Acoustic Attenuation in Silica in the 100-250 GHz Range Using Colored Picosecond Ultrasonics

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Attenuation in the hypersonic range

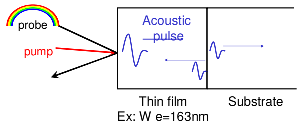
Abstract

We report on new measurements of the attenuation of longitudinal acoustic waves in vitreous silica using picosecond ultrasonics. We present a new way of using this ultrafast technique which overcomes the difficulties encountered in the pioneering work of H. J. Maris.

[P. Emery, A. Devos, Applied Physics Letters 89, 191904 (2006)]

Picosecond Ultrasonics

Ultrafast technique based on a pump-probe scheme that enables non destructive mechanical measurements on µm to nm scale stacks

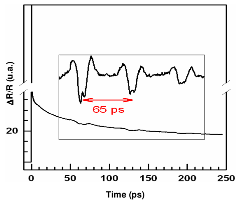


The given example illustrates the classical Picosecond ultrasonic technique to measure acoustic attenuation

Any materials[4] :

Comparison between the Fourier transform of the successive ehoes

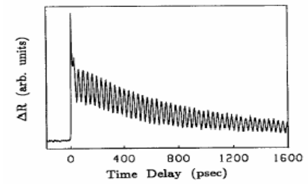
- A high impedance contrast is needed to produce several echoes,
- Reflections at the free surface can affect the result



Transparent materials[5] :

Analysis of the damping of the Brillouin oscillation

- Needs thick sample to reveal the low frequency oscillation and the attenuation effect

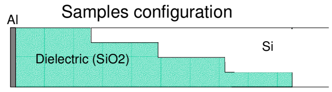


4 C. Thomsen, H. T. Grahn, H. J. Maris, J. Tauc, Phys. Rev. B 34, 6, p4129 (1986)
5 H. –N. Lin, R. J. Stoner, H. J. Maris, and J. Tauc, JAP 69, 3816 (1991)

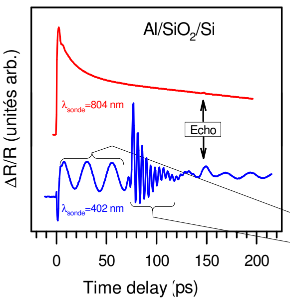
Protocol description and Experimental results

Definition : The protocol enables attenuation measurements in thin films. We measure α, defined by: Along the distance *z*, the acoustic energy is attenuated by a factor $e^{-\alpha z}$ at a given frequency[6]

Samples configuration



In some cases attenuation has to be measured in thin films deposited on a substrate with a low impedance contrast :



Classical technique :

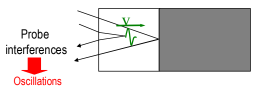
No impedance mismatch

- 1 weak echo !!

Wavelength protocol :

2 frequencies come out

- 40 GHz (travelling in Silica)
- 240 GHz (travelling in Silicon)



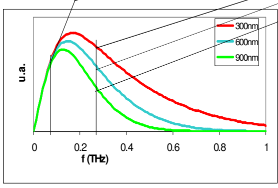
6 P. Emery, A. Devos, Appl. Phys. Lett. 89, 191904 (2006)
7 A. Devos, R. Côte, G. Caruyer and A. Lefèvre, Appl. Phys. Lett. 86, 211903 (2005)

The probed frequency depends on the material characteristics[7]

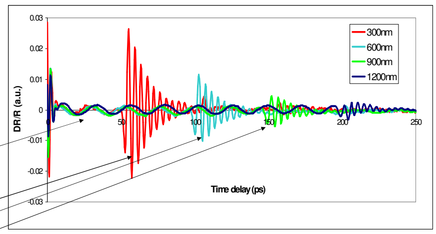
In thin films, high frequencies are needed to be sensitive to the attenuation effect on small distances ~ a few 100 nm

f_{SiO2} = 40 GHz (negligible)

f_{Si} = 240 GHz (measurable)



Strain pulse Fourier components after different propagation distances assuming a f^2 dependent attenuation coefficient



Superimposition of experimental results obtained on 4 thicknesses of SiO2 (300, 600, 900, 1200nm) probed at 400nm

Results :

measured **energy** attenuation at 236 GHz in *v*–SiO_2 (LPCVD sample)

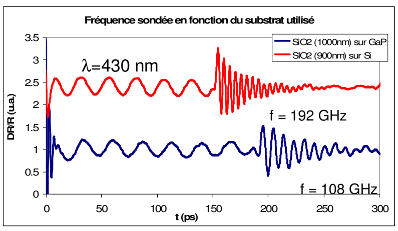
α = 5,1 ± 0,9 .10^{-3} nm^{-1}

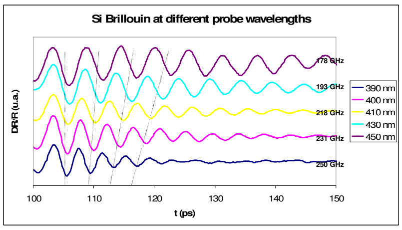
(corresponding to β=1.16 ± 0,2.10^{-3} nm-1.THz^{-2} strain field)

Wide band results : Using different probe wavelengths and substrates, the protocol can provide attenuation measurements in the hypersonic frequency range

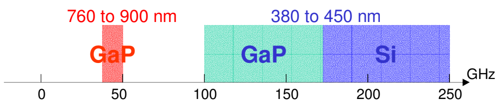
$$f = \frac{2nv\cos\theta}{\lambda}$$

Use of different substrates — Use of different wavelengths



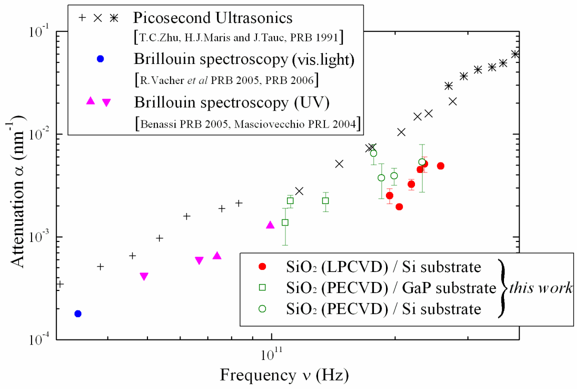


Achievable frequency range :



Results :

frequency dependence of LA attenuation in *v*–SiO_2 at 300 K



Conclusion

- We measured a LA attenuation for *v*–SiO_2 two times lower than that found in the pioneering work of H.J.Maris [Zhu *et al* PRB **44** 4281 (1991)].
- Our results seems to be in line with a quadratic frequency dependence of attenuation up to 250 GHz.