$$

Thus, the internal transmittance of the resist can be related to two measurable quantities: the light transmitted by the resist coated substrate $I_m(t)$ and the light transmitted by the uncoated substrate I_{mo} .

$$T(t) = \frac{I_m(t)}{I_{mo}} \quad (14)$$

Experimental Procedure

The quantities needed to calculate the A, B, and C parameters can be measured using the apparatus shown in Figure 2. A collimated beam of UV light is filtered to the desired wavelength and incident on the photoresist system shown in Figure 1. A UV detector is placed directly beneath the substrate. A strip chart recorder is connected to the UV meter so that the pen deflection is proportional to the voltage on the meter.

With the meter on and the strip chart recorder running, open the shutter and begin exposing the photoresist. The recorder will trace out a curve similar to that shown in Figure 4. This curve represents $I_m(t)$. Continue the exposure until there is no longer any change in the recorder reading (the flat region in Figure 4). Remove the resist coated substrate and put a blank substrate in its place. This is the measurement of I_{mo} . Remove the blank substrate and measure the incident intensity with the UV meter. Be sure that all appropriate data for the run is recorded including the resist preparation conditions (e.g., prebake conditions, etc.). A data sheet similar to the one at the end of this paper can be used.

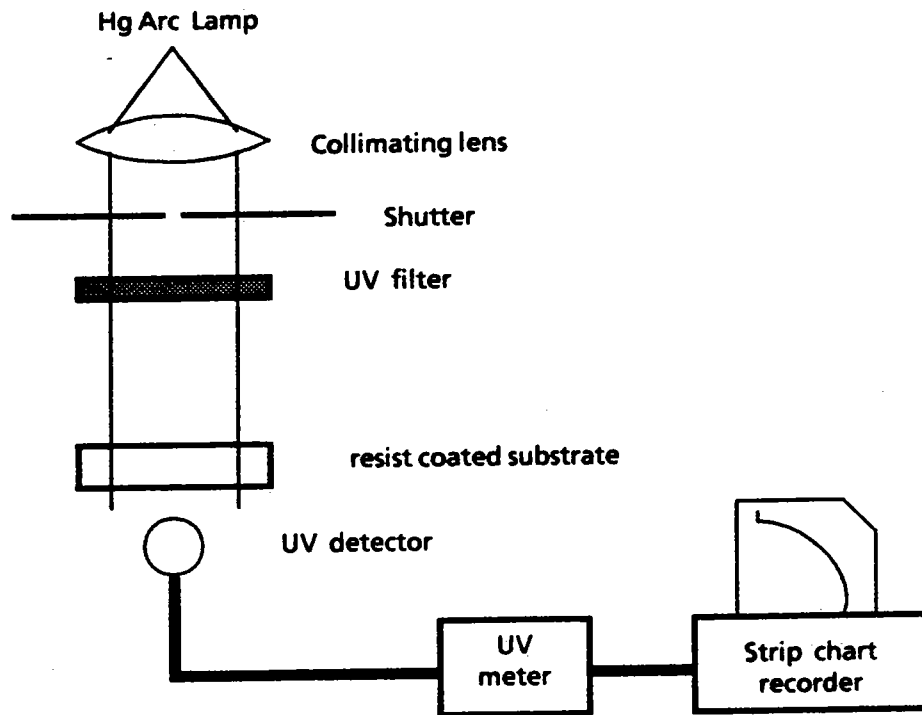


Figure 2 : Experimental apparatus for determining the ABC parameters

The information obtained by this experiment can be used to calculate the ABC parameters. As an example, let us perform the calculations on the data given in Figures 3 and 4. The following measurements can be made. Draw a line tangent to the initial part of the transmission curve. This line is used to measure the initial point and the slope.

blank substrate = 6.03 y units

Initial point = 1.78 y units

Final point = 5.57 y units

slope of line = 0.924 y units/x unit

Using these values,

$$T(0) = 1.78/6.03 = 0.295$$

$$T(\infty) = 5.57/6.03 = 0.925$$

$$\frac{dT}{dt}\bigg|_{t=0} = (0.924 \text{ y units/x unit}) \left(\frac{4 \text{ x units/min}}{60 \text{ sec/min}} \right) \left(\frac{1.0 \text{ transmittance}}{6.03 \text{ y units}} \right) = 0.0102 \text{ sec}^{-1}$$

From these transmittance values, the ABC parameters can be calculated.

$$A = (1.1 \mu\text{m})^{-1} \ln\left(\frac{0.925}{0.295}\right) = 1.04 \mu\text{m}^{-1}$$

$$B = (1.1 \mu\text{m})^{-1} \ln(0.925) = 0.0719 \mu\text{m}^{-1}$$

$$C = \frac{(1.04 + 0.0719)(0.0102 \text{ sec}^{-1})}{1.04(0.933)(2.81 \text{ mW/cm}^2)(0.295)(1 - 0.295)} = 0.020 \text{ cm}^2/\text{mJ}$$

Note that the factor 0.933 in the expression for C is τ_{12} and converts the incident intensity to I_0 .

**ABC Parameter Measurement
Data Sheet**

Investigator Chris A. Mack

Date 10 May 85

Sample # 44

Resist Kodak 820

Resist Thickness 1.08 μm

Prebake Conditions: Convection Oven

Prebake Temperature 95 $^{\circ}\text{C}$

Prebake Time 30 min

Wavelength 405.5 nm

Incident Measured Intensity (I_{inc}) 2.81 mW/cm²

Intensity Through Substrate (I_{mo}) - (optional)

From the graph (attach accompanying chart recorder trace):

Blank Substrate 6.03

Chart Speed 4 cm/min

Initial point 1.78

T(0) 0.295

Final point 5.57

T(∞) 0.925

Slope 0.924

dT/dt 0.0102

Results:

$$A = 1.04 \mu\text{m}^{-1} \quad B = 0.0719 \mu\text{m}^{-1} \quad C = 0.020 \text{ cm}^2/\text{mJ}$$

Figure 3 : Typical data for ABC measurement (see Figure 4 for graph)

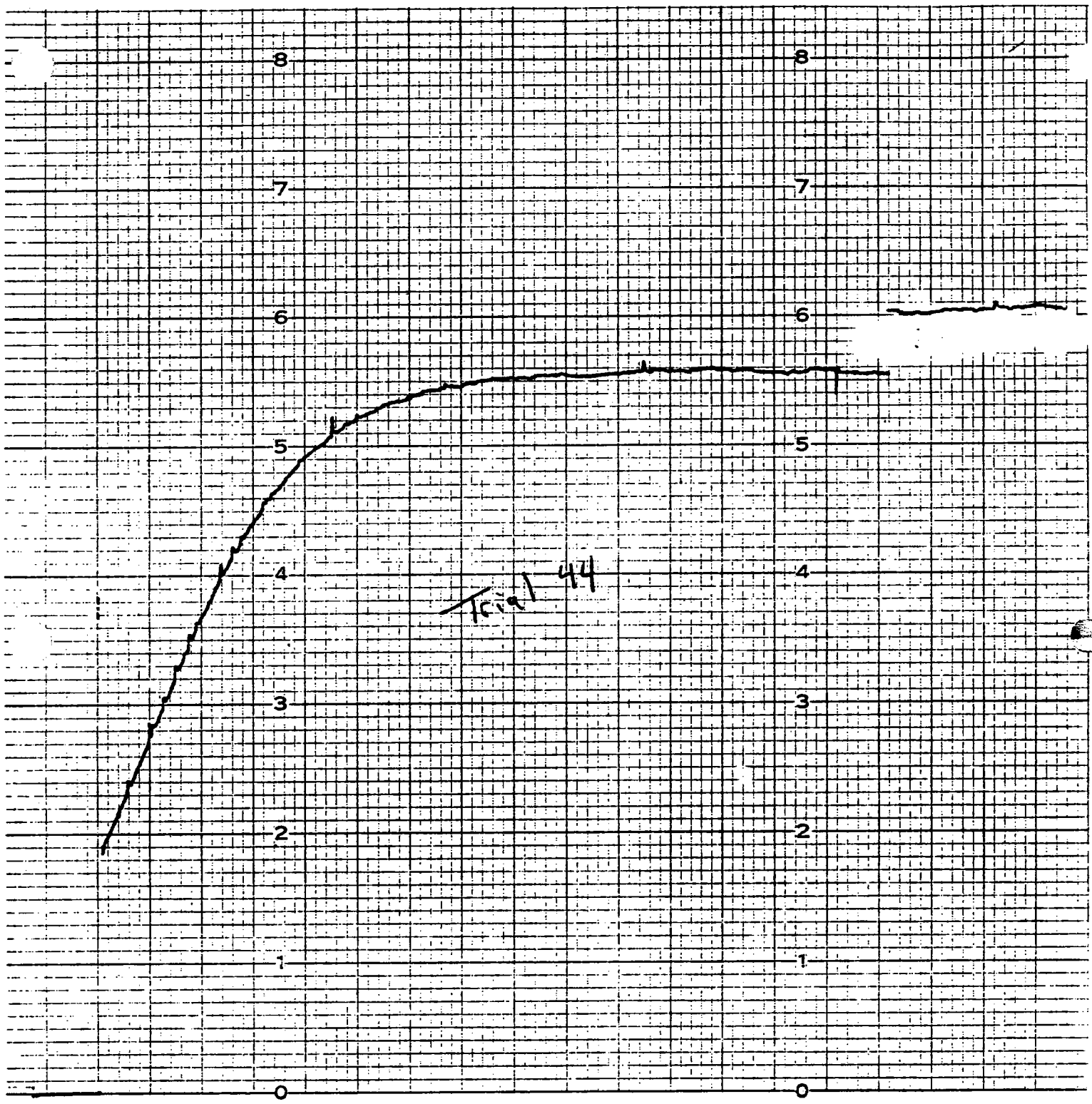


Figure 4 : Typical graph for ABC measurement (see Figure 3 for data)

Conclusions

The preceding section describes a simple experimental procedure for determining the A, B, and C parameters of a positive photoresist at a given wavelength. This experiment is a simplified version of the original method proposed by Dill [3]. Dill's method uses an A/D converter to change the UV detector signal to a digital signal that is computer compatible. The computer then uses regression analysis to determine the ABC parameters which best fit the entire curve. These "best fit" numbers were found to differ by five percent or less from the values given by a graphical approach similar to the one used in this paper [3]. Thus, the above method of determining the ABC parameters yields values which are accurate to within $\pm 5\%$.

REFERENCES

1. C. A. Mack, "Light Absorption by a Positive Photoresist," R5 Technical Report, TR-R53-17-84, (Oct., 1984).
2. C. A. Mack, "Chemistry and Kinetics of Positive Photoresists," R5 Technical Report, TR-R53-20-84, (Oct., 1984).
3. F. H. Dill, et al, "Characterization of Positive Photoresist," *Trans. Electron Dev.*, Vol. ED-22, No. 7, (July, 1975) pp. 445-452.

ABC Parameter Measurement Data Sheet

Investigator _____

Date _____

Sample # _____

Resist _____

Resist Thickness _____

Prebake Conditions:

Prebake Temperature _____

Prebake Time _____

Wavelength _____

Incident Measured Intensity (I_{inc}) _____

Intensity Through Substrate (I_{mo}) _____ (optional)

From the graph (attach accompanying chart recorder trace):

Blank Substrate _____

Chart Speed _____

Initial point _____

$T(0)$ _____

Final point _____

$T(\infty)$ _____

Slope _____

dT/dt _____

Results:

A =

B =

C =