RECENT PROGRESS IN SIGNAL PROCESSING FOR THE ACOUSTIC SIGNATURE IN HIGH FREQUENCY.

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Abstract

The accuracy of the so called acoustic signature V(z) in acoustic microscopy high frequency is limited in high range of surface acoustic velocity mode (4 ~ 5000 m/s) and small area analysis (< 10µm²) due to the poor numbers of maximum or minimum in interference patterns. Besides this problem, their amplitudes, connected to the efficiency of the leaky waves are sometimes so small, especially for skimming longitudinal and transverse modes, that no measurement of these velocities was possible or accurate in the best cases. This work is based on the new high frequency scanning acoustic microscope (0.5-1.2 GHz) developed in the laboratory, upgraded by a full digital data acquisition system at a sampling frequency of 4 GHz. This instrument allows module and phase measurement and thus analysis of the complex V(z) in real time.

Introduction

In high frequency scanning acoustic microscopy (500MHz and more), the signal processing is analog and usually the phase of the signal is not available. Moreover, the fluid attenuation limits the lens object distance and thus the defocusing. Then, the measurement accuracy of surface acoustic velocity mode is limited around 0.5% and fast modes are difficult to measure.

A new high frequency scanning acoustic microscope (0.5-1.2 GHz) was developed in the laboratory, upgraded by a full digital data acquisition system. This instrument allows module and phase measurement in real time.

The traditional data processing is implemented by two new signal processing. First we use a spatial derivative method, along the defocusing axis, to reduce coherent noise and remove unwanted echoes limiting the defocusing. Thus the obtained signal is free from any spurious interferences across a large temporal window.

The second process is a vectorial one to enhance the signal to noise ratio and provides measurement at large defocusing distances in case of fast propagation mode. For surface acoustic velocity modes below 4 ~ 5000 m/s this vectorial process allows to reduce the area analysis by a microdefocusing technique.

New instrumentation

This new instrumentation can image samples sized from 50 µm x 50 µm to 90 000 µm x 90 000 µm and perform acoustic signature V(z). The frequency sensors is ranged between 500 MHz and 1200MHz in emission reflection or transmission mode. Plane or focused sensors are used.

The input signal is a sinusoidal tone burst down to 10 ns wide switched by MMIC switches with a peak power around 1W depending of the sensor.

The receiver is a flash digitising device in single shot mode. The maximum sampling (in single shot) is 4GHz on 8 bits with a fast storage data system.

A particularity of this acquisition system is the synchronization that minimizes the wait state. If there are too much data for a real time transfer to the computer, they are stored in the acquisition board and transferred during the displacement back of the mechanical part of the SAM system. All this system allows a fully digital signal acquisition and many digital signal processing unavailable with an analog system.

Digital signal processing

The traditional analog data processing is now fully digitised. To reject a maximum of noise we use a vectorial treatment. With the sampled signal and the reference acquired separately the amplitude and the phase of the signal is computed for all windows timing. For a 600 MHz central frequency sensor, the Figure 1 presents the raw sampled signal with amplitude and phase in a time windows of 100 ns. We can notice on the part where there is no acoustical echo, that the amplitude is very low and the phase noisy.

Using these curves (amplitude and phase) we first calculate the amplitude and the phase of the echo. Many methods are possible, such as to extract the maximum of the amplitude and read the phase at the same acquisition time. Another method is to plot in the complex graph or the phasor diagram all the vectors from amplitude and phase curves.

Each vector is calculated from sampled points. The addition of these vectors give a mean vector representative of the amplitude and the phase of the average echo. This method is very interesting: adding up non-coherent signal (generally white or pink noise) gives a vector very close to the null vector.

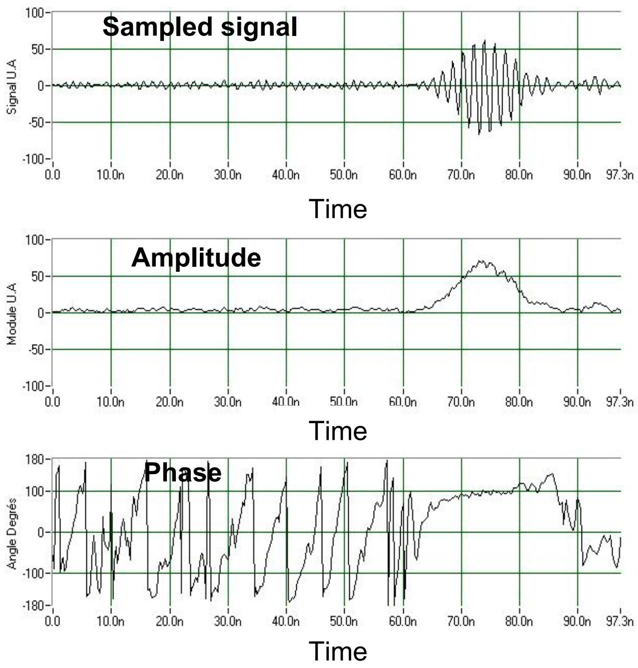

Figure 1: Raw sampled signal (top), computed amplitude (centre) and phase (bottom) of an acoustical echo on Pyrex obtained in reflection mode with a 600MHz central frequency sensor.

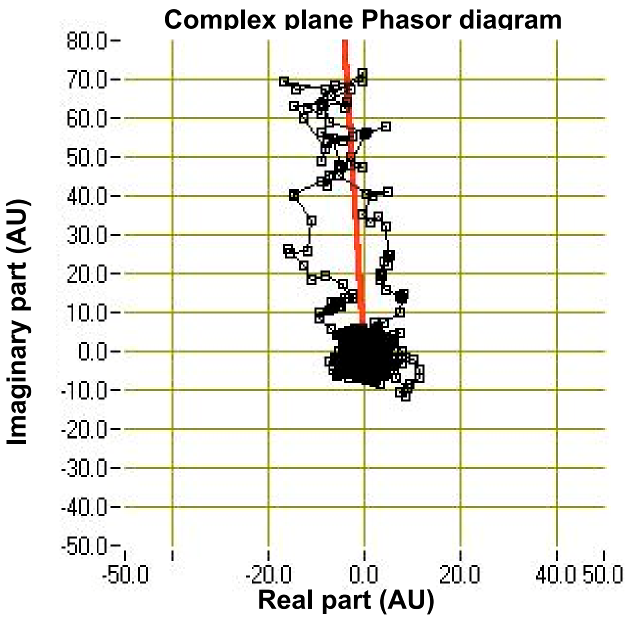

Figure 2: Phasor diagram or complex plane. Data from the figure 1

The noise is filtered in the same way of a synchronous detection. The figure 2 presents the phasor diagram of the curves of the figure 1.

Enhancement of the V(z) curve

For higher frequency input signal we use shorter focal lens. So the coupling fluid attenuation can be limited. However many steady echoes (like front-end lens echo) are present. To reduce coherent noise and to remove theses unwanted echoes limiting the defocusing we use a spatial derivative method, along to the defocusing axis. The signal thus obtained is free from any spurious interference over a large temporal window.

The figure 3 shows a sampled data of an acoustical signal of an acoustic signature V(z) near the focus plane and the difference between the signal and the preceding one during the defocusing. The coherent steady echoes are removed inside the windows acquisition.

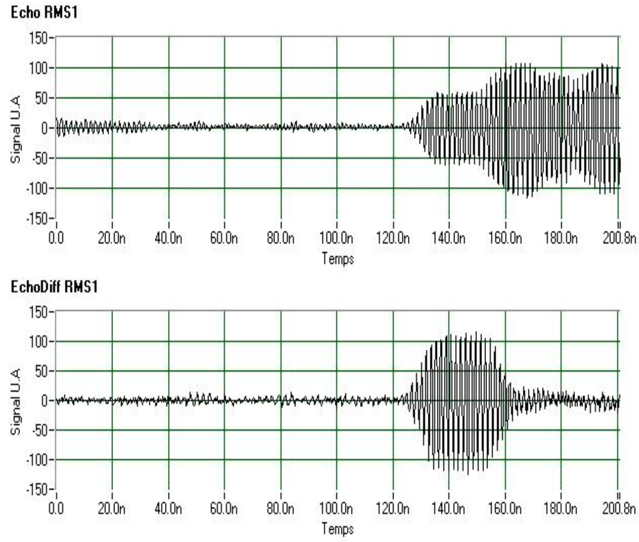

Figure 3: Sampled data of an acoustical signal of an acoustic signature V(z) near the focus plane and the difference between the signal and the preview signal during the defocusing

This signal processing is a spatial derivative method. From a theoretical point of view, we must be sure that the measurement of the velocity mode with this new method gives same results compared to traditional amplitude method. If we use for instance the Sheppard and Wilson equation for the V(z) curve (equation 1), the signal obtained with this new spatial derivative method is shown an equation 2. This process changes amplitude but not the pseudo periodicity of the interference of the V(z) curve. So it is possible to extract the pseudo periodicity with the regular V(z) process.

$$\left\|\underline{V}(z)\right\| = \left\| \int_0^{\pi/2} \underline{R}(\theta) \times \underline{P}(\theta) e^{2jkz\cos(\theta)} d\theta \right\|$$

Equation 1

$$\left\|\underline{X}(z)\right\| = \left\| 2jk \int_0^{\pi/2} \cos(\theta) \times \underline{R}(\theta) \times \underline{P}(\theta) e^{2jkz\cos(\theta)} d\theta \right\|$$

Equation 2

The second process is a vectorial one to enhance the signal to noise ratio and provides measurement at large defocusing distances. When defocusing increases, the specular echo and the surface wave echo are separated in the time domain due to the difference of travel due to the difference of propagation velocity. The figure 4 shows such signal.

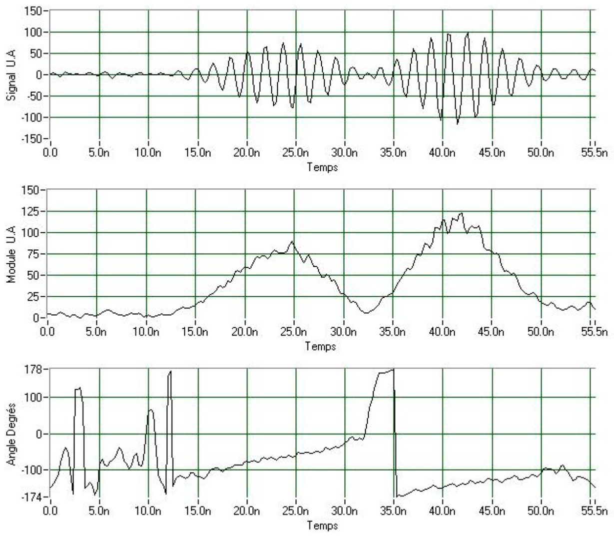

Figure 4: Raw sampled signal (top), computed amplitude (centre) and phase (bottom) of acoustical echoes separated by a wide defocusing on Pyrex. Central frequency sensor is 600MHz.

Using the phasor diagram, the time dependence disappears and the interference between both echoes can be reconstructed. The figure 5 shows the phasor diagram of echoes relative to the figure 4.

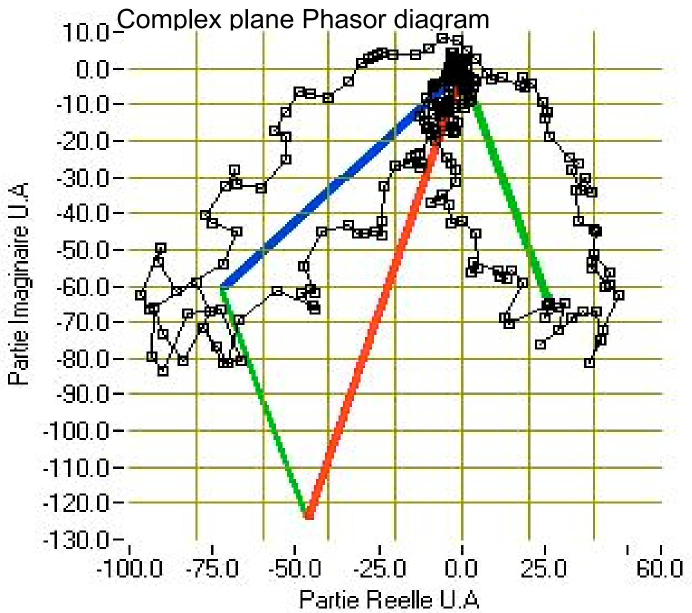

Figure 5: Phasor diagram or complex plane. Data from the figure 4

Using this method, the non-coherent noise is removed and amplitudes of the interference patterns, connected to the efficiency of the leaky waves is increased, especially for skimming longitudinal and transverse modes interference. The figure 6 presents amplitudes of V(z) curves using or not this signal processing.

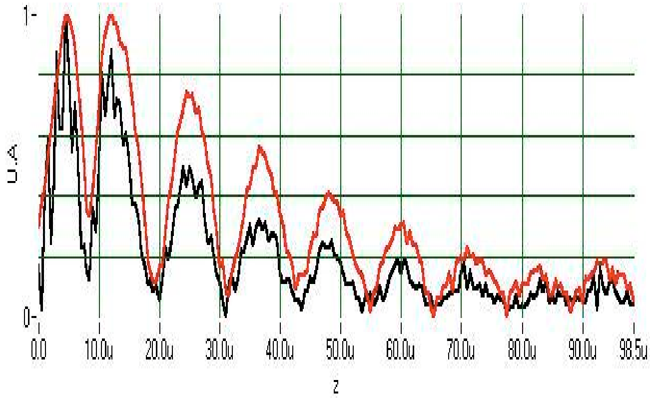

Figure 6: Amplitude of V(z) curves. In black: standard signal processing. In red spatial derivative method associated with the vectorial method on Pyrex. Central frequency sensor is 600MHz.

Microdefocusing

Using the techniques presented above, the accuracy of surface acoustic velocity modes is increased. However in high range of surface acoustic velocity mode (4 ~ 5000 m/s) or for small area analysis (< 10µm²) the accuracy is limited due to the poor numbers of maximum or minimum interference patterns. To improve the accuracy of the measure, increasing the defocusing distance is a possible way but the area analysis increased too with a square law. A solution is to increase the amount of data. Phase data associated with the amplitude of the signal is a possible way. The figure 7 shows such signals.

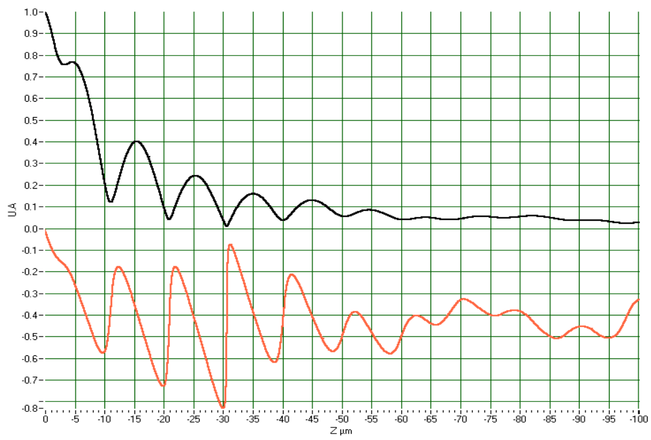

Figure 7: Amplitude (black) and phase (red) of V(z) curves and on Pyrex obtained in reflection mode with a 600MHz central frequency sensor.

For a best exploitation of these signals, a complex transform Fourier must be used. The figure 8 shows the results of this computation.

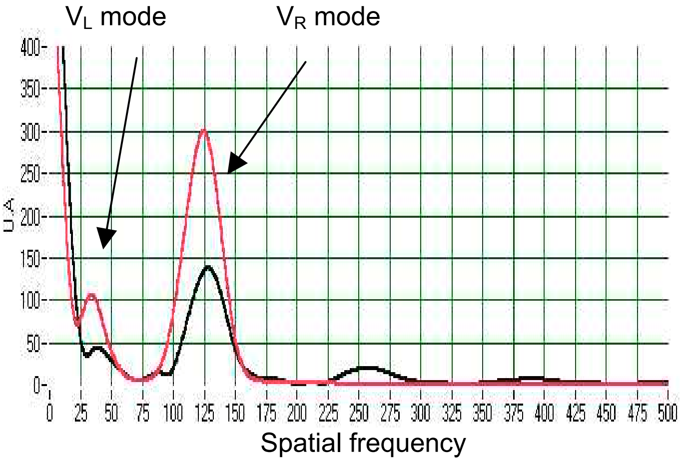

Figure 8: Amplitude of amplitude V(z) curves Fourier transform (black) and amplitude of complex V(z) curves Fourier transform (red).

We can notice that the amplitude Rayleigh mode peak is approximately twice larger. The accuracy of the measurement be increased especially when the efficiency of the leaky waves is small. The second peak corresponding to leaky longitudinal mode is non-detectable using only the amplitude of the V(z) curve and allows a accuracy measurement better than 1% with the complex signal.

Results

Using the enhancement of the V(z) curve associated to the vectorial computation the following curves can be plotted (figure 9 and figure 10).

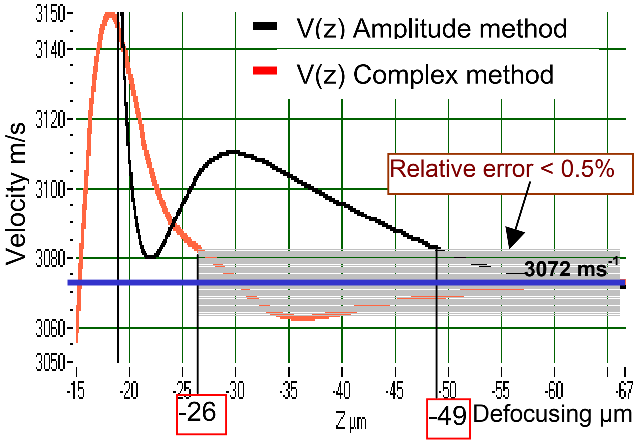

Figure 9: Accuracy of the velocity of Rayleigh mode versus defocusing distance computed with amplitude and complex V(z) curve.

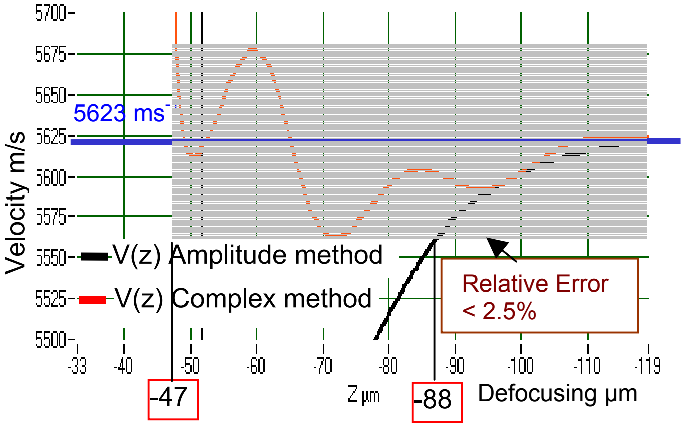

Figure 10: Accuracy velocity of leaky longitudinal mode versus defocusing distance computed with amplitude and complex V(z) curve.

For this specific sample we gain a factor 1.9 on the defocusing distances for Rayleigh and leaky longitudinal mode. On many samples the leaky longitudinal mode is only available using the phase of the signal.

Conclusion

This new method of measurement and data acquisition improve by up to 10 the area under analysis and allows the determination of fast modes up to approximately 10000 m/s including skimming longitudinal and transverse modes or Lamb modes.
Hard materials such as silicon, protective coatings or other new hard materials can be characterised with accuracy. The size of investigations on materials with small structures or small grains allows measurement on only one structure or one grain.

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