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MEASUREMENT OF SOUND VELOCITIES IN SHOCK-COMPRESSED TIN UNDER PRESSURES UP TO 150 GPa

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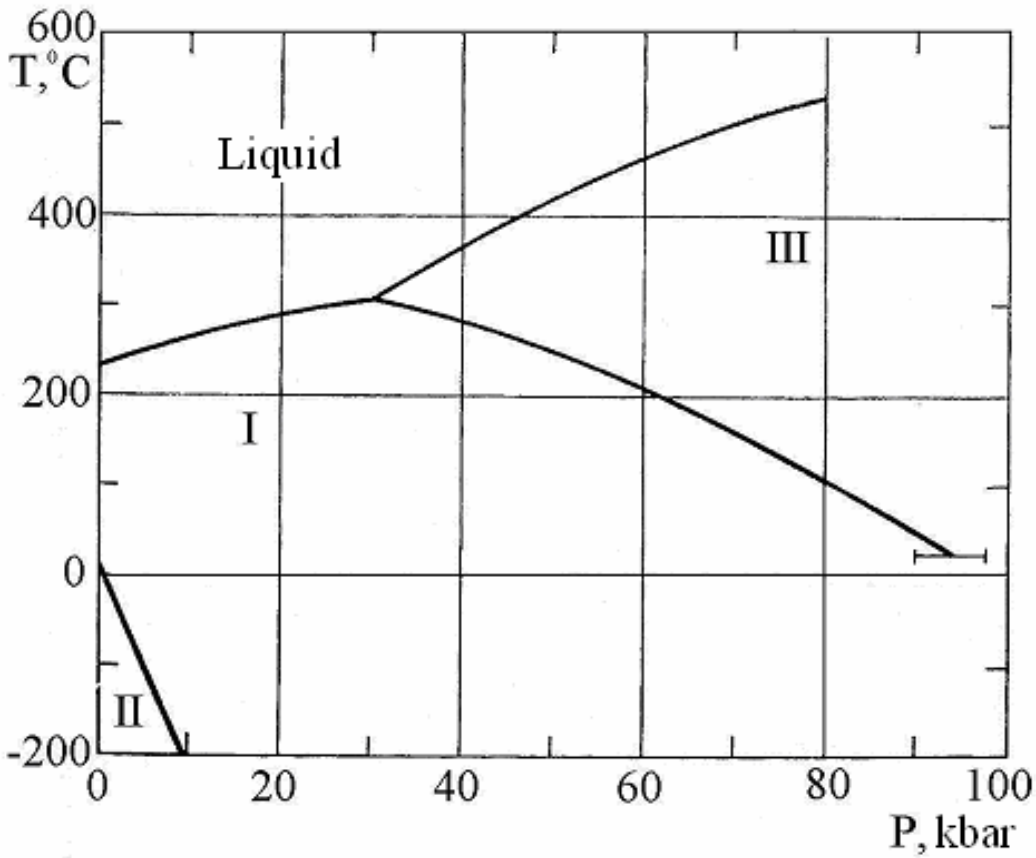
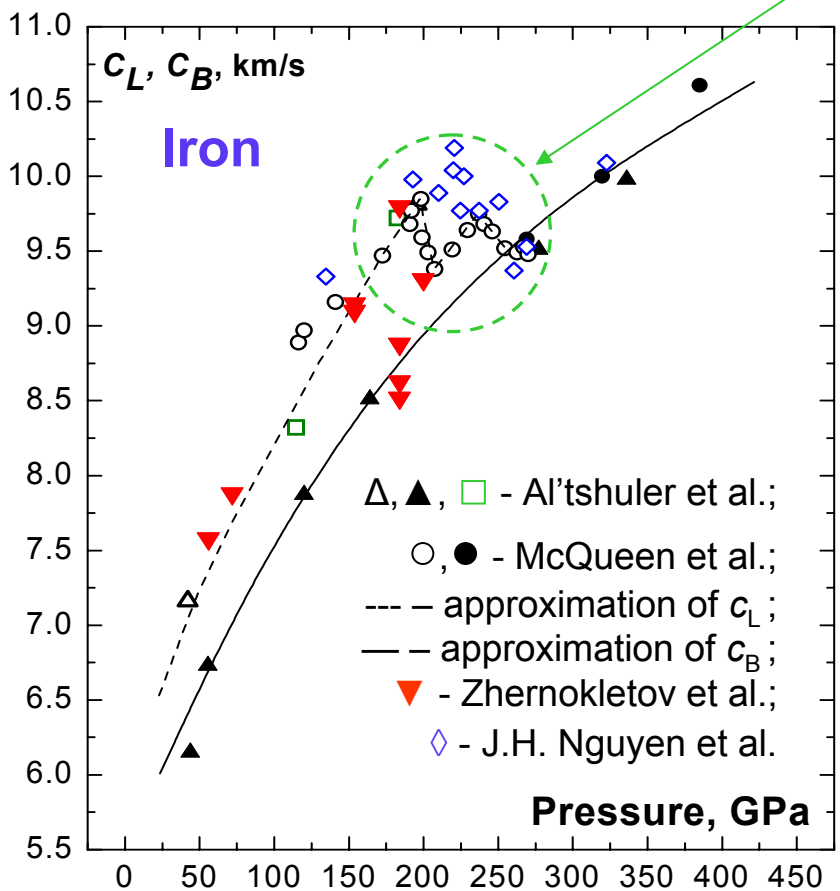
Introduction

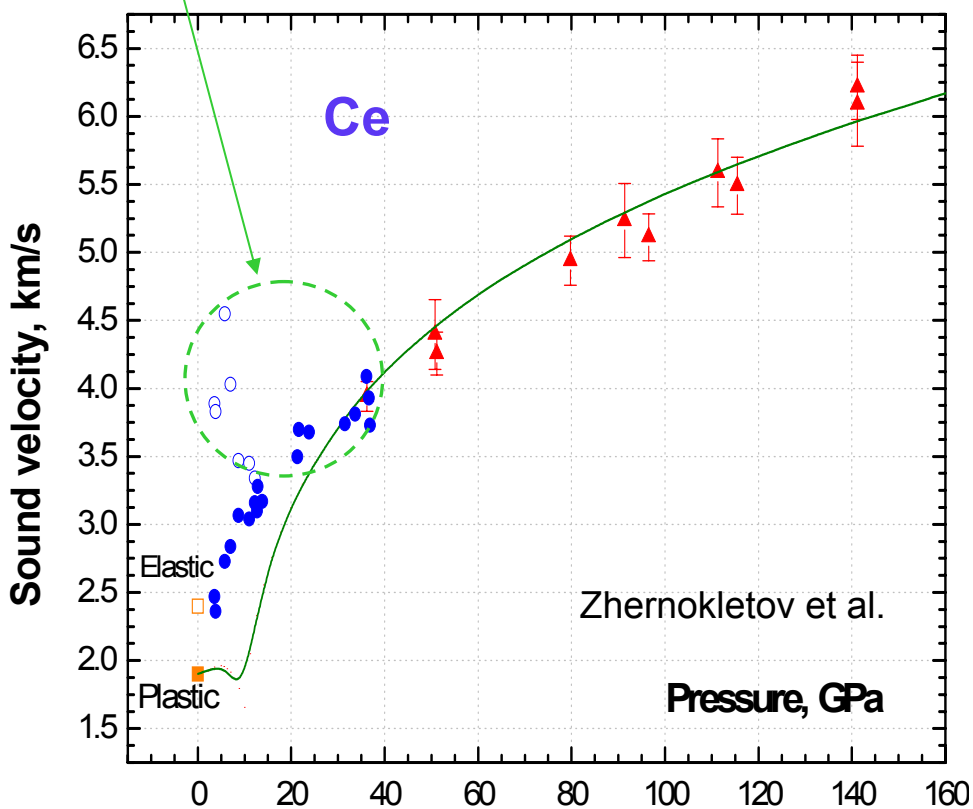
- Tin is of considerable interest to both experimental and theoretical researches because of abundant structural changes that occur with increasing pressure.
- It was found in diamond-anvil cell experiments at room temperature that tin transformed from *β* to *bct* phase at ~ 9.7 GPa and to *bcc* phase at ~ 40 GPa.
- However, only the *β* to *bct* transition was inferred in shock experiments by Hugoniot measurements.
- The *bct* to *bcc* phase transformation is difficult to determine due to the slight volume change.



The example of dependence of sound velocity in iron and cerium on pressure

Melting





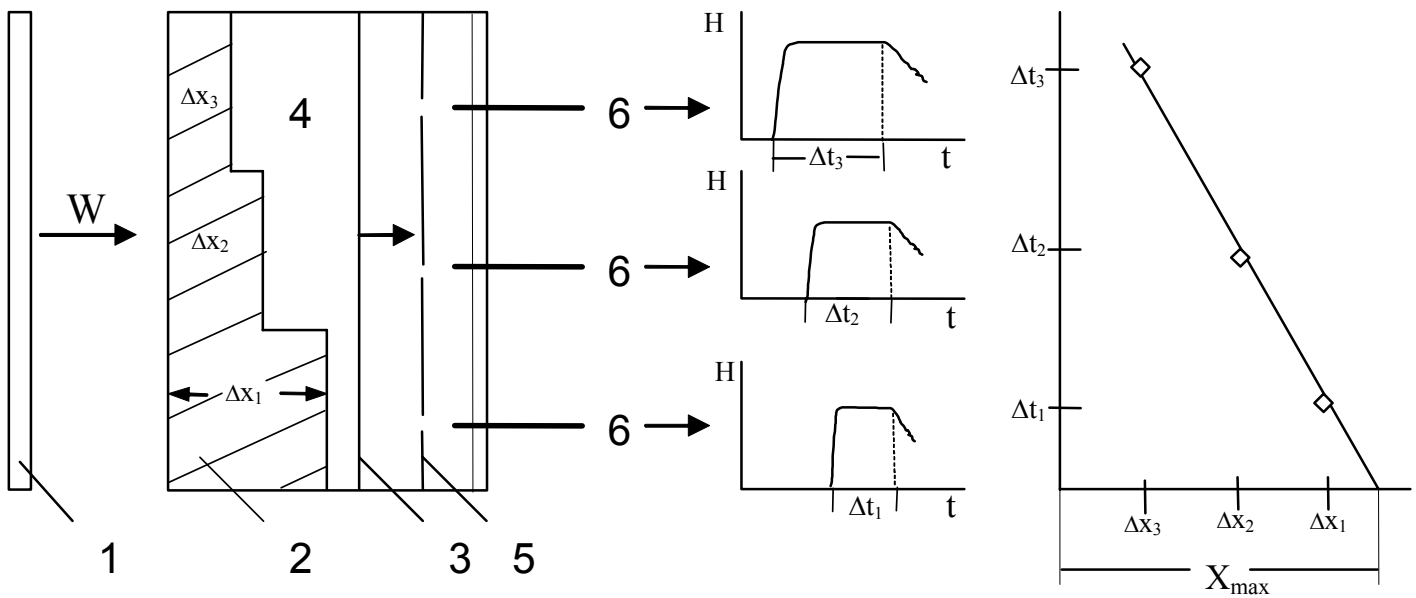
Objective of this work

- Determination the elastic C_L and plastic C_B sound velocities in the shock wave (SW) pressure region 2-140 GPa by the methods:
  - of overtaking unloading with use of indicator liquids (35-140 GPa),
  - of piezogauges based on manganine (2-35 GPa).
- Determination the melt boundary of tin on the shock adiabat.
- Make the comparison of getting data with other available data.

Tin samples

- We studied samples of tin with a density of 7.28 g/cm^3 and purity of 99.92%. Contents of the other elements (mass %) were the following: As – 0.01%, Fe – 0.009%, Cu – 0.01%, Pb – 0.025%, Bi – 0.01%, Sb – 0.015%.

Scheme of experiment with measurement of sound velocity with use of stepped sample and liquid indicator (Hixson R.S. et al.)



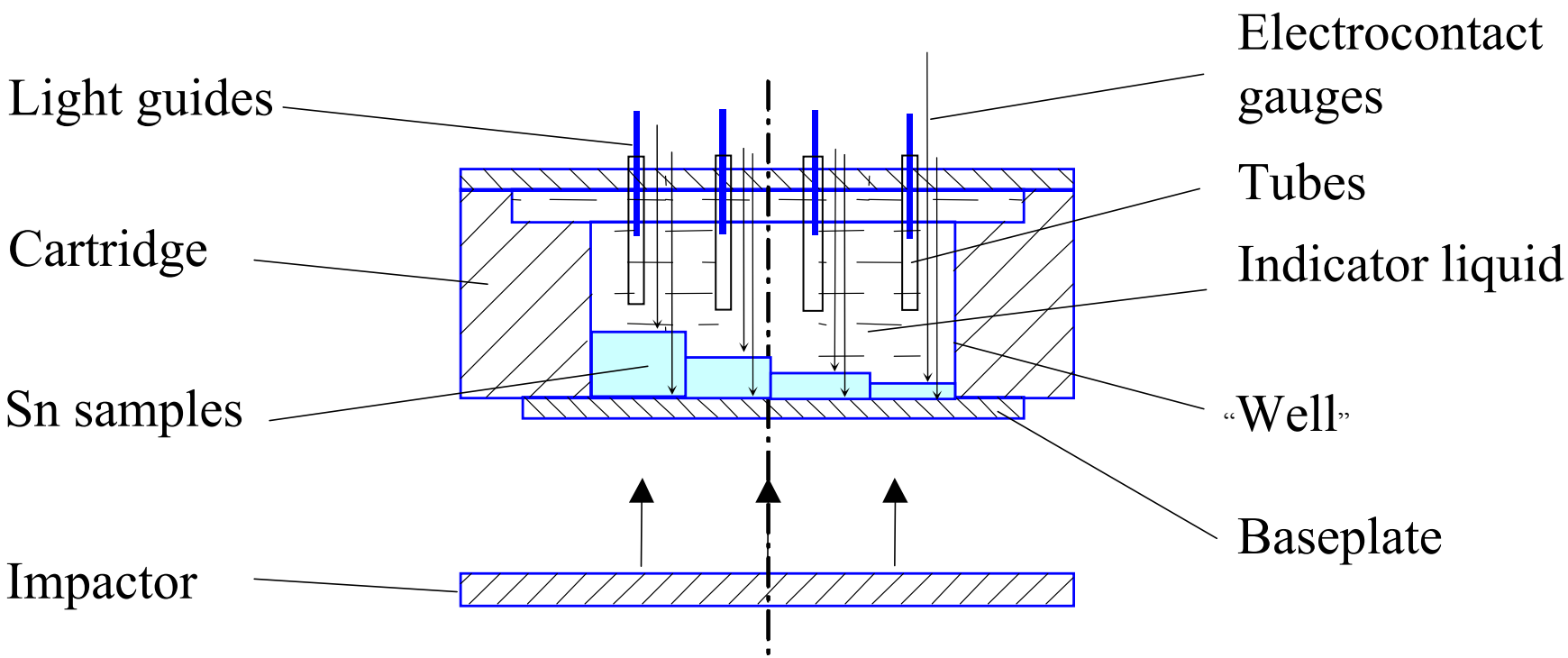
a) b) c)

a) 1 – impactor; 2 – stepped sample; 3 – SWF; 4 - liquid indicator; 5 – diaphragm; 6 – optic fibers

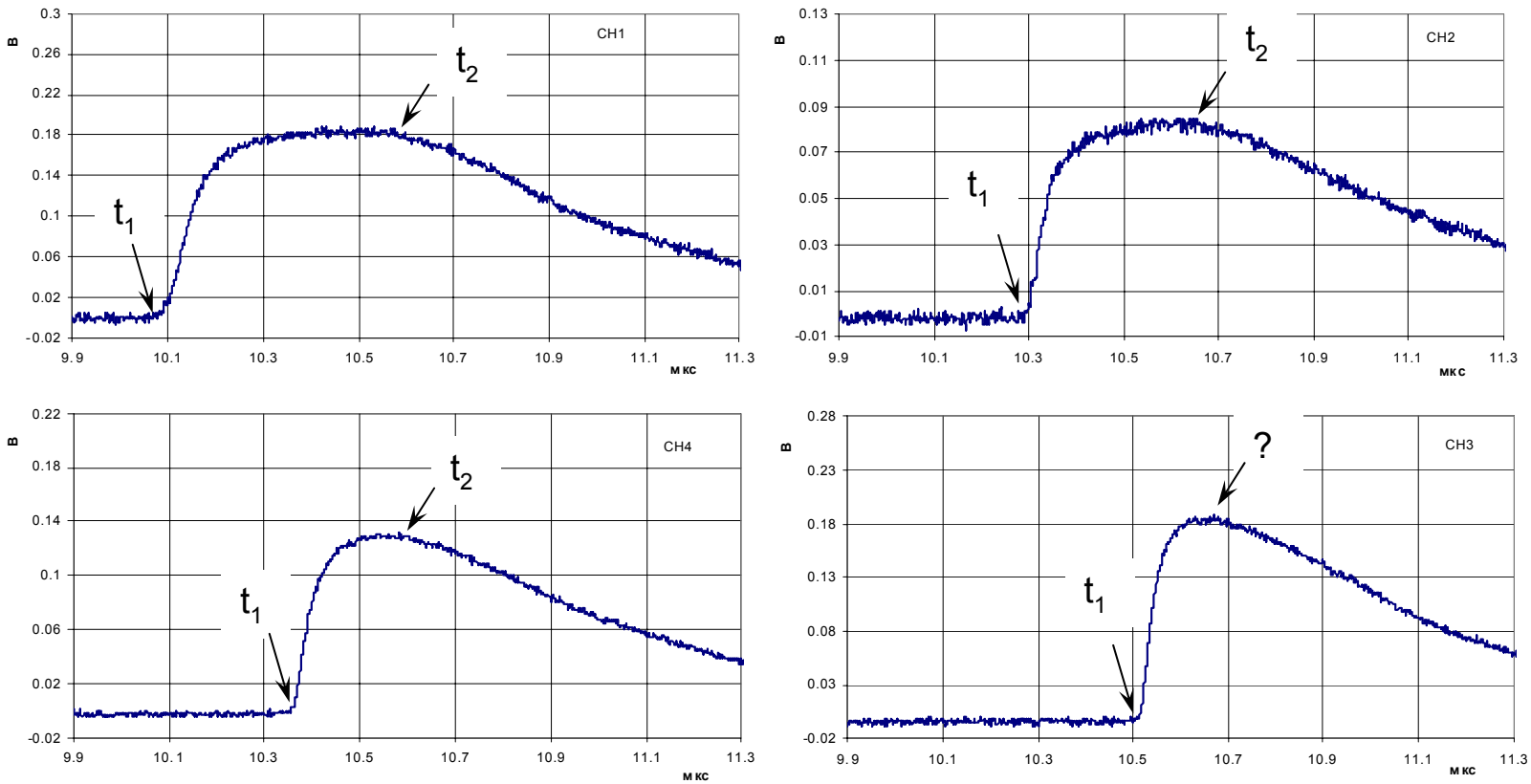
b) recorded signals of luminescence (H – amplitude, Δt – luminescence duration)

c) extrapolation of the $\Delta t(\Delta x)$ dependence for determination of X_{max}

We used the experimental cell for optical method of overtaking unloading

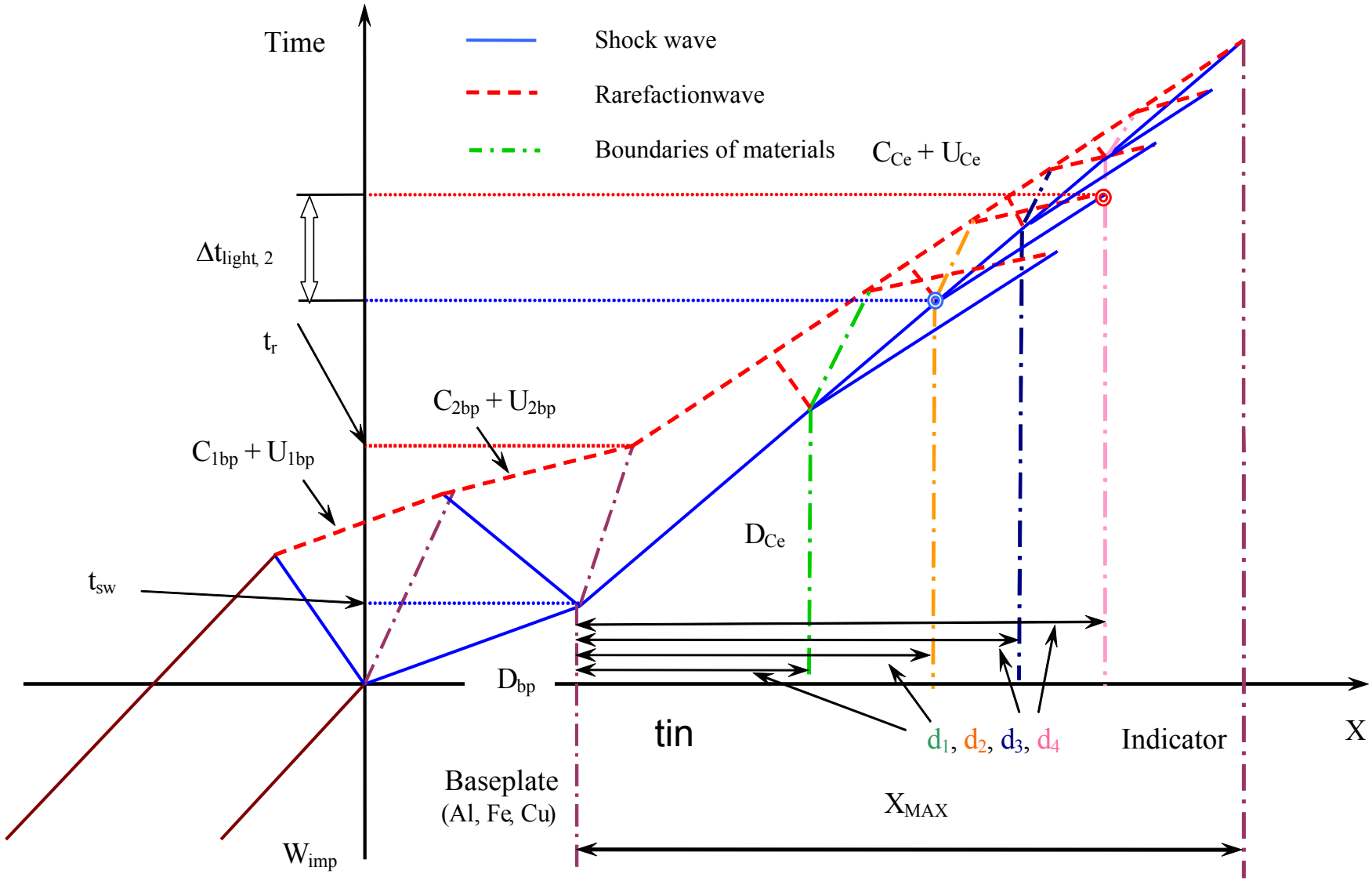


Oscillograms of radiation of shock wave front in $CHBr_3$ at P_{Sn} = 72 GPa behind steps of tin



We used carbogal, tetrachloromethane, and bromoform as the indicator liquids

X –t diagram of experiment



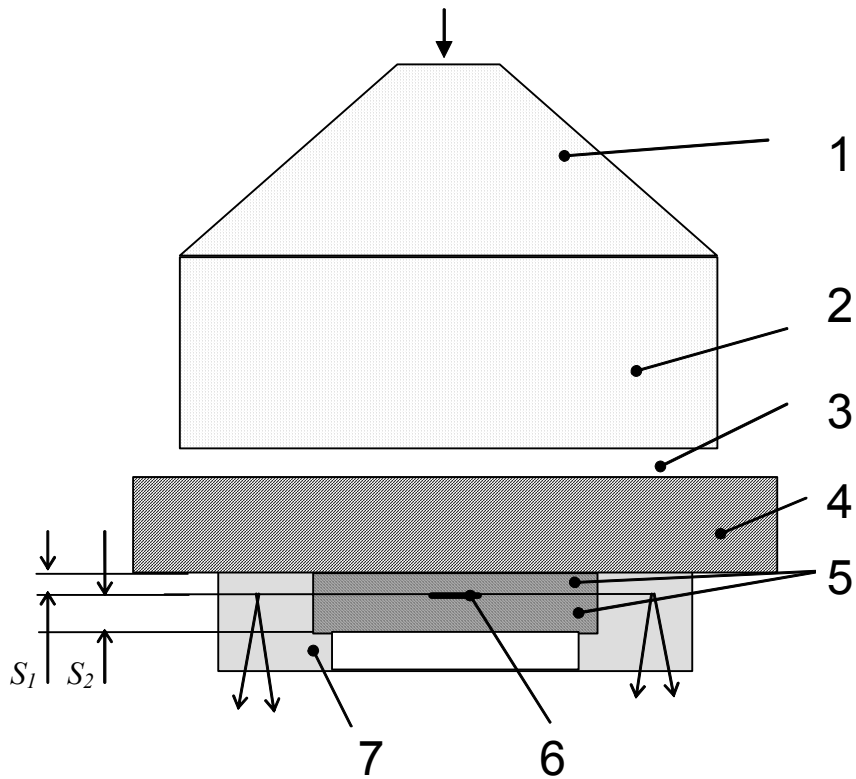
Sound velocity calculation

The sound velocity was determined from the following formula:

$$C_{Sound} = \frac{X_{MAX}}{\sigma \cdot (t_{SW} - t_{RW} + \frac{X_{MAX}}{D_{Sample}})}$$

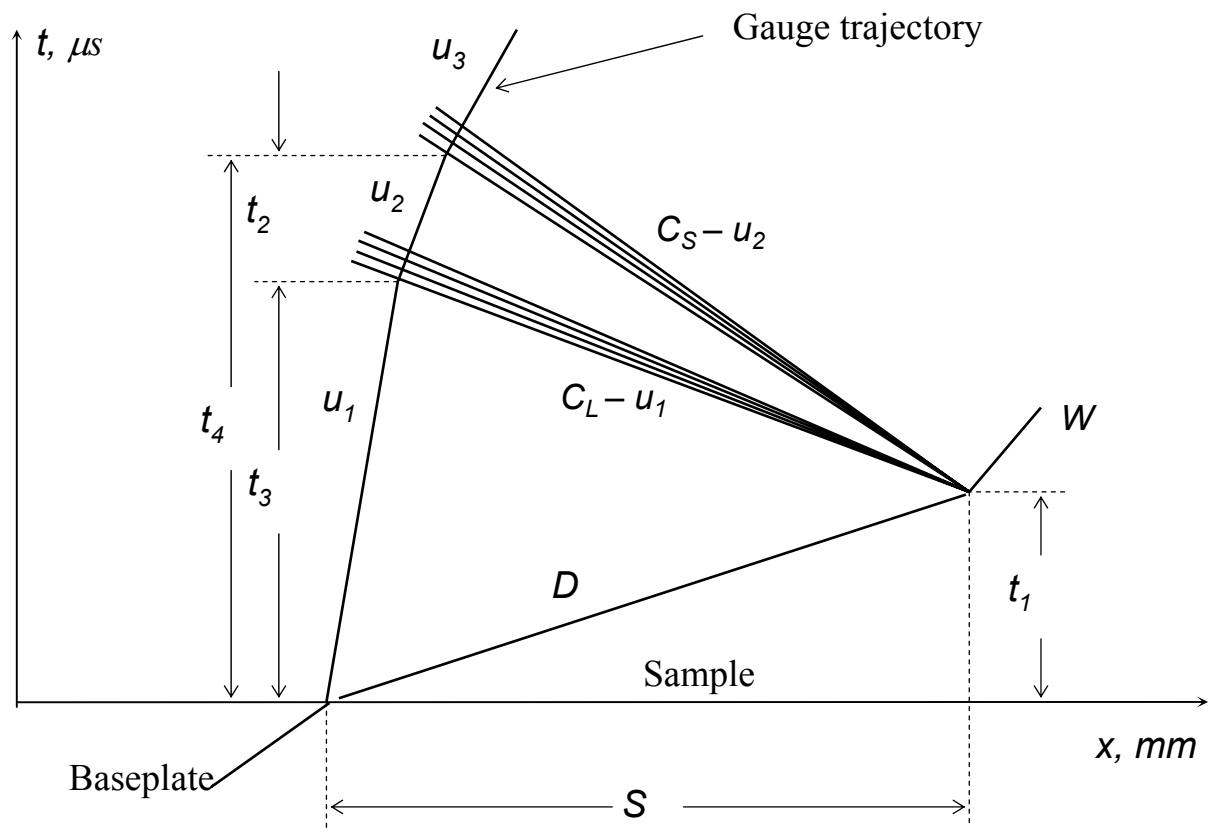
where σ is the compression; t_{SW} is the time of shock wave entering the sample; t_{RW} is the time of rarefaction wave entering the sample (times are determined from the *Xt*-diagrams); *D* is the velocity of shock wave in tin; X_{MAX} is the step thickness where overtake would occur at the “sample – indicator” interface.

Manganin pressure gauge method

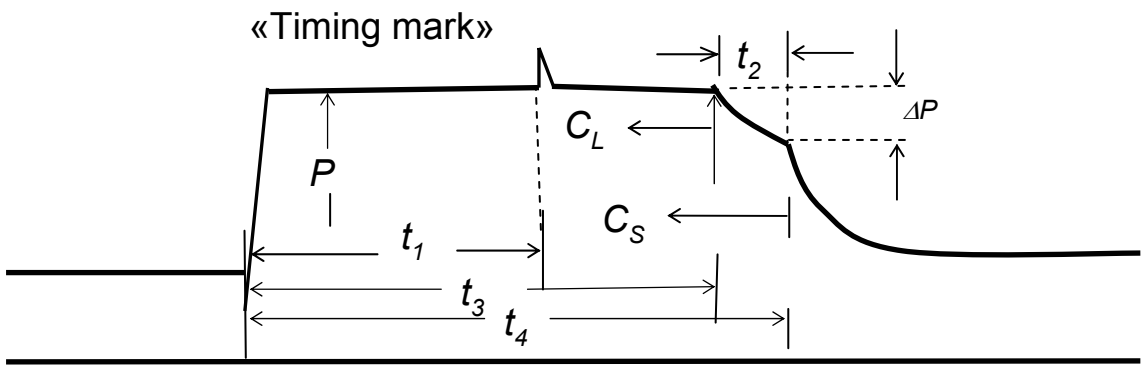


1 – SW generator, 2 – explosive, 3 – 5 mm air gap,
4 – baseplate (∅90×10 mm), 5 – cerium sample,
6 – manganin gauge, 7 – epoxy

Schematic *X-t* diagram and profiles of the direct shock wave and the rarefaction wave



P – the SW amplitude,
ΔP - the *elastic* rarefaction wave amplitude



Calculations

Elastic sound velocity:

$$C_L = u_1 + \frac{S - u_1 t_3}{t_3 - S / D}$$

Bulk sound velocity:

$$C_s = u_2 + \frac{S - u_1 t_3 - u_2 (t_4 - t_3)}{t_4 - S_2 / D}$$

where:

$$u_1 = \frac{P}{\rho_0 D}, \quad u_2 = u_1 + \frac{\Delta P_{el}}{\rho C_L}.$$

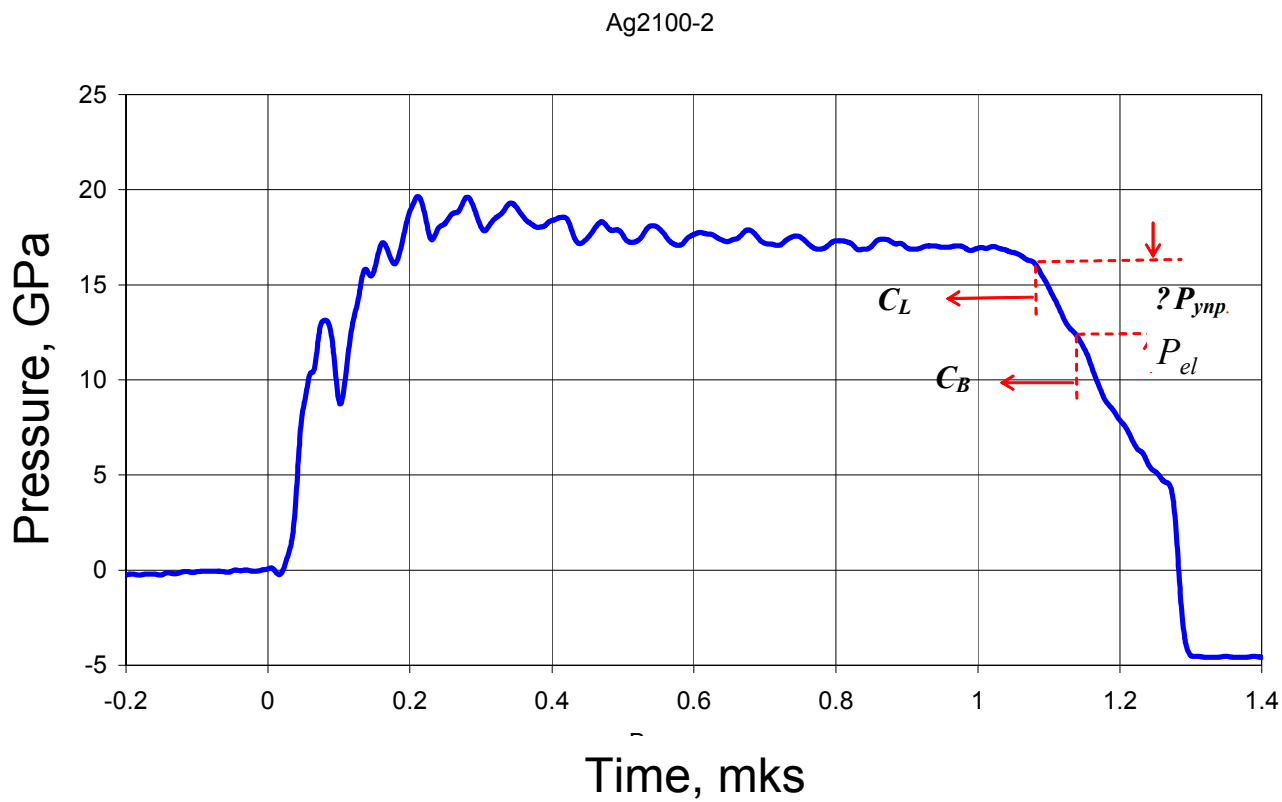
Poisson's ratio:

$$\nu = \frac{3 - (C_L / C_S)^2}{3 + (C_L / C_S)^2}$$

Dynamic yield strength *Yg* (shear strength):

$$Y_g = \frac{1 - 2\nu}{2(1 - \nu)} \Delta P_{el}$$

One of the oscillograms obtained from a recording of the stress profile in tin



ΔP_{el} is pressure jump in elastic wave of release. The «timing mark» was sent to the other beam of the oscilloscope.

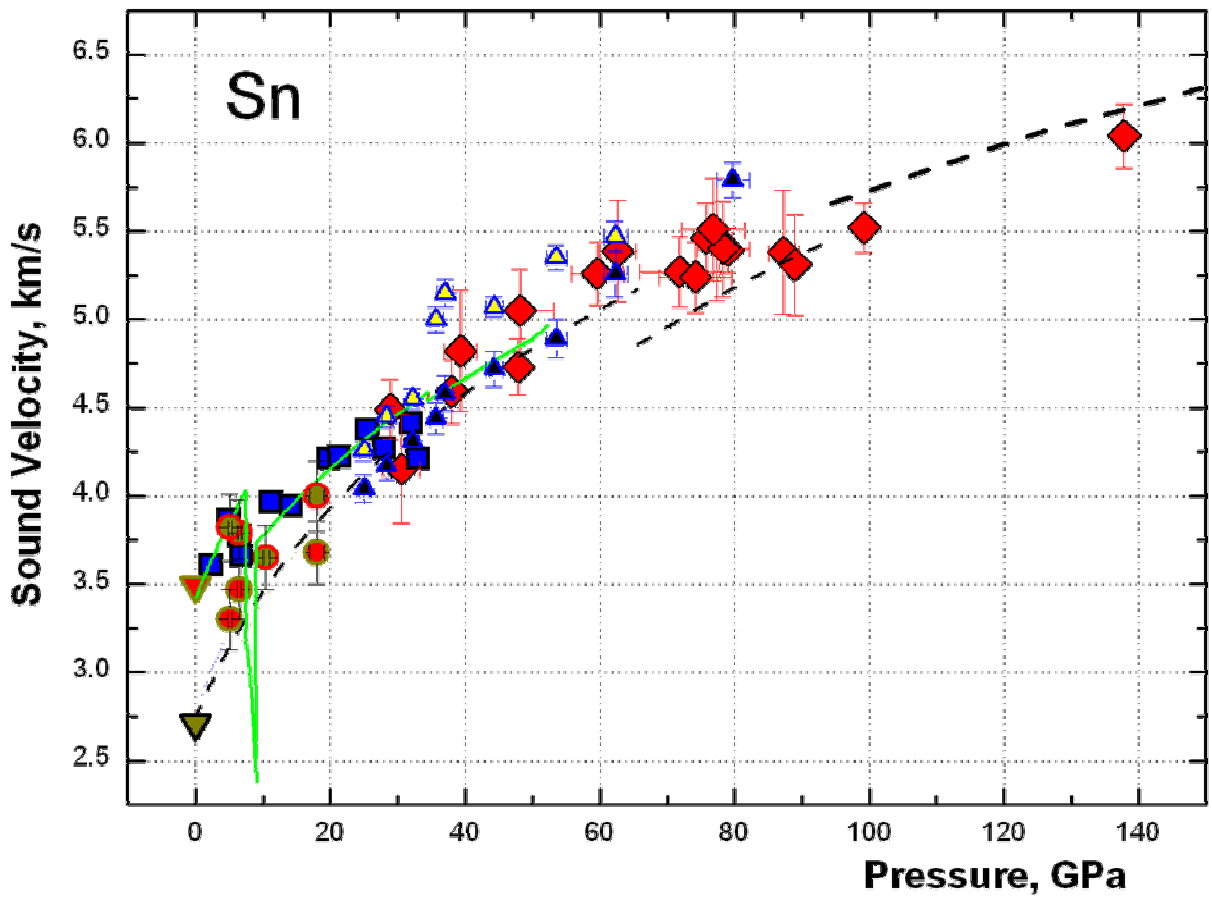
Parameters of states in tin (optical method)

N	Parameters of states in tin			
	D, km/s	*u*, km/s	*P*, GPa	C_{sound}, km/s
1	4,05	0,98	29±3	4,49±0,17
2	4,38	1,19	38±1	4,59±0,18
3	4,43	1,22	39±2	4,82±0,34
4	4,71	1,40	48±5	5,05±0,23
5	5,05	1,62	60±4	5,26±0,18
6	5,13	1,67	63±3	5,39±0,29
7	5,38	1,84	72±6	5,27±0,20
8	5,44	1,87	74±5	5,24±0,20
9	5,48	1,90	76±1	5,46±0,20
10	5,50	1,92	77±5	5,51±0,29
11	5,52	1,93	77±2	5,45±0,34
12	5,54	1,94	78±4	5,40±0,27
13	5,59	1,95	79±1	5,39±0,13
14	5,75	2,08	87±2	5,38±0,35
15	5,79	2,11	89±2	5,31±0,22
16	6,02	2,26	99±1	5,52±0,14
17	6,78	2,79	138±1	6,04±0,18

Parameters of states in tin (method of manganin gauge)

N	*D*, km/s	*u*, km/s	*P*, GPa	C_L, km/s	C_B, km/s
1	2,85	0,25	5,09±0,15	3,82±0,19	3,30±0,17
2	2,94	0,30	6,48±0,19	3,79±0,19	3,47±0,17
3	3,18	0,45	10,4±0,31	3,65±0,18	-
4	3,58	0,69	18,0±0,54	4,00±0,20	3,68±0,18

Experimental dependence of sound velocities in tin on pressure of shock compression



– – – - calculation by EOS [Khishenko K.V.]; —— - calculation by EOS [Cox G. A.];
■ - sound velocity from [Martinez E.]; △ , ▲ - sound velocity from [J. Hu, X. Zhou];
▼ - plastic (bulk) sound velocity, ▼ - elastic (longitudinal) sound velocity (ultrasonic method);
◆ - present work (optical method); ●, ● - present work (manganin)

Conclusions

- We have performed experiments on tin to measure sound velocities using optical technique and manganin gauge method. The accuracy of the sound velocity measurements is approximately 5%. We observed a break in the sound velocity versus pressure in the (60-90) GPa, which is, in our opinion, caused by melting.
- In order to determine the upper boundary of the melting range, it is required to perform additional tests under pressures higher 90 GPa.

SPASIBO

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