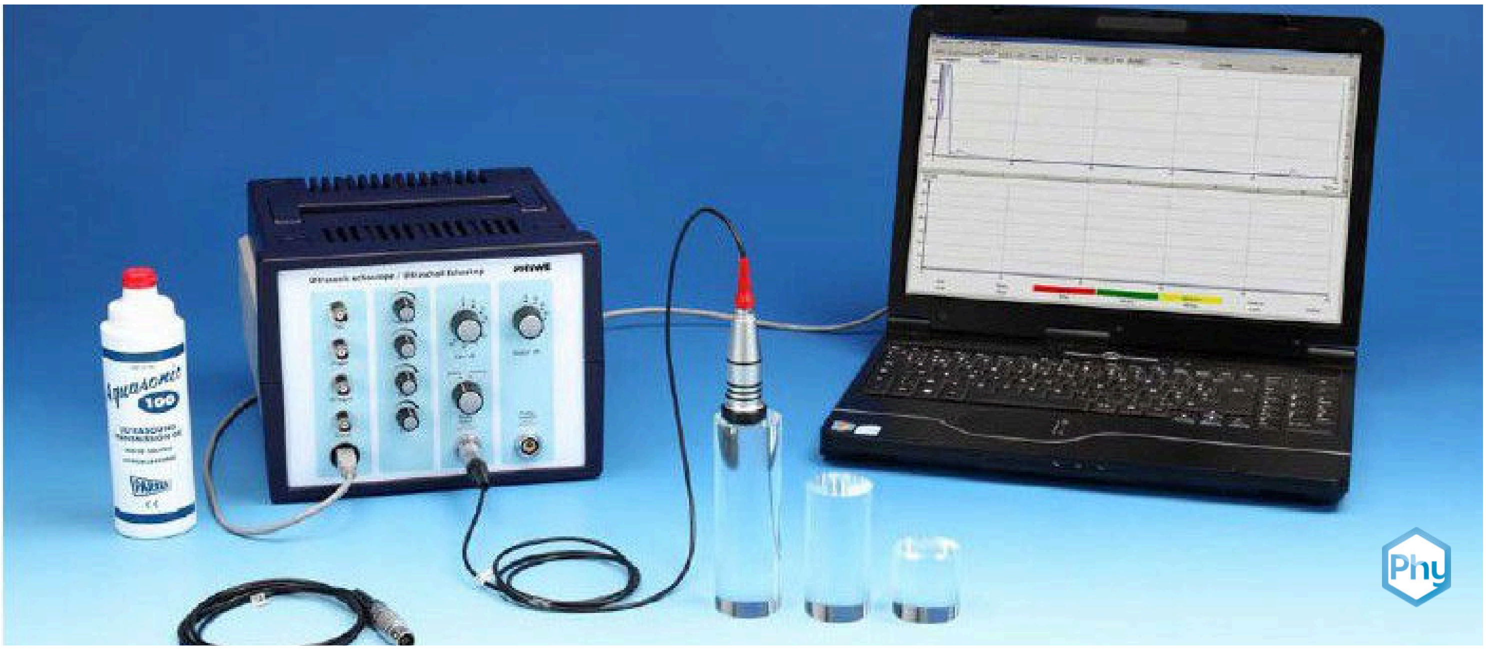
Velocity of ultrasound in solid state material



Physics | Acoustics | Ultrasounds

Applied Science | Engineering | Non Destructive Testing (NDA) | Ultrasound examination

Applied Science

Medicine | Radiology & Ultrasonic Diagnostics | Ultrasonic Imaging

Difficulty level	Group size	Preparation time	Execution time
hard	2	10 minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/6015b69cd817db0003ba0259

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General information

Application

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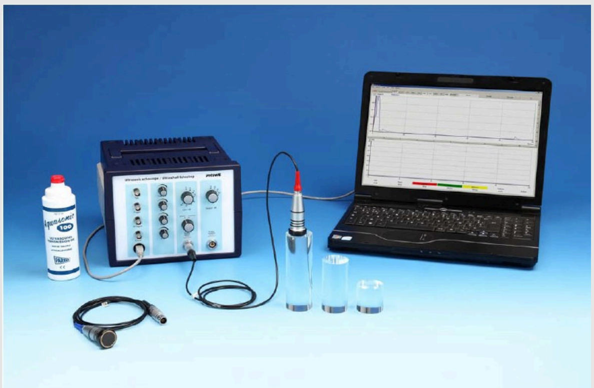

Fig.1: Experimental set-up

Ultrasonic waves can be used in medical fields to look inside the body. For that the knowlege about the behaviour of ultrasonic waves in solit matter is very important.

This experiment can be used to gain a first understanding of ultrasonic waves.

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Other information (1/2)

Prior knowledge

The prior knowlege required for this experiment is found in the theory section.

Main principle

The velocity of sound is determined by time of flight technique with an ultrasonic echoscope using solid bodies made of acrylics. The measurements are done, by reflection method, on three cylinders of different length. Two measurement series are carried out with ultrasonic probes of different frequencies.

Other information (2/2)

Learning objektive

The aim of this experiment is to study the behaviour of ultrasonic waves in solit matter.

Tasks

1. Measure the length of the three cylinders with the calliper.
2. Determine the time of flight of the ultrasonic reflection pulses for the three cylinders with the two ultrasonic probes.
3. Calculate the sound velocities and probe delays.
4. Introduce the 2 mean values obtained in the software and measure cylinders length again

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Theory (1/3)

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A short mechanical wave will be produced by a short voltage pulse applied to a piezoelectric ceramic. If this wave is coupled into solid state material it propagates in a linear way and will be reflected on interfaces with acoustic impedance changes (boundaries).

From the known distance (s), between the ultrasonic probe and the boundary of a solid, and the measured time of flight (t), the sound velocity (c) can be determined for perpendicular sound incidence, in the following way:

In reflection mode $c = \frac{2s}{t}$ (1)

Nearly all ultrasonic probes are covered with a protective layer on the active surface (ceramics). The time needed by the ultrasound waves to pass through this layer is added to the time of flight measured for the sample. This additional time causes errors in sound velocity measurements. The measured time of flight (t) is built up from the time of flight through the protective layer (t_{2l}) and the time of flight through the sample (t_{2s}).

Theory (2/3)

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$c = \frac{2(s_1 - s_2)}{t_1 - t_2} = \frac{2(s_1 - s_2)}{(t_{2s_1} + t_{2L}) - (t_{2s_2} + t_{2L})}$ (2)

$c = \frac{2(s_1 - s_2)}{t_{2s_1} - t_{2s_2}}$

The thickness of the protective layer t_{2l} (probe delay), is different for each individual ultrasonic probe. The time of flight through this layer can be calculated in the following way:

$t = (t_{2s} + t_{2L})$ (3)

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Theory (3/3)

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$t_{2*L} = (t - t_{2s})$

$t_{2L} = (t - \frac{2s}{c})$

If the ultrasound velocity (c) and the probe delay are known, the system parameters are calibrated and the sample thickness can be measured using the following formula:

$s = \left(\frac{(t-t_{2L})\cdot c}{2}\right)$ (4)

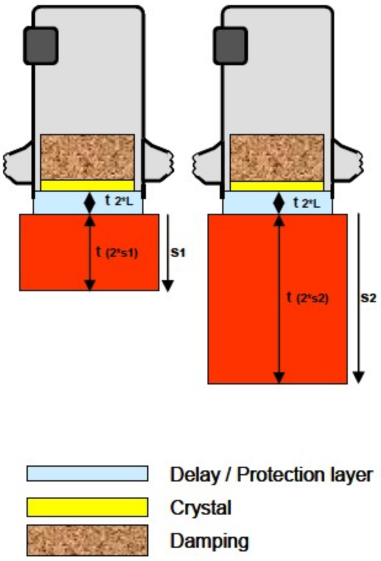

Fig. 2: UT probe layout

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Equipment

Position	Material	Item No.	Quantity
1	Basic Set Ultrasonic Echography II	13924-99	1
2	Vernier calliper stainless steel 0-160 mm, 1/20	03010-00	1

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Setup and Procedure

Setup and Procedure (1/4)

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The system Basic Set "Basic Set Ultrasonic echoscope II " consists of an ultrasonic echoscope controller which connects to a computer via USB interface, ultrasonic probes (1 MHz and 2 MHz), an ultrasonic test block, an ultrasonic cylinder set, ultrasonic test plates, ultrasonic gel and echoscopy software for Windows. Proceed as follows:

- Measure the length of the cylinders with a calliper gauge.
- Prepare the echoscope (read manual of echoscope)
- Connect the echoscope to the PC.
- Connect the 1 MHz probe to the "Probe (Reflexion)" plug.
- Switch the selection knob to "Reflexion".

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Setup and Procedure (2/4)

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- Couple a probe to the test cylinders using a gel or a water film. For ultrasound velocity measurement we recommend to put the cylinder on his round side. Place the probe with a drop coupling gel on the flat side and search the back wall echo.
- When using water as couplant make sure it does not run under the cylinder. It could produce ghost echoes.
- The measure Ultra Echo software shows the reflected wave as a peak. Adjust the transmitter and receiver amplifier settings until the peak height maximum covers at least 75% of the window height. The peak shape can be optimised adjusting the time-TGC (Time Gain Control) parameters.
- Measure the time of flight at the bottom of the rising echo peak edge. Time of flight measurements at peak maximum can lead to wrong results. The peak shape can be influenced by probe frequency and damping of the ultrasonic signal.

Setup and Procedure (3/4)

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- More precise measuring values can be achieved with small overdrive of receiver amplification.
- The time of flight can be read out directly using the software cursors.
- The echo peak position has to be determined very carefully. The error on the time of flight measurements has a big influence on the precision of the final results.
- Repeat the same procedure with the 2 MHz probe
- Calculate ultrasound velocity and probe delay (time shift)
- Adjust this values in the measure Ultra Echo software (A-scan window: US velocity, time shift: menu: "options" then "parameters").
- Toggle from Time to depth settings and measure the thickness of the 3 cylinders, directly in mm.

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Setup and Procedure (4/4)

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Software

The measure Ultra Echo software records, displays and evaluates the data transferred from the echoscope. After starting the program the measure mode is active and the main screen "A-Scan mode" is open. All actions and evaluations can be selected and started in this window.

The main screen shows in the upper part the A-scan signal, the frequency of the connected transducer, the mode (reflection/ transmission). Actual positions of cursors (red and green line) are displayed at the bottom of the window. The cursors can be positioned by mouse click. The time of flight is displayed under the cursor buttons.

Note: The ultrasonic cylinders and the probes should be cleaned immediately after use with water or a normal detergent. Dried residues of ultrasonic gel are hard to remove. If necessary use a soft brush. Never use alcohol or liquids with solvents to clean the cylinders or the probes. Deep surface scratches influence the coupling and can induce measurement errors.

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Evaluation

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Results (1/9)

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Cylinder N°	Length [mm]
1	39.25
2	79.30
3	119.75

Table 1: Cylinder lengths measured with Vernier calliper

Cylinder N°	Time of flight [μs]	
	1 MHz	2 MHz
1	29.3	29.1
2	58.8	58.6
3	88.6	88.4

Table 2: Time of flight measurements of cylinders in reflection mode:

Results (2/9)

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Calculation of the sound velocities with formula (1) and (2)

s_1 [mm]	t_1 [μs]	s_2 [mm]	t_2 [μs]	c (formula (1)) [m/s]	c (formula (2)) [m/s]
39.25	29.3	79.30	58.8	2679	2715
79.30	58.8	119.75	88.6	2697	2715
119.75	88.6	39.25	29.3	2703	2715
			mean value:	2693	2715

Table 3: Calculation of sound velocity with the 1 MHz probe using formula (1) and (2):

s_1 [mm]	t_1 [μs]	s_2 [mm]	t_2 [μs]	c (formula (1)) [m/s]	c (formula (2)) [m/s]
39.25	29.1	79.30	58.6	2698	2715
79.30	58.6	119.75	88.4	2706	2715
119.75	88.4	39.25	29.1	2709	2715
			mean value:	2704	2715

Table 4: Calculation of sound velocity with the 2 MHz probe using formula (1) and (2):

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Results (3/9)

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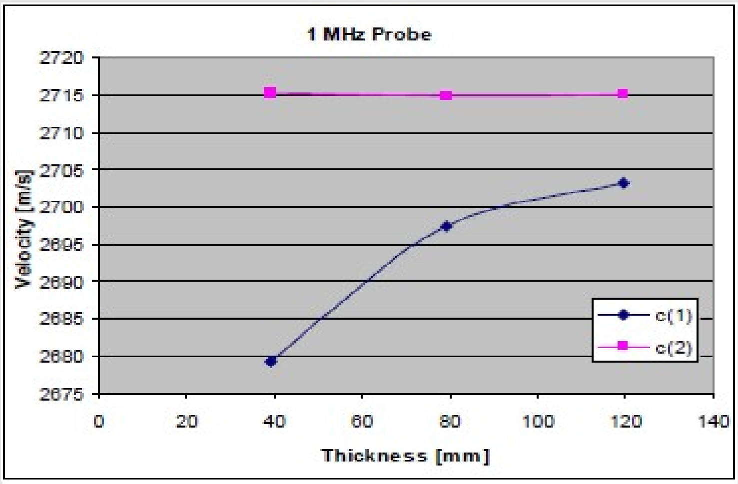

Fig. 3: Sound velocity measured with the 1 MHz probe

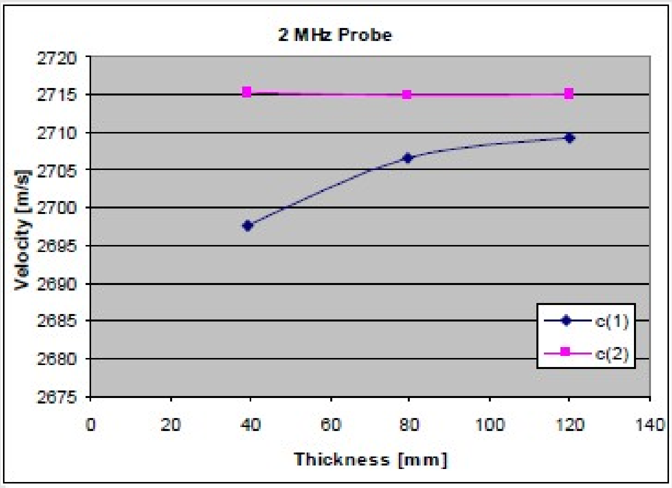

Fig. 4: Sound velocity measured with the 2 MHz probe

Results (4/9)

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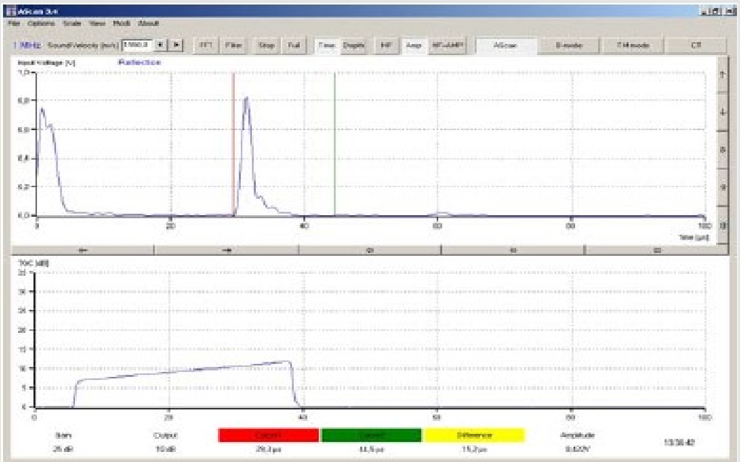

Fig. 5: 1 MHz probe, cylinder with app. 40 mm length

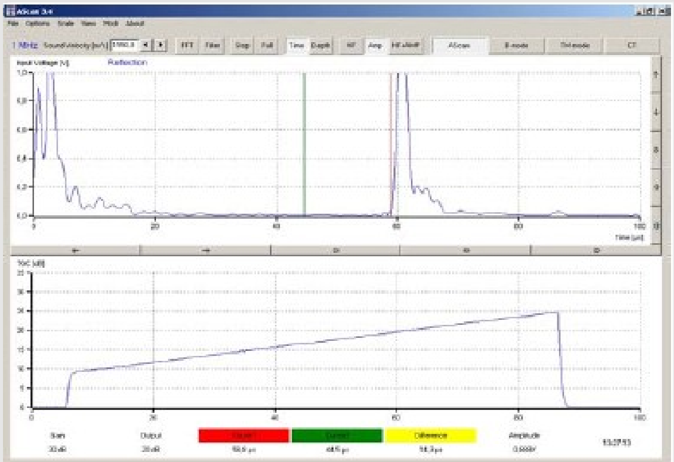

Fig. 6: 1 MHz probe, cylinder with app. 80 mm length

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Results (5/9)

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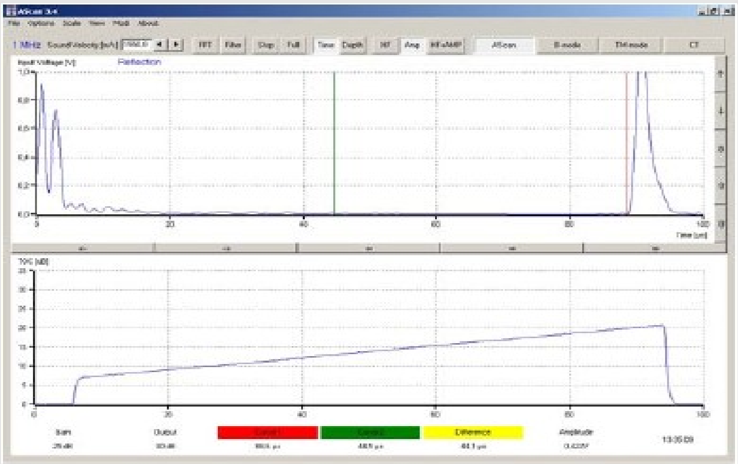

Fig. 7: 1 MHz probe, cylinder with app. 120 mm length

Fig. 8: 2 MHz probe, cylinder with app. 40 mm length

Results (6/9)

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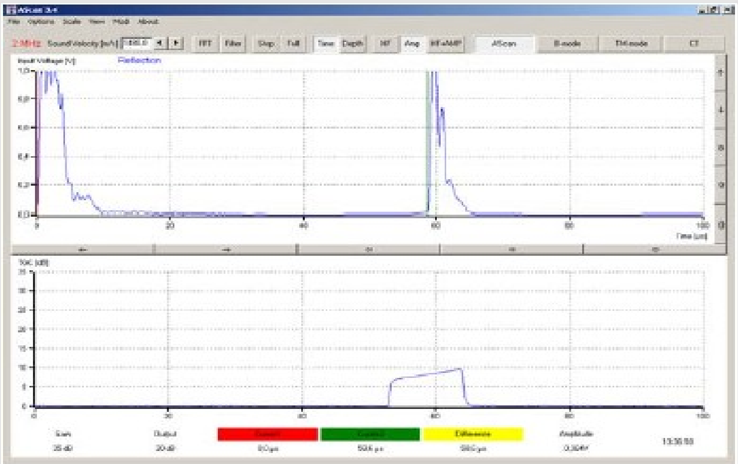

Fig. 9: 2 MHz probe, cylinder with app. 80 mm length

Fig. 10: 2 MHz probe, cylinder with app. 120 mm length

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Results (7/9)

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The sound velocities calculated with formula (1) shows a systematic error, whose influence becomes smaller with increasing measuring length.

This error is larger for 1 MHz (see Fig. 3) than for 2 MHz (see Fig. 4) probes.

The reason is that the protective layer of a 1 MHz probe is larger then the layer of a 2 MHz probe.

The homogeneity of the values calculated with formula (2) shows that this error has been eliminated.

The mean value is 2715 m/s for 1 MHz and 2 MHz.

Literature value: longitudinal sound velocity of acrylics =2600-2800 m/s.

In this frequency range, no frequency dependence of sound velocity (dispersion) occurs for acrylics.

Results (8/9)

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Probe delay

The flight of time through the protective layer can be calculated using formula (3)

s [mm]	t [μs]	t_{2L} [mm]
39.25	29.3	0.387
79.30	58.8	0.384
119.75	88.6	0.386
	mean value:	0.386

Table 5: Calculation 1 MHz Probe

s [mm]	t [μs]	t_{2L} [mm]
39.25	29.1	0.187
79.30	58.6	0.184
119.75	88.4	0.186
	mean value:	0.186

Table 6: Calculation 2 MHz Probe

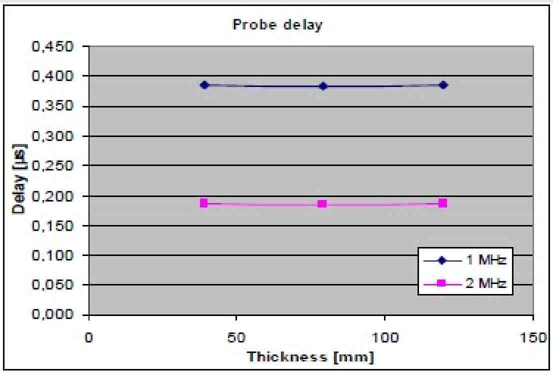

Fig. 11: Probe delay measurement of a 1 MHz and a 2 MHz probe

These data show that the probe delay of the 1MHz probe is nearly twice the delay for the 2 MHz probe. The delays of two different probes of the same frequency and same type could also be slightly different.

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Results (9/9)

Thickness measurements

As the ultrasound velocity and the probe delay have been determined, the sample thickness can be measured with ultrasound echography, applying the formula (4). The measure Ultra Echo software applies this formula to transform the TOF values [µs] in depth values [mm]. The depth can be displayed directly on the A-scan diagram. These tables show that the ultrasound measured and the mechanical measured thickness are identical. Using this parameter the Ultrasound Echoscope is perfectly calibrated to measure the accurate thickness on acrylic samples.

t [μs]	s (UT meas.) [mm]	s (vernier) [mm]
29.3	39.25	39.25
58.8	79.30	79.30
88.6	119.75	119.75

Table 7: 1 MHz Probe US Thickness measurement c = 2715 m/s; t_{2L} = 0.386 μs

t [μs]	s (UT meas.) [mm]	s (vernier) [mm]
29.1	39.25	39.25
58.6	79.30	79.30
88.4	119.75	119.75

Table 8: 2 MHz Probe US Thickness measurement c = 2715 m/s; t_{2L} = 0.186 μs

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