# Radiation heat exchange 방법을 이용한 금속박막의 열전도도 측정
# Thermal conductivity measurement of thin metallic films using radiation heat exchange method

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**초 록 :** Thermal conductivities of copper thin films on silicon wafer was obtained from temperature distribution on the surface of wafer measured by radiation thermometry, when sample was heated with constant temperature ate the both ends in a vacuum and dissipate heat by radiation heat transfer into an environment.

## 1. 서 론

Few methods have been developed for thermal conductivity measurement of a thin film on a substrate. Boyce et al.[1] used a technique to pass an electric current along the film, thus creating a temperature gradient, and deduce the thermal conductivity from the measured change in resistance with time. Wieczorek et al.[2] obtained thermal conductivity from the total rise of temperature at the film surface and the rise of temperature of the bare substrate with uniform heat flux on each limited surface. The photo-acoustic method was applied to the measurement of thermal properties of thin films on substrates, which has been used for spectroscopy[3]. Picosecond transient thermo-reflectance technique was used to determine the thermal diffusivity of metallic film[4]. Above two methods are non-contacting and non-destructive to a film and independent of thermal properties of a substrate.

In this paper, radiation heat exchange method[5] was applied to the measurement of thermal conductivity of a thin film on a substrate, which has been applied for a single thin film. The advantages of the radiation heat exchange method are; i) the measurement method and apparatus are relatively simple, ii) specimen is not altered and there are no disturbances of temperature distribution. It is a disadvantage of this method that thermal conductivity of the substrate must be known. Theoretical analyses of the temperature distribution were performed in two-layered composite material with radiation heat exchange on the surface. We developed the equation which gives thermal conductivity of a sample from the temperature distribution on the surface of the substrate. Temperature measurements were carried out for sputtered copper thin films on borosilicate glass substrate to get thermal conductivity of thin metallic films.

## 2. 본 론

### 2.1 Physical statement

The composite medium consisting of the layer of substrate in $0<y<d_s$, and the layer of thin film in $-d_f<y<0$, are considered as illustrated in Fig. 1. Two layers are in perfect thermal contact. Both ends of the sample at x=-L and x=L are kept at a constant temperature $T_b$. The outer surface of the substrate at $y=d_s$ dissipates heat by radiation heat transfer into surroundings at temperature $T_e$. The outer surface of the metallic film is assumed to be insulated, and this insulated boundary condition can be obtained by using two samples metallic film surfaces of which are put into contact with each other. Since thickness of the sample is small in comparison with the width of the sample surface, heat dissipated at the surface normal to z-axis is neglected. Thus the temperature distribution over the width (along z-axis) of the sample is assumed to be uniform so that the problem reduces to two-dimensional heat conduction problem on the plane region parallel to x-y plane. The temperature difference between the surface of a sample and surroundings is assumed to be small over entire surfaces, so the usual forth power law for radiation heat transfer may be approximated by the linear formula, ${}_{h.t}(T^4 - T_e^4) = h(T - T_b) + h(T_b^4 - T_e^4)/(4 T_b^3)$ where is the Stefan-Boltzmann constant, and ${}_{h.t}$ is the hemispherical total emissivity of the surface of a substrate. The parameter of radiation heat trasfer into surroundings is given by $h = 4_{h.t}\ T_b^3$. Materials are assumed to be isotropic in thermal conductivity, and ${}_f$ and ${}_s$are thermal conductivities of the film and the substrate respectively. Some boundary conditions can be homogeneous by an introduction of the variable ${}_i = T_i - T_b$ where $T_i$ is temperature in a sample and the subscript i=1 for a substrate and i=2 for a thin film.

### 2.2 Temperature Distribution

The governing equation with boundary conditions and detailed solution procedure can be found in reference [6]. The temperature distribution along the sample is given as

$$\frac{\theta_1(x,y)}{\theta_0} = 4Bi \sum_{n=1}^{\infty} \frac{(-1)^n}{(2n-1)\pi} \frac{1}{D} \times \left[ \left(\cosh \mu_n d_f - \frac{\lambda_f}{\lambda_s} \sinh \mu_n d_f\right) e^{-\mu_n y} + \left(\cosh \mu_n d_f + \frac{\lambda_f}{\lambda_s} \sinh \mu_n d_f\right) e^{\mu_n y} \right] \cos \mu_n x \quad (1)$$

$$\frac{\theta_2(x,y)}{\theta_0} = 8Bi \sum_{n=1}^{\infty} \frac{(-1)^n}{(2n-1)\pi} \frac{1}{D} \times \cosh \mu_n (d_f + y) \cos \mu_n x \quad (2)$$

where

$$D=(Bi-\mu_n L)e^{\mu_n d_s}(\cosh\mu_n d_f-\frac{\lambda_f}{\lambda_s}\sinh\mu_n d_f)$$

$$+(Bi-\mu_n L)e^{\mu_n d_s}(\cosh\ \mu_n d_f+\frac{\lambda_f}{\lambda_s}\sinh\ \mu_n d_f)$$

$$Bi=\frac{hL}{\lambda_s},\quad \mu_n=\frac{(2n-1)\pi}{2L},\quad \theta_0=\frac{(T_b^4-T_e^4)}{4T_b^3}$$

When the sample is very thin, $d_f/L << 1$, $d_s/L << 1$, we can neglect heat flow in the direction of sample thickness and assume the one-dimensional heat flow along the sample length. The temperature distribution along the sample is given as

$$\frac{\theta(x)}{\theta_0}=\frac{\cosh mx}{\cosh mL}-1 \qquad (3)$$

where

$$m=\sqrt{\frac{h}{\lambda_f d_f+\lambda_s d_s}}$$

It is noted that for $d_f/L << 1$ and $d_s/L << 1$, the solutions Eqs. (1)-(2) of two-dimensional problem can be converted into the solution Eq. (3) of one-dimensional heat conduction problem using the Fourier series expansion of hyperbolic trigonometric functions in Eqs. (1)-(2). The conversion into one-dimensional heat conduction problem leads to get the compact form of equation for the calculation of thermal conductivity from the measured temperatures along the sample length as given as

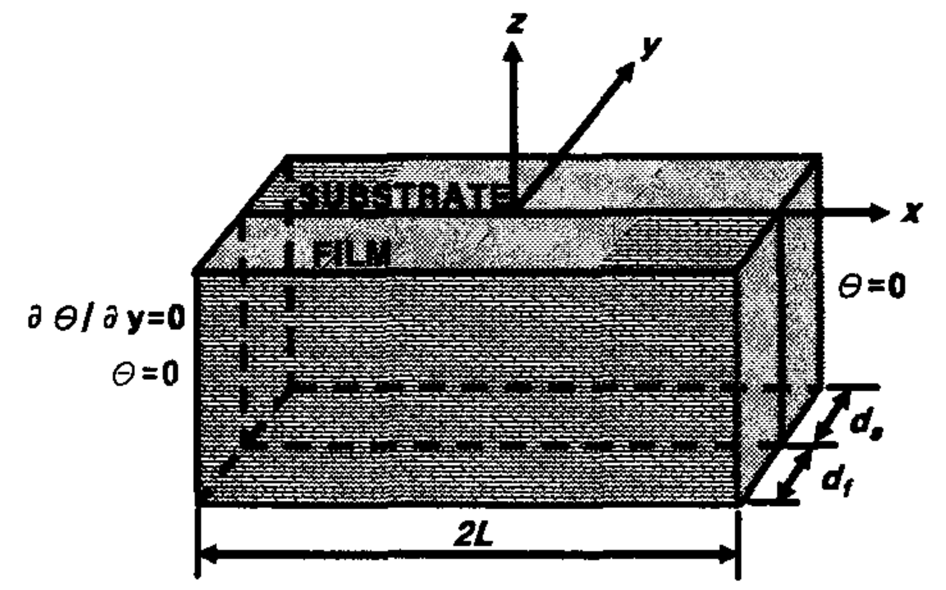

Fig. 1 Geometry and boundary conditions for theoretical analysis of a thin film on a substrate

$$\lambda_f=\frac{4\sigma\varepsilon_{h.t}T^3x^2}{d_f}$$

$$\div\{\operatorname{arccosh}[(T^4-T_e^4)/(4T^3T_m-3T^4-4T_e^4)]\}^2 \qquad (4)$$

$$-\frac{\lambda_s d_s}{\lambda_f}$$

Eq. (4) is used to get the thermal conductivity from the temperature of a sample $T$ at a position $x$ and the measured minimum temperature $T_m$ at $x$=0 in this paper.

### **2.3 EXPERIMENTS**

The apparatus for thermal conductivity measurement consists of an assembly of heating supports, a vacuum vessel with an optical window, a vacuum pumps, a thermograph and signal averager. The thermograph, whose spectral range is 8m to 13m, was in situ calibrated against a isothermal blackbody cavity in a copper block. The samples are sputtered copper thin films about 1 ㎛ in thickness on silicon wafer 100 ㎛ thick, which are assumed to be in perfect thermal contact. Thin metallic films are deposited on silicon wafer by the sputtering process. Samples were heated at both ends by the heating supports kept at constant temperature $T_b$. Two samples were used to fit the insulated boundary conditions on metallic film surface. The surfaces of substrates are brought to outer surfaces and the metallic film surfaces were put into contact with each other so that surfaces of metallic films might be insulated. The outer surfaces of substrates dissipates heat by radiation heat transfer into an environment at temperature $T_e$ surfaces and the metallic film surfaces were put into contact with each other so that surfaces of metallic films might be insulated. The outer surface of substrate dissipates heat by radiation heat transfer into an environment at temperature $T_e$. The hemispherical total emissivity of the glass substrate was experimentally determined from measurements of the temperature of the silicon wafer surface and radiation heat loss in vacuum. Thermal conductivity of the silicon wafer was measured by the radiation heat exchange method using the same apparatus. Temperature distribution along the centerline of a sample surface was measured by the infrared thermograph through a germanium window on vacuum chamber.

## 3. 결 론

A measuring method of the thermal conductivity of a thin film on a substrate using radiation heat exchange was investigated theoretically. And radiation heat exchange method can be applied to measure the thermal conductivity of a thin film on a substrate. For $d_f/L<<1$ and $d_s/L<<1$, the one- dimensional heat flow assumption along the length-direction can be used for thermal analysis in a thin film on a substrate. It should be recommended that $(\lambda_s d_s)/(\lambda_f d_f)$ is as small as possible to minimize the effect of the error in $\lambda_s$. Thermal conductivity of a thin metallic film on a silicon wafer deposited by sputtering process was lower than that of bulk metals. Wiedemann-Franz law can be applied to thin metallic films about 1 ㎛ in thickness. Thermal conductivity could be calculated from the resistivity of thin film and Lorenz number of bulk material.

## 감 사 의 글

본 연구는 과학재단 (R11-2000-086-02011-0)의 지원으로 이루어졌습니다.

## 참 고 문 헌

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