Study of Porous Materials Acoustic Signatures Behaviour in Dark Field

S Bouhedja, F Hamdi, A Doghmane and Z Hadjoub

1Laboratoires des Hyperfrequences et Semi-conducteurs, Université de Constantine; B.P. 125, DZ-25000 Algeria
2Laboratoire des Semi-Conducteurs, Département de Physique, Faculté des Sciences, Université Badji-Mokhtar, BP 12, Annaba, DZ-23000, Algeria.

E-mail: bouhedja_samia@yahoo.fr ; a_doghmane@yahoo.fr

Abstract. Several kinds of lens-transducer system exist in the scanning acoustic microscope. In this work, annular lenses are chosen in order to quantify the occultation limiting angle to suppress Rayleigh mode generation. Hence, we have numerically simulated, through variable occultation of generated rays at the lens center, the porous silicon acoustic signatures at an operating frequency of 142 MHz. In non destructive control, this investigation is of a great importance in the measurement of the surface waves attenuation. The obtained results enabled us to evaluate the maximum relative occultation at Rayleigh waves.

1. Introduction

Scanning acoustic microscope (SAM) is a key technique not only in qualitative micro characterizations, but also in quantitative measures [1, 2]. In micro-analysis, it can be used to directly determine the mechanical properties of materials via acoustic signatures, V (Z); this signature is obtained by recording the change in the reflected acoustic signal with the defocusing distance, z, as the sample is moved towards the acoustic lens [3]. Hence, acoustic microscopy is applied in fundamental research as well as in industry. It can successfully be used in the investigations of porous materials in general and porous silicon, PSi, in particular.

Several types of acoustic microscopes can be designed with various forms of transducer lens systems such as linear acoustic microscopy, spherical concave transducer, flat lens microscope, low opening lens-angle and annular lenses etc. [4, 5]. For annular lens acoustic microscope, the incident energy on the central part of the transducer is blocked by using an absorbing stop that blocks the transmission of the central ultrasound beam. This type of lens was mainly used in a qualitative way in the dark field imaging to examine objects with high transmission and low diffraction [6, 7]. On the other hand their applications in quantitative control remain still a subject of investigations.

The dimensions of these stops could be varied in order to study the influence of the occultation of the central energy in acoustic materials signatures. This leads to a better understanding of the interaction incident and reflected beams. Hence, this would be of great importance in optimizing the characteristics of transducer-lens system as well as improving the generation of surface modes.

Published under licence by IOP Publishing Ltd
In this context, we proceed via a program that simulates the oscillations of the acoustic signature, in dark field. We first show the effects of porosity on the Rayleigh mode and the amplitude of the acoustic signature. Then, we evaluate the angle of maximum decrease and therefore the attenuation of the signal $V(z)$ at this critical angle.

2. Methodology

In the theory of acoustic microscopy, the angular spectral model [8] is the most widely used to calculate the acoustic materials signature which is written as:

$$V(z) = \int_0^{\pi/2} P(\theta) R(\theta)^2 \sin \theta \cos \theta \exp(2ikz \cos \theta) d\theta$$

(1)

$R(\theta)$ is a complex function which allows amplitude and phase is given by:

$$R(\theta) = \frac{Z_L \cos^2 2\theta_L + Z_T \sin^2 2\theta_T - \rho_{liq} V_{liq}/\cos \theta}{(Z_L \cos^2 2\theta_L + Z_T \sin^2 2\theta_T + \rho_{liq} V_{liq}/\cos \theta)}$$

(2)

In this work we focus on the effect of the dark field on the attenuation of Rayleigh waves propagating in PSi. We have therefore used the relations given by the theory of elastic media [9, 10] to write the dependence of velocity, $V$, and porosity, $P$, as:

$$V_{RP} = V_R(1 - P)^{1.095}$$

(3)

Porosity is, by definition, the ratio of the volume of the vacuums to the total volume of the body considered. Its value remains unchanged by dilation/contraction of all dimensions of the structure) [11]. The density of PSi is also given by the following expression:

$$\rho_{PSi} = \rho_S(1 - P) + \rho_{liq} P$$

(4)

3. Condition of simulation

The removal of surface modes has been applied to lenses with a large half-opening angle (50°) whose center was occulted by stops of variable diameters. The methodology consists of covering, by an absorbing material of circular form, the central part of the lens [5] then calculating $R(\theta)$ and $V(z)$ for each occulted angle, $\theta_{occ}$. In order to compare some results, we considered both crystalline and porous. It should be noted the PSi possess good photoluminescent properties [10,12] that are applied in many modern technologies and the industrial fields.

Calculations are performed under normal operating condition of simulation of a scanning acoustic microscope operated in the reflection mode: the working frequency is 142 MHz, a half-opening angle of 50° and water as coupling fluid (velocity = 1500 m/s and density ($\rho$) = 1000 kg/m$^3$) and silicon ($V_L = 9160$ m/s, $V_T = 5085$ m/s, $\rho_{Si} = 2300$ kg/m$^3$). Note that these conditions favour the excitation of the Rayleigh mode which represents the most dominant mode.

4. Influence of illumination intensity on $V(z)$: results and discussion

Figure 1 illustrates the amplitude (— — —) and the phase (——) of the reflection coefficient as functions of the incidence angle for water/silicon interface. $R(\theta)$ provides important information on the angles of different excited modes. It is clear that as $\theta$ increases, the longitudinal mode appears first at $\theta_L = 9.43°$ and the transverse mode occurs at $\theta_T = 17.16°$. Beyond it, all the energy is reflected, this is due to the absence of transmission in the solid and, therefore, the module $R(\theta)$ becomes constant and equal to unity. However, the biggest fluctuation in phase occurs a few degrees after $\theta_T$; this corresponds to the excitation of Rayleigh waves at $\theta_R = 18.54°$. Note that the $R(\theta)$ phase changes with
2π for a very small change in θ. The shaded area corresponds to the different diameters of stop absorbing.

Figure 1. Amplitude (---) and phase (——) of the reflection coefficient as functions of incidence angle for water/silicon interface.

4.1. Bulk Silicon

Figure 2 shows V(z) curves at different occulted angles for the structure water/Silicon. It is clear that as θ_{occ} increases the apparent period increase and the oscillation amplitude decreases. These results are in agreement with those recently reported [13, 14]. For the largest occulted angle, the amplitude of the oscillations of the acoustic signatures tends towards an exponential decay of type: \( A e^{-\alpha z} \) where \( A \) is the amplitude of \( V(Z) \) at the focal distance \( Z = 0 \mu m \) and \( \alpha \) is the total attenuation of the wave of Rayleigh in material considered.

This attenuation can be evaluated by using an optimization method for fitting of the curve \( V(Z) \) by a mathematical function; it is found to be 0.041 \( \mu m^{-1} \) in the case of water/Silicon structure.
Porosity effects on $V(z)$ curves are shown in Figure 3 for water/PSi (at $P = 20\%$) and in Figure 4 for water/PSi (at $P = 47\%$). Similar observations, as above, can be formulated.

![Figure 3](image3.png)

**Figure 3.** Effects of occultation angles on acoustic signatures for Water/PSi at $P=20\%$.

![Figure 4](image4.png)

**Figure 4.** Effects of occultation angles on acoustic signatures for Water/PSi at $P=47\%$.

The decrease in amplitude of signatures $V(Z)$ as well with focal distance ($Z = 0\ \mu m$) as for the other distances from defocusing is explained by the fact that the distribution of energy at the transducer decreases. For a porosity of 20\%, we note that with $\theta_{occ} = 17.5^\circ$, the oscillations persist and disappear only at $\theta_{occ} = 22^\circ$. Consequently we find the value of the total attenuation equalizes with $0.038\mu m^{-1}$. For 47\% porosity, the oscillations disappear for $\theta_{occ} = 38^\circ$ accompanied by a total attenuation of about $0.023\ \mu m^{-1}$. 
In order to quantify the effects of porosity, we plot on Figure 5 the shift the critical angle of excitation of Rayleigh, \( \theta_R \), as a function of porosity. Two important observations are deduced from this study: the first is the shift of the critical angle of excitation of Rayleigh, \( \theta_R \), to large values when the porosity increases. This is explained by the presence of air in the pores.

![Figure 5. Effects Variation of the apparent shift of Rayleigh Angle with Porosity.](image)

The second consequence concerns the wave attenuation. We found that the value of the attenuation decreases as the porosity increases. This result is physically acceptable since the Rayleigh velocity of PSi decreases with porosity. In the same context, we calculated the values of the attenuation of the wave function of the porosity at the same angle occulted and we found that the attenuation values increased gradually as the porosity increases. This is due the presence of air in the pores that leads to ultrasonic attenuation.

5. Conclusion

In quantitative dark field investigation, we found that the decrease of the energy distribution at the transducer strongly influences both the amplitude of acoustic signatures as well as their periods. This threshold angle of total disappearance of \( V(z) \) oscillations shift to large values when the porosity increases. The decay in \( V(z) \) curves with porosity is related to Rayleigh total attenuation. This parameter is found to be much lower for porous Silicon. Note that the attenuation at the same angle of occultation increases when the porosity increases.

6. References

[1] Briggs A 1995 Advances in Acoustic Microscopy Ed (Plenum Press, New York Technical).
[2] Zinin P V 2001 Handbook of Elastic Properties of Solids, Liquids and Gases, Ed Levy, Bass and Stern (Academic Press) vol 1. p.187
[3] Achenbach J D 1993 Ed Evaluation of Materials and Structures by Quantitative Ultrasonic, (Springer, Verlag)
[4] Hadjoub Z, Alami K, Doghmame A, Saurel J M, Attal J, 1991 Electron.Lett. 27 11 981
[5] Doghmame A, Hadjoub Z, 1997 Appl. Phys. 30 2777
[6] Smith I R, Wickramasingh, H K e. 1982 Electron. Lett, 18 22 955.
[7] Al-Surayhi I, Doghmame A, Hadjoub Z 2009, Damage and Fracture Mechanics (Springer Verlag) p 415
[8] Sheppard C G R, Wilson T. 1981 Appl. Phys. Lett. 38 858.
[9] Da Fonsesa R J M Y, Saurel J M and Despaux G. 1994, Appli, Surf, 16, 21
[10] Boumaiza Y, Hadjoub A, Doghmane A, Deboub L 1999; J. Mat. Scie. Lett 18 295
[11] Bourbié T, Coussy O, Zinszner B 1986, Ed TEHNIP.
[12] Da Fonsesa R J M, Saurel J M, Foucaran A 1995 Appli. Surf, Scie, 255 155
[13] Bouhedja S, Hadjoub I, Doghmane A & Hadjoub Z 2005, Phys.Stat. Soli. (a) 202 1025-1032
[14] Bouhedja S, Hadjoub I, Doghmane A and Hadjoub Z 2009 J. optoelec. Advanced. mat. Symp, 1 420-423