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Sensitivity Evaluation of a Love Wave Sensor with Multi-guiding-layer Structure for Biochemical Application

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Abstract: This paper presents a sensitivity evaluation of a Love wave based sensor with multi-guiding-layer structure consisting of polymethyl methacrylate (PMMA)/SiO_2/ST-90^{o}X quartz for biochemical application. A theoretical model was established to describe the wave propagation properties in Love wave devices with multilayer structure on large piezoelectric substrate. A complex dispersion equation expanded into Taylor series was presented to describe the lossy mechanism of the polymer guiding layer. Using the gold thin film as the sensitive interface to target species, the mass loading sensitivity of the Love wave sensor for biochemical application was evaluated theoretically, and the effects from the SiO_2 and PMMA guiding layers on the sensor sensitivity were investigated to allow the design of an optimized structure. From the calculated results, the optimal thicknesses of SiO_2 and PMMA in the multilayered structure were determined, and there is larger mass loading sensitivity in Love wave devices in multi-guiding-layered structure over other Love wave sensor configurations. *Copyright © 2008 IFSA.*

Keywords: Love wave, mass loading sensitivity, PMMA, SiO_2

1. Introduction

In recent years, interests for Love wave-based devices are increasing in (bio) chemical sensing application owing to low acoustic loss in contact with liquid, high sensitivity, and interdigital transducers (IDTs) protection in harsh gas and liquid environments [1-6]. Typical Love wave sensors are composed of a piezoelectric substrate with IDT pattern supporting a shear horizontal surface acoustic wave (SH SAW), a thin waveguide layer on the top of the substrate, and a receptor layer responding to a specific biocell. Due to the waveguide effect, the acoustic wave energy was trapped into the guiding layer, resulting in larger mass loading effect from the external perturbation. One of the conditions for the

Love wave formation is the SH-SAW with larger shear velocity provided by the piezoelectric substrate. The AT and ST quartz with low temperature coefficient are used widely for Love wave sensor appellation. However, low piezoelectric coefficient of such quartz substrate results in large insertion loss, which would deteriorate the frequency stability of the oscillator. Recently, a new shear horizontal (SH) wave propagating along the ST-90^{o}X quartz substrate (with Euler angles of (0^o, 132.75^o, 90^o)) by composing heavy metal IDTs was reported to provide superior temperature stability, large acoustic velocity (over 4500m/s) and higher electromechanical coupling factors (over three times than the ST-X quartz) at a small metal thickness (h/λ<0.01) [7-8]. However, there is still no any report about the Love wave application based on ST-90^{o}X quartz.

Another condition for the existence of Love wave mode is that the shear velocity in the guiding layer is smaller than the shear velocity in the substrate. As the difference of the shear velocities between the substrate and guiding layer becomes larger, the conversion efficiency of acoustic energy into the Love wave is increased, resulting in higher sensitivity to the external perturbation. Thus, the choices of the overlay material with low shear velocity, low density and low acoustic adsorption were very important. Various dielectric materials such as silicon dioxide (SiO_2), and polymers can be used as the waveguide materials [9]. SiO_2 has been widely used for Love wave sensors because it presents some advantages of good rigidity, low acoustic loss, and high mechanical and chemical resistance. Nevertheless, the polymers have some advantages over SiO_2 for Love wave sensor implementation because they are more efficient than SiO_2 in converting the bulk SH mode to the Love wave mode due to their lower shear bulk velocity and lower density as compared to that of SiO_2, resulting in an order of magnitude improvement in mass sensitivity. Also, they are easier to deposit onto the substrate than SiO_2.

Recently, a new Love wave structure containing both SiO_2 and polymer films as a multilayer waveguide was proposed, and some promising results were reported. Du et al present the new Love wave structure consists of PMMA/SiO_2/ST-quartz, which aims to utilize the merits of both PMMA and SiO_2 and improve the overall performance of the devices [10-11]. Also, due to the reversed temperature coefficients of frequency for PMMA and SiO_2 (and piezoelectric substrate), it is possible to realize a significant reduction in the temperature coefficients of the hybrid device, resulting in improvement of the temperature stability. However, to our knowledge, despite some meaningful performance of such Love wave structures, there is still no systematic theoretical study concerning the structure parameters and their influence on the sensor sensitivity, which will provide the optimal design parameters of the Love wave devices.

The purpose of this paper is to describes the Love wave propagation along the ST-90^{o}X quartz substrate using multi-guiding-layer structure as SiO_2/PMMA, as shown in Fig. 1. Also, to investigate the lossy mechanism of the PMMA guiding layer, an analytical formula relating the attenuation coefficient of the Love wave and the viscoelastic parameters of the waveguide structure was established.

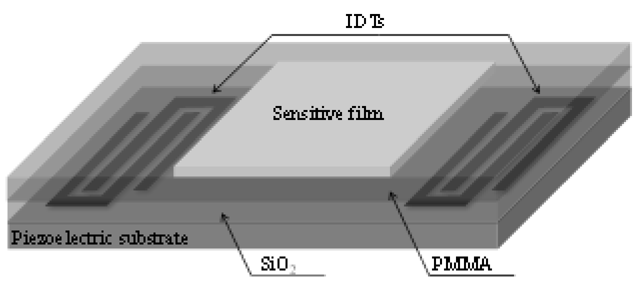

Fig. 1. Love wave devices with multi-guiding-layered structures.

The other aim of this paper is to provide the mass loading sensitivity of Love wave sensor on ST-90^{o}X with multi-guiding-layer structure using the gold as the sensitive film, and the effects from the device parameters on the sensor performance are investigated, and the optimal guiding layer thicknesses were extracted. The calculated results are consistent with the reported experimental data, and the theoretical model was valid for the simulation of Love wave propagation in multi-guiding-layered structure.

2. Theoretical Analysis

2.1. Love Wave Modelization

For the theoretical approach of the Love wave device, a structure composed of a semi-infinite piezoelectric substrate with IDT pattern, guiding layer consisting of SiO_2 and PMMA and a sensitive thin film was constructed as shown in Fig. 1. The original feature of our theoretical work is the description of Love wave propagation of the analytical resolution of motion equations, which allows us to obtain analytical expressions of the dispersion relation, so that the effects of different parameters on device performances appear clearly. A solution for an isotropic Love wave structure was given by Dieulesaint et at. [12]. Also, solution for the Love wave piezoelectric structure in the case of quartz with various cuts was presented by Zimmermann and Jakoby et al. [13, 14], in which SiO_2 was used as the guiding layer. Kielczynski established the theory of Love wave propagating in a lossy viscoelastic layer deposited on an elastic substrate, the attenuation induced by the viscoelastic polymer guiding layer was described theoretically [15].

In this paper, we propose to use this method of resolution for the Love wave mode structure in the case of an anisotropic substrate with large piezoelectricity (ST-90^{o}X quartz), guiding layers consist of SiO_2 and PMMA, and a sensitive coating (gold layer). The guiding layers and the sensitive layer are considered to be isotropic. The coordinate system for the Love wave propagation analysis is shown in Fig. 2. All the parameters of the mediums are transformed into this coordinate system. Each material in Fig. 2 is defined by its physical parameters: stiffness constant C_{ijkl}, the piezoelectric module e_{ikl}, components of permittivity ε_{kl}, density ρ for quartz (i,j,k,l=1,2,3), stiffness shear modules μ_s and μ_a, densities ρ_s and ρ_a, thicknesses h_1 and h_3 of the SiO_2 and gold. Complex shear modulus G_p: ($G_p'+jG_p''$), density ρ_p , and thickness h_2 for PMMA, here, the G_p' are the storage shear modulus, G_p'' represents the so-called loss moduli, for ideal elastic film would have G'' =0.

The phase velocity dispersion relationship of the Love wave can be calculated by solving the elastic wave equations from particle displacement u_i within Eq. (1),

$$\begin{aligned} &\rho\partial^2 u_i / \partial t^2 = C_{ijkl}\partial^2 u_k / \partial x_j \partial x_l + e_{kij}\partial^2 \phi / \partial x_k \partial x_j \\ &e_{kij}\partial^2 u_k / \partial x_i \partial x_l - \varepsilon_{ik}\partial^2 \phi / \partial x_k \partial x_i = 0 \end{aligned} \tag{1}$$

And then, due to the necessary condition for obtaining Love wave propagation in the guiding layer of shear horizontal polarization and symmetry properties in structures, the particle displacement u_i for the substrate can be reduced as Eq. (2):

$$\begin{aligned} &\rho\partial^2 u_2 / \partial t^2 = C_{66}\partial^2 u_2 / \partial x_3{}^2 + C_{44}\partial^2 u_2 / \partial x_3{}^2 + e_{16}\partial^2 \phi / \partial x_1{}^2 + e_{34}\partial^2 \phi / \partial x_3{}^2 \\ &e_{16}\partial^2 u_2 / \partial x_1{}^2 + e_{34}\partial^2 u_2 / \partial x_3{}^2 = \varepsilon_{11}\partial^2 \phi / \partial x_1{}^2 + \varepsilon_{33}\partial^2 \phi / \partial x_3{}^2 \end{aligned} , \tag{2}$$

here, u_2 is the acoustic displacement of particles in the x_2 direction, C_{44}, and C_{66} are stiffness constants, e_{16}, e_{34} are the piezoelectric module, ε_{11} and ε_{33} are the permittivity constants. The displacement u_2 and the potential φ of the acoustic wave should decrease with increasing depth into the substrate and vanish at infinity. Therefore, the solutions of eq. (1) have the following forms:

$$\begin{cases} U_2 = \beta_1 \exp(j\alpha_1 kx_3) \times \exp(jkx_1 - j\omega t) \\ \varphi = \beta_2 \exp(j\alpha_1 kx_3) \times \exp(jkx_1 - j\omega t) \end{cases}, \tag{3}$$

where β_1 and β_2 are normalized amplitudes, $k=\omega/v=2\pi/\lambda$ is the wave number (along the propagation direction), α_1 is a decay constant, and v is the phase velocity of the Love wave. To ensure the decrease in the displacement u_2 and the potential φ into the substrate, the generally complex constant α_1 must have a negative imaginary part. Then, by substituting eq. (3) into eq. (2), a set of linear homogeneous equations for the relative amplitudes β_1 and β_2 are obtained and 2 eigenvectors α_{11} and α_{12} with a negative imaginary part are deduced.

The displacement motion equation in waveguide layers (SiO_2 and PMMA) and gold film is described as

$$\begin{cases} \mu_s \partial^2 u_2 / \partial x_3 + (\rho_s \omega^2 - k^2 \mu_s) u_2 = 0 \\ G_p \partial^2 u_2 / \partial x_3 + (\rho_p \omega^2 - k^2 G_p) u_2 = 0 \\ \mu_a \partial^2 u_2 / \partial x_3 + (\rho_a \omega^2 - k^2 \mu_a) u_2 = 0 \end{cases} \cdot \tag{4}$$

Also, substituting series solutions similar to Eq. 3 into eq. (4), the decay constants for each layer can be deduced:

$$\alpha_2 = \sqrt{\rho_s v^2 / \mu_s - 1}, \alpha_3 = \sqrt{\rho_p v^2 / G_p - 1}, \alpha_2 = \sqrt{\rho_a v^2 / \mu_a - 1} \tag{5}$$

To solve these equations, we have to take into account the mechanical and electrical boundary conditions: (1) At the top of the structure (free surface of the waveguide layer (PMMA) or of the sensitive layer), there should be zero stress. (2) At the interfaces between two materials (substrate/SiO_2, SiO_2/PMMA, and PMMA/sensitive layer), there should be continuity of stress and continuity of mechanical displacement. (3) At the interface between the substrate and SiO_2, there should be continuity of the electric displacement. Using the mechanical and electric boundary conditions, the resolution of eq. (2) in the substrate and eq. (4) in the waveguide layers and sensitive film leads to the following dispersion relations:

$$h_1 = 1/(k\alpha_2) \times \arctan(-i(\lambda_1\lambda_4 + \lambda_2\lambda_3)/(\lambda_1 + \lambda_2)\mu_s\alpha_2) + n\pi/(k\alpha_2) \tag{6}$$

for the simple two-layer Love wave structure (substrate and guiding layer SiO_2), and

$$\begin{aligned} h_1 = 1/(k\alpha_2) \times \arctan[(\mu_s\alpha_2(\lambda_1\lambda_4 + \lambda_2\lambda_3) - i\lambda_5(\lambda_1 + \lambda_2)] \\ /[i\mu_s^{\,2}\alpha_s^{\,2}(\lambda_1 + \lambda_2) + \lambda_1\lambda_4\lambda_5 + \lambda_2\lambda_3\lambda_5] + n\pi/(k\alpha_2) \end{aligned} \tag{7}$$

for the three layered structure (substrate/SiO_2/PMMA). Here,

$$\begin{aligned} &\lambda_1 = i\varepsilon_{33}\alpha_{11}k_1 - ie_{34}\alpha_{11} - \varepsilon_0 k_1, \lambda_2 = \varepsilon_0 k_2 + ie_{34}\alpha_{12} - i\varepsilon_{33}\alpha_{12}k_2 \\ &\lambda_3 = C_{44}\alpha_{p1} + e_{34}k_1\alpha_{p1}, \lambda_4 = C_{44}\alpha_{p2} + e_{34}k_2\alpha_{p2} \\ &\lambda_5 = \mu_p\alpha_3 \tan(\alpha_3 kh_2), k_1 = (\rho v^2 - C_{66} - C_{44}\alpha_{11}^{\,2})/(e_{16} + e_{34}\alpha_{11}^{\,2}) \\ &k_2 = (\rho v^2 - C_{66} - C_{44}\alpha_{12}^{\,2})/(e_{16} + e_{34}\alpha_{12}^{\,2}) \end{aligned},$$

and n is an integer that represents mode order. And

$$\gamma_6(\gamma_2\gamma_3 + \gamma_3 - \gamma_2 + 1) - \gamma_5(\gamma_2\gamma_4 + \gamma_4 - \gamma_2 + 1) = 0 \quad (8)$$

for the three layered Love wave structure of PMMA/SiO_2/$LiNbO_3$ and sensitive layer. Here,

$$\gamma_1 = -(\mu_a\alpha_4 + j\mu_p\alpha_3 \tan(\alpha_4 kh_3))/(\mu_a\alpha_4 - j\mu_p\alpha_3 \tan(\alpha_4 kh_3))$$
$$\gamma_2 = (\mu_s\alpha_2 \exp(2j\alpha_2 kh_1(\exp(2j\alpha_3 kh_2) - \gamma_1) - \mu_p\alpha_3 \exp(2j\alpha_3 kh_2) + \gamma_1))/$$
$$(\mu_s\alpha_2 \exp(2j\alpha_2 kh_1(\gamma_1 - \exp(2j\alpha_3 kh_2)) - \mu p\alpha_3 \exp(2j\alpha_3 kh_2) + \gamma_1))$$
$$\gamma_3 = (c_{44}\alpha_{11} + e_{34}k_1\alpha_{12})/\mu_s\alpha_2, \gamma_4 = (c_{44}\alpha_{11} + e_{34}k_2\alpha_{12})/\mu_s\alpha_2$$
$$\gamma_5 = j\varepsilon_{33}\alpha_{11}k_1 - je_{34}\alpha_{11} - \varepsilon_0 k_1, \gamma_6 = j\varepsilon_{33}\alpha_{12}k_2 - je_{34}\alpha_{12} - \varepsilon_0 k_2$$

From eqs. (6) - (8), the Love wave phase velocity versus layer thickness and mechanical properties can be calculated. Also, the mass loading effect for biochemical application is modeled by considering that the sorption of compounds modifies only the sensitive layer density (ρ_a in Fig. 2), and it is defined as the velocity change $\Delta v/v_0$ in this paper. Thus, using the eqs. (6)-(8), the mass sensitivity for different structures can be predicted.

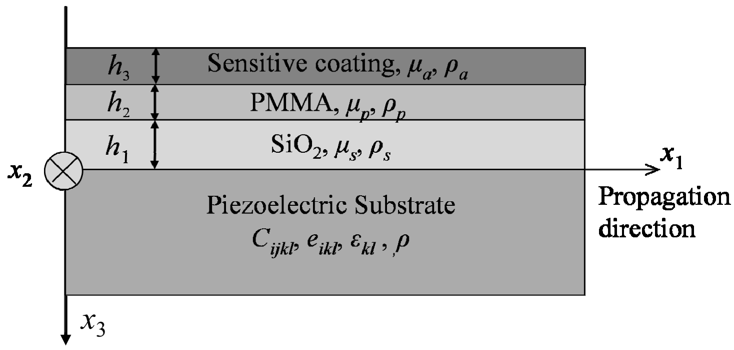

Fig. 2. The coordination system used in this work (x_1: propagation direction, x_2: SH waves polarization direction).

2.2. Lossy Mechanism of PMMA Layer

Due to the viscoelastic nature of the polymer guiding layer as PMMA with complex shear modulus of G ($G' + G''$), the lossy mechanism can be considered using the complex dispersion equation expanded into Taylor series at given SiO_2 thickness h_1, referring to the method of numerical calculation of Ref.15, the complex dispersion Eq.(8) can be written as

$$\Phi(k, G, \omega, \rho, \rho_s, \rho_p) = 0, \quad (9)$$

where Φ is identical to left side of Eq.7. The quantities ρ_s, ρ_p and ω in Eq.(9) are real, while quantities k and G are complex. Then, treating the quantities k and G as variables, the dispersion Eq.(7) can be expanded into the Taylor series about the point (k_0, G′) with respect to small increments (α, G″) and, neglecting terms higher than linear, a new dispersion equation can be obtained:

$$\Phi(k, G) = \Phi(k_0, G') + \left.\frac{\partial\Phi}{\partial k}\right|_{\substack{k=k_0\\G=G'}} \cdot j\alpha + \left.\frac{\partial\Phi}{\partial G}\right|_{\substack{k=k_0\\G=G'}} \cdot jG'' = 0. \quad (10)$$

The partial derivatives in Eq.(10) are calculated at the point (k_0, G′) for given values of the parameters ρ_p, ρ_g and ω. the solution of Eq.(10) requires that both the real and imaginary parts be set equal to zero. By equating to the zero to the real part of Eq.(10), we have the eq.(7) By equating to zero an imaginary part of Eq.10, we obtain

$$\alpha = -G''.\frac{\partial \Phi}{\partial G}\bigg|_{\substack{k=k_0\\ G=G'}} / \frac{\partial \Phi}{\partial k}\bigg|_{\substack{k=k_0\\ G=G'}}, \tag{11}$$

Performing calculations in Eq.7 and 11, we have

$$\alpha h_2 = -\frac{G''}{G'}\times\frac{\frac{1}{2\cos^2(Ah_2)}\frac{\rho_p.v^2}{G'}\times(k_0h_2)^2+\tan(Ah_2)[\frac{1}{2Ah}\frac{\rho_p.v^2(k_0h_2)^2}{G'}-Ah_2]}{\frac{k_0h_2}{\cos^2(Ah_2)}+\frac{\rho_p C_{44}k_0h_2}{BG'h_2(C_{44}C_{66}-C_{46})}+\tan(Ah_2).\frac{k_0h_2}{Ah_2}} \tag{12}$$

$$A=\sqrt{\rho_p w^2/G'-k_0^2},\ B=\pm\sqrt{k_0^2-w^2\rho C_{44}/(C_{44}C_{66}-C_{46})}$$

Equation 12 shows an analytical formula for the normalized attenuation coefficient of the Love wave αh_2 as a function of the normalized PMMA thickness $k_0 h$, also, it presents that attenuation coefficient of the Love-wave is directly proportional to the imaginary part of shear modulus G.

2.3. Mass Loading Sensitivity

The sensitivity to surface mass loading for biochemical sensor can be defined as a relative change of oscillation frequency due to mass loading of the surface, i.e.,

$$S_m = \lim_{\Delta M\to 0}\frac{\Delta f}{f_0}/\frac{\Delta M}{A}(cm^2g^{-1}), \tag{13}$$

where $\Delta f/f_0 \approx \Delta v/v_0$ is the frequency change due to the mass loading ΔM, which can be calculated using the dispersion relationship of Eq. (8) for given guiding layer thickness. A is the sensitive film area.

3. Numerical Results and Discussion

In this section, we illustrate the numerical results of fundamental properties of the Love wave from a layered structure of PMMA/SiO_2/ST-90^{o}X quartz, dispersion relation, and particular sensitivity to mass loading on the sensitive film. The stiffness constants, piezoelectric modules and permittivity constants of quartz are obtained from Ref.16. The stiffness shear constants and densities of SiO_2, PMMA and gold are shown in Table.1.

Table 1. Material parameters of the PMMA, SiO_2 and gold.

Materials	**Stiffness shear constant (*GPa*)**	**Density (*g/cm*^{3})**
PMMA	1.7	1.17
SiO_2	31.2	2.2
Gold	42	19.3

3.1. Dispersion Relation

As shown in eqs. (6)-(7), the Love wave with multilayered structure is dispersed and multimode. To simplify the calculation, the PMMA guiding layer was assumed as ideal elastic film with G″=0. First, the dispersion curves of the Love wave structure of SiO_2/ST-90°X was calculated employing Eq.(6). Fig. 3(a) shows the phase velocity as a function of normalized layer thickness kh_1 (k: wavenumber depending on the operation frequency and h_1: SiO_2 thickness) for the fundamental mode and the next three Love modes in SiO_2/ ST-90°X. With increasing of the SiO2 guiding layer thickness, the Love wave velocity is close to the shear velocity of SiO2, around 3780 *m/s*. Under the given SiO_2 thickness (kh_1:2), the Love wave propagation in the multilayered structure of PMMA/SiO_2/ST-90°X is shown in Fig. 3 (b) using Eq. (7). In the case of the fundamental mode with very thin PMMA layer, most of the acoustic energy propagates in the SiO_2 layer and, consequently, the phase velocity is close to the shear velocity of SiO_2. With increasing waveguide layer thickness, the wave velocity is decreased, and for very thick layers it approaches the shear velocity of PMMA (around 1200 *m/s*). Moreover, the number of Love wave modes is decreased even if only one mode exists in the thin guiding layer. Usually, the particle displacement on the surface of the PMMA layer increases with increasing overlayer thickness, which results in more sensitive to surface perturbations. However, as the PMMA thickness increases, the attenuation in the PMMA becomes the predominant mechanism of acoustic loss due to the viscoelatic property of the polymer film, so it can't be ignored and discussed as below.

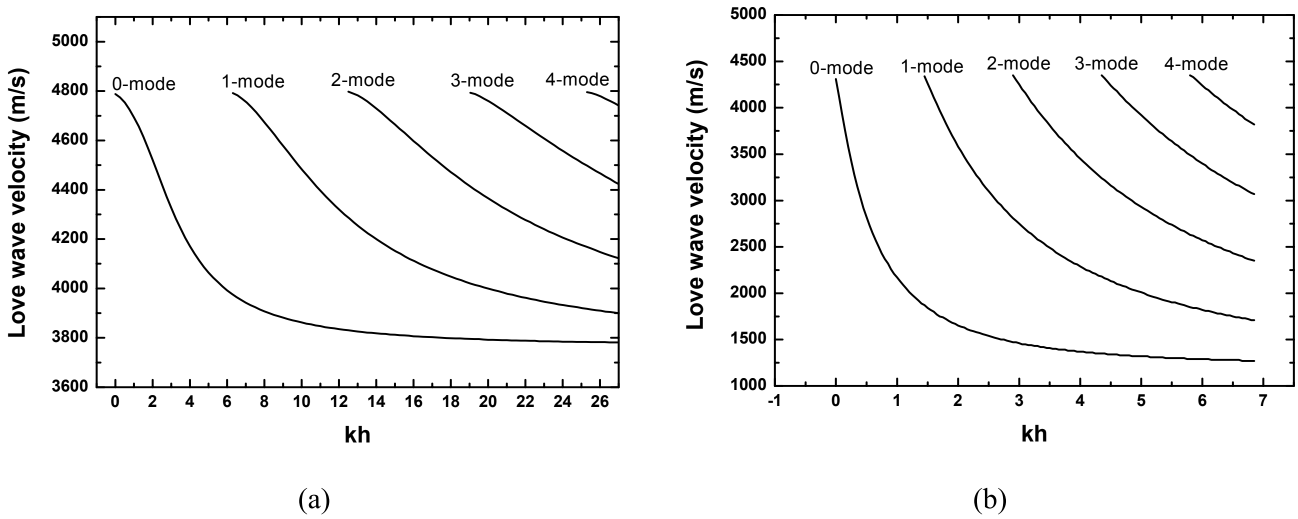

Fig. 3. The dispersion calculation of the Love wave in two layer structure SiO_2/ST-90°X quartz (a) and multilayered structure PMMA/SiO_2/ ST-90°X quartz (b).

3.2. Attenuation Coefficient of PMMA Guiding Layer

The dispersion curves of the attenuation coefficient αh_2 versus PMMA thickness h_2 at different operation frequencies (represented as different wavelengths, 10λ and 20λ) and given fractional SiO_2 thickness kh_1 of 2 was calculated from Eq. 12 as shown in Fig. 4. In this simulation, the complex shear modulus of the PMMA is assumed as $1.7e^{10}+j\times1.4e^{8}$ *Pa*. From the picture, the αh increases monotonically with the layer thickness h, also, large attenuation coefficient αh is observed at higher operation frequency (10λ). From the calculated result, it shows that the thick PMMA guiding layer will induce large acoustic attenuation of the Love wave devices. This suggests that the lossy nature of the polymer film determine the optimum guiding layer thickness of the Love devices and should be taken into account when designing an efficient Love wave device and the suitable normalized thickness (kh) of the PMMA guiding layer can be considered small than 1 in our work.

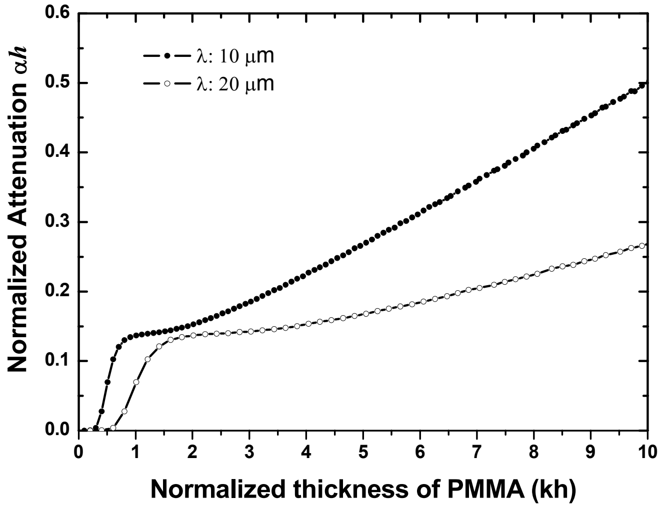

Fig. 4. The attenuation coefficient versus PMMA guiding layer thickness as a function of different operation frequency.

3.3. Guiding Layer Thickness Influence on the Mass Sensing

In this calculation, the Love wave devices are assumed to fabricate on ST-90°X quartz with gold IDTs pattern with metal thickness (h/λ) of 0.05, thus, a ~4750 m/s shear velocity can be obtained [7]. The periodicity of the IDT is assumed as 40 μm. The size of Love wave devices (A) is 15 mm×12 mm. A gold film (h_3: 50 nm) was deposited onto the PMMA surface as the sensitive film toward to the target species. Using the Eq. (8) and Eq. (13), the mass loading sensitivity of the Love wave sensor with multi-guiding-layer (PMMA/SiO_2/ST-90°X quartz) structure can be computed using the sensitive film density change $\Delta\rho_a$ due to mass loading effect. The mass change of the sensitive film ΔM can be obtained approximately using $\Delta M=\Delta\rho_a\times A\times h_3$. First, the mass sensitivity evaluation of the Love wave sensor with two layer structure (PMMA/ST-90°X quartz and SiO_2/ST-90°X) are performed to extract the optimal thickness of the PMMA/SiO_2 guiding layer, as shown in Fig. 5. From the picture, we can found that there are the max mass sensitivities of 72 m^2/kg and 30 m^2/kg in case of 2.2 μm PMMA layer and 6.2 um SiO_2, respectively; owing to the lower shear velocity and lower density, the PMMA guiding layer is more efficient than SiO_2 in converting the bulk SH mode to the Love wave mode, resulting in larger mass sensitivity over SiO_2. However, due to the visco-elastic property of polymer film, higher thickness would induce larger acoustic attenuation mentioned in Fig. 4. Compromising the attenuation induced by the PMMA itself (Fig. 4) and mass sensitivity evaluation (Fig. 5) synthetically, we can find that the optimal thickness of the PMMA guiding layer was smaller than 2 μm. Therefore, the guiding layer thickness is assumed as 2 μm in the following calculation, and it is similar to the results obtained by Gizeli et al [6].

Then, under the given PMMA thickness of 2 μm, the optimal SiO_2 thickness for the mass loading sensitivity of the Love wave sensor with multi-structure can be calculated, as shown in Fig. 6. The max mass sensitivity (108 m^2/kg) was observed in the SiO_2 thickness of 3.2 μm, and it is better than the two-layer Love wave structure of PMMA/substrate and SiO_2/substrate. The calculated results are consistent with the experimental data in Table 2 [10], in which, a Love wave sensor with PMMA/SiO_2/ST-quartz was reported, larger mass sensitivity was obtained using the multilayer structure of 2.2 μm SiO_2/1.4μm PMMA over other Love wave structures. It demonstrates the validity of the theoretical analysis of the Love wave sensor with multilayer structure in this paper. The calculated results indicate that the Love wave sensors with multi-guiding-layered structure are very promising for the bio(chemical) application owing to their larger mass loading sensitivity. The experiment for the Love wave devices on multi-guiding-layer structure of PMMA/SiO_2/ST-90°X quartz will be performed in the future work.

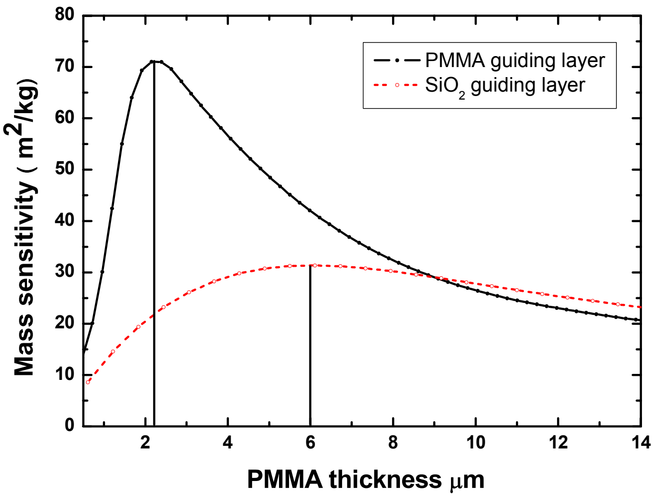

Fig. 5. Effects of PMMA and SiO_2 guiding layer thicknesses on Love wave sensor mass sensitivity.

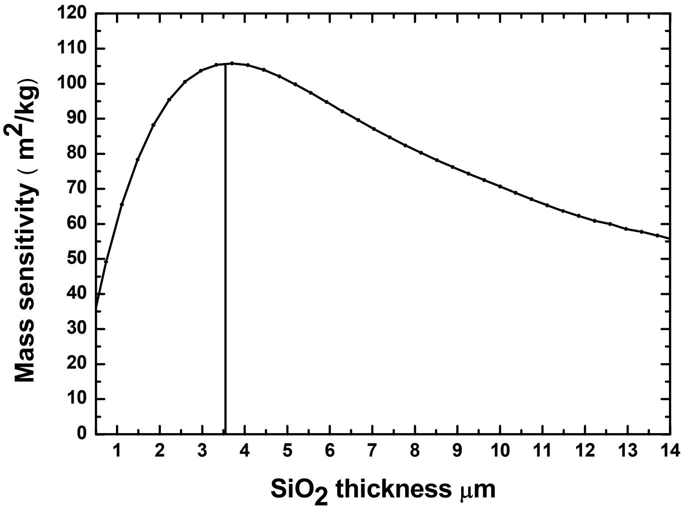

Fig. 6. Effect of normalized SiO_2 thickness on mass loading sensitivity of Love wave device with PMMA/SiO2/ST-90°X quartz under 2 µm thick of PMMA layer.

Table 2. The mass sensitivity of SiO_2 Love mode, PMMA Love mode and PMMA/SiO_2 Love mode on ST-quartz [10].

Device characteristics	Sensitivity (m^2/kg)	Device characteristics	Sensitivity (m^2/kg)	Device characteristics	Sensitivity (m^2/kg)
2.2µm SiO_2	12.6	1.53µm PMMA	9.9	2.2µm SiO_2/1.4µm PMMA	51.9
3.2µm SiO_2	25	1.9µm PMMA	31.3	3.2µm SiO_2/1.16µm PMMA	41
1.25µm PMMA	5.9	2.2µm SiO_2/1.18µm PMMA	41.5		

4. Conclusion

A theoretical analysis on the sensitivity evaluation of Love wave sensor with multilayered structure was performed. The Love wave propagation in PMMA/SiO_2/ST-90°X was described using the dispersion curves. The lossy mechanism of the polymer guiding layer as PMMA was investigated using the complex dispersion equation expanded into Taylor series. Using the gold as sensitive film, the mass loading sensitivity of the Love wave sensor with multilayer structure was calculated, and the optimal guiding layer thickness was determined.

Acknowledgments

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