XIII International Symposium on Explosive Production of New Materials

OPTICAL DETONATION MEASUREMENTS AND DESIGN OF EXPLOSION CHAMBER FOR SMALL OF EXPLOSIVES

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Contents

Initial proposed presentation was

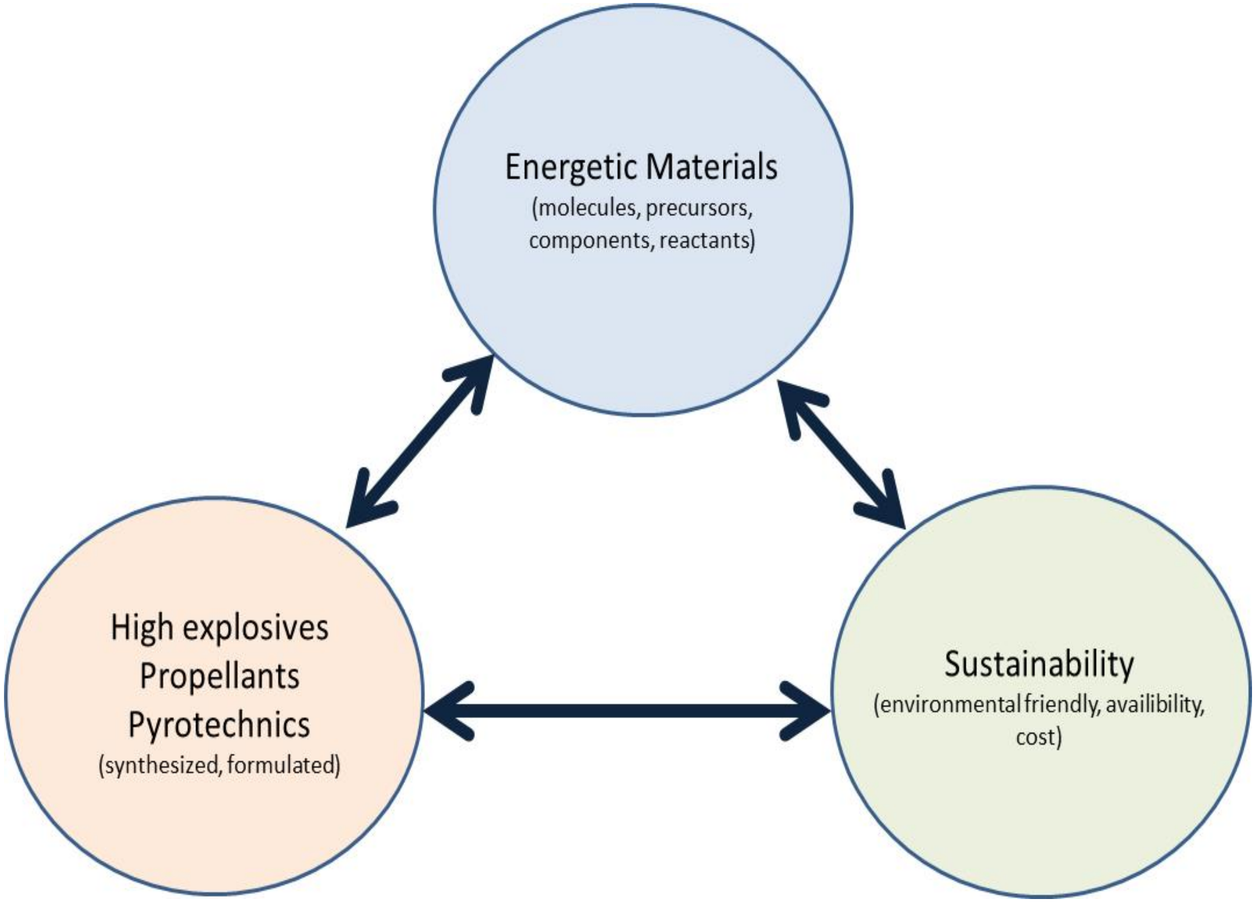
1. Optical detonation measurements
2. Design of explosion chamber for small **test samples**

Design of explosion chamber was presented before

The present presentation will concerns the optical measurement techniques and results

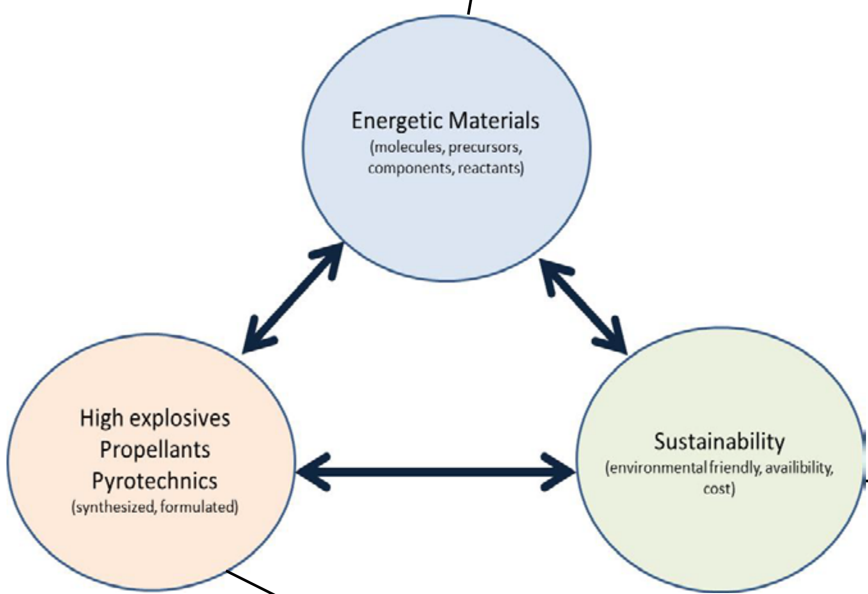
Contents

Motivations



Motivations

Synthesis of 20 energetic polyurethane binders based on GAP and different diisocyanates



Binders that are recyclable by melting and / or dissolution. Reactants available on the market

Why do we investigate explosives?
What are we interested in?

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Motivations

Why do we investigate explosives?

It is the cheapest way to get very high power in a short period of time, released by a reliable chemical reaction induced by a supersonic shock wave

What are we interested in?

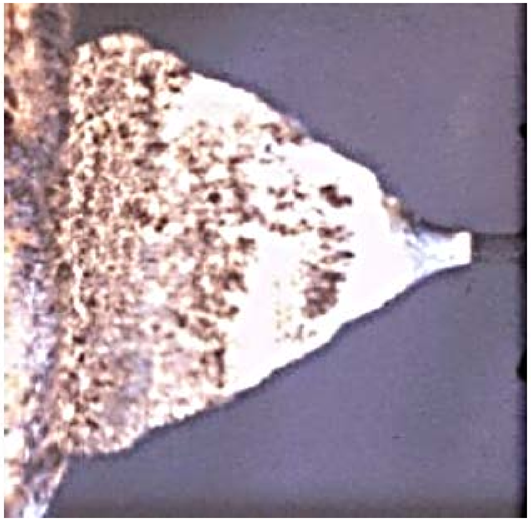
Characterization of the thermodynamic properties (D, P, ρ, E) through the kinetic properties of the main shock wave:

- propagation / detonation velocity
- particular velocity

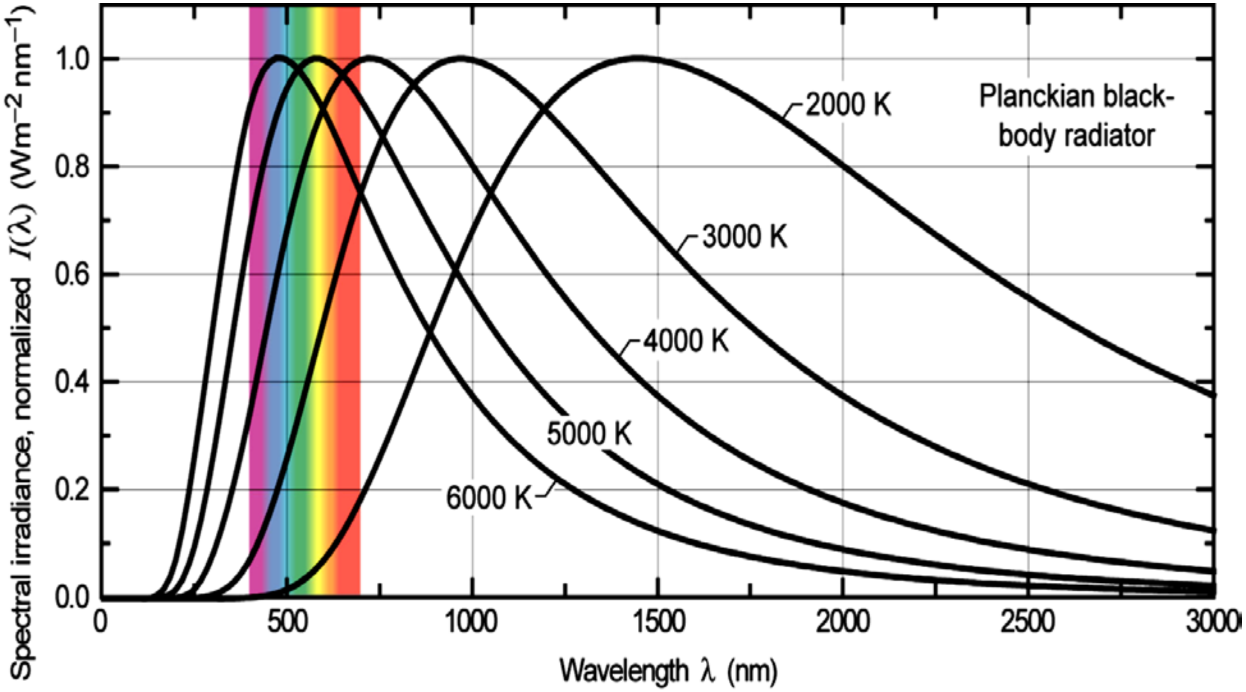
} **Development of a metrology**

Why optical methods?

The detonation can be assumed as a shock-reaction process – the thermal radiation is generated by the detonation products behind shock front, mainly the solid carbon.



Nitromethane detonation in 25 mm glass tube



Why optical methods?

Since detonation emits radiation, our metrology uses optical fibers, to “catch” that radiation for measurements.

Optical fibers can offer:

- Accurate and fast response
- Channel independence
- Reliability
- Scalability – small and big tests are correlated
- Favorable electromagnetics – the captured radiation are not affected by the electromagnetic fields generated during the detonation
- Not expensive method – fibers are cheap and we lead with a destructive process

Detonation theory – metrology background

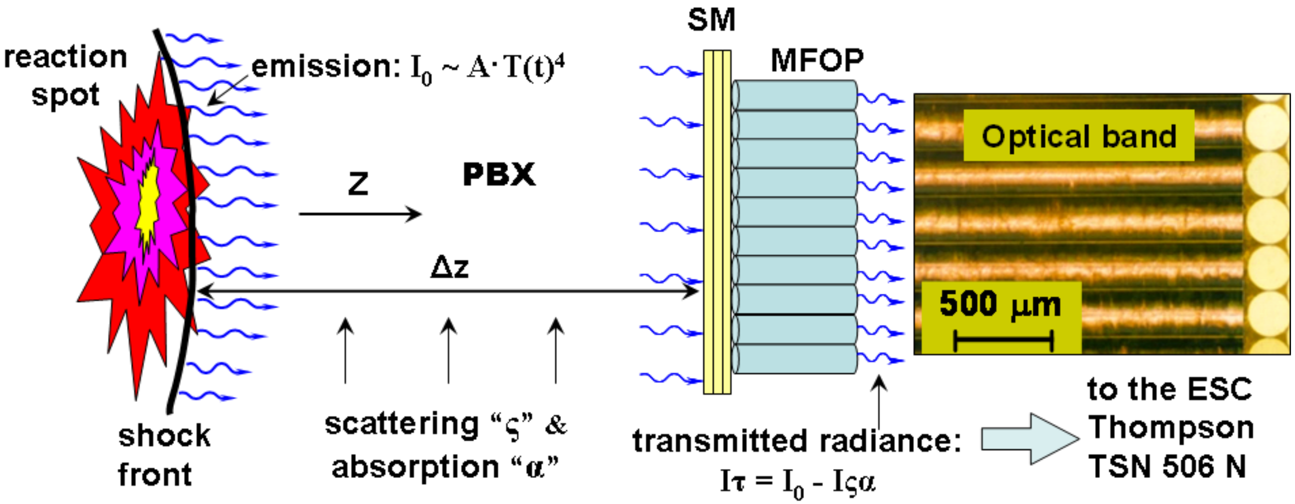
Initial model was developed by **Chapman (1899)** and **Jouguet (1905)** combining the shock and reaction, respectively in fresh and products mixtures, starting by a single approach:

i. **Shock front compresses and heats the fresh material,**
ii. **The exothermic reactions are completed instantly,**
iii. The heat produced by the reaction feeds the pressure shock front and drives it forward
iv. Gaseous products behind the shock wave are expanding and a rarefaction wave is then generated,
v. The shock front, the chemical reactions and the leading edge of the rarefaction are in equilibrium – they are moving with the same velocity called detonation velocity and, at last
vi. **The shock front can be assumed as mono-dimensional – pressure step constant value with a constant detonation velocity.**

Zeldovich (1940), von Neumann (1942) and Doering (1943) individualized shock from reaction zones.

Previous works – metrology background (I. Plaksin, R. Mendes 2009)

Time-resolved measurements of the detonation/reaction zone structure were performed by mean of the **96-channel Multi-Channel Optical Analyzer** (MCOA)



- **Spatial and temporal resolution of hot spots** with the 0.6 ns and 100 μm accuracy

-**Kinetic parameters → time history of reaction radiance**, 450 < λ < 850nm spectrum

-**Dynamic parameters → stress field in optic monitor**

-**The application of the MCOA has provided meso-scale resolution of reaction zones.**

Previous works – Existing problems and purposed solutions

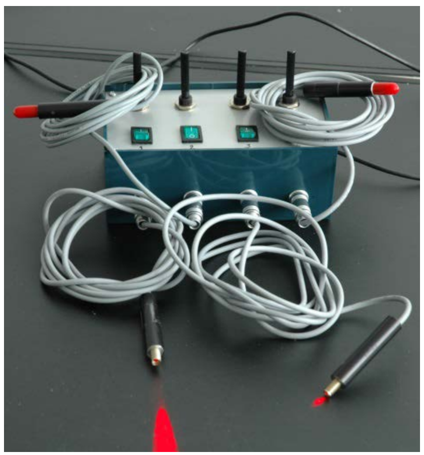
(i) Despite the last fifteen years passed, since MFOP was developed, it remains, up to the present, **a very complex diagnostic technique** that offers a complex compromise between high temporal/spatial resolutions.

(i) However, their design stays complex and a **fast streak camera is always a condition to record the results as image (and its analysis).**

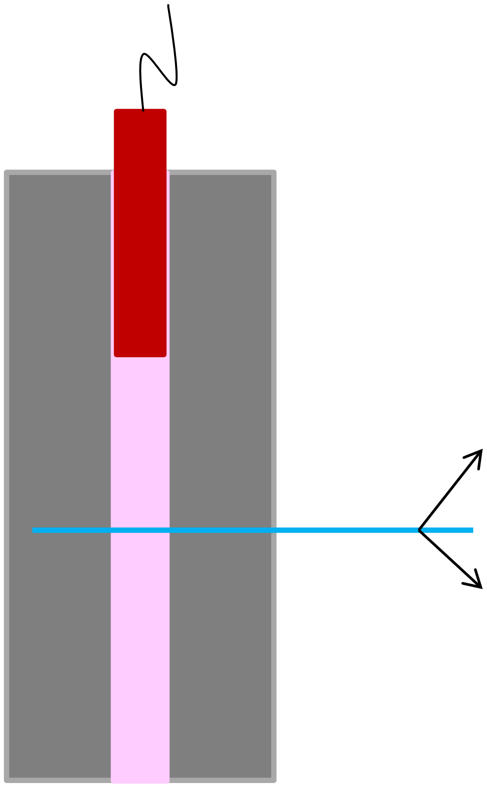
(ii) Triggering mechanisms and sweep time evaluations stay as delicate operations.

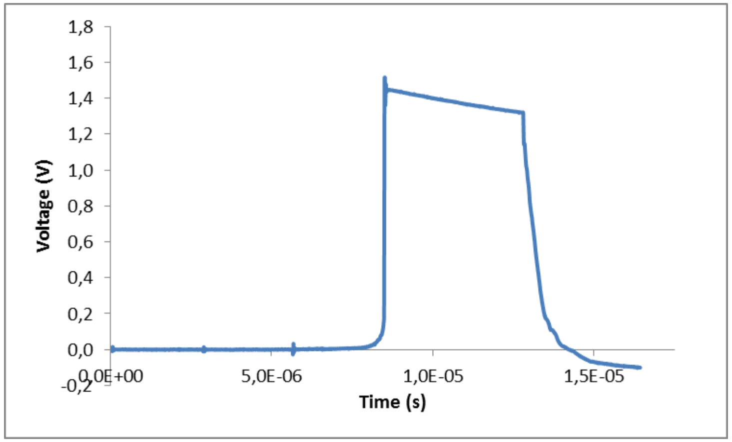
These facts lead us to develop **a more simplified method,** based on optical fibers and **fast optical/electric sensors connected and quantified by a digital signal analyzer**.

Metrology – Set-up for metrology

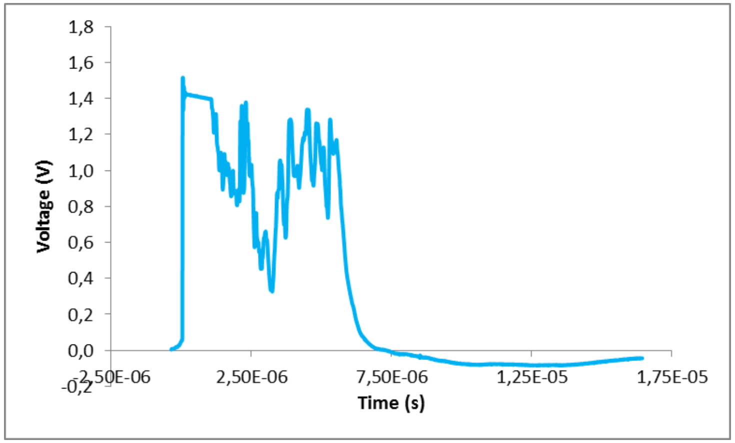


Metrology – First step



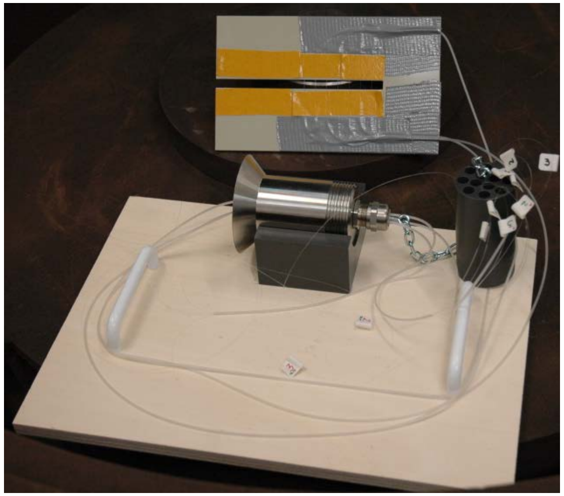


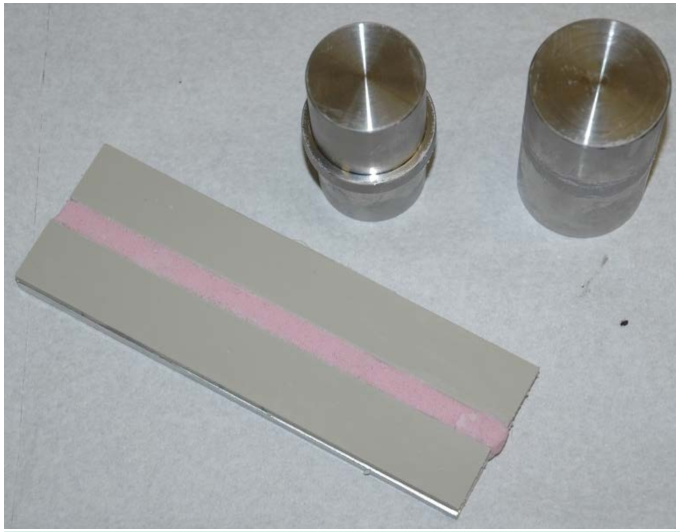
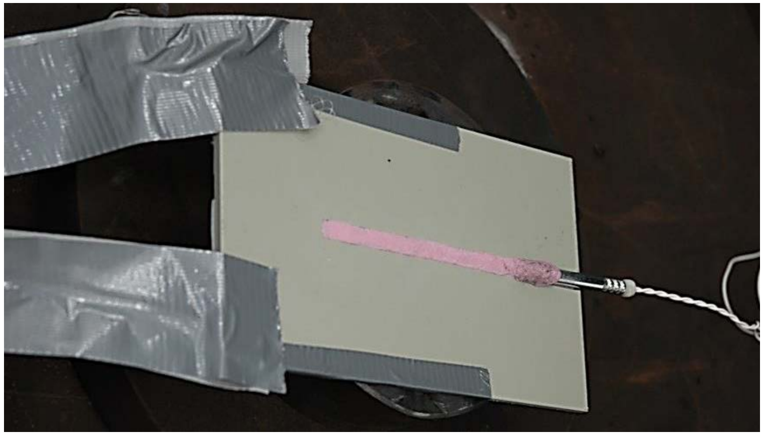
Completely saturated signal



Partially saturated signal

Metrology – First Experiment



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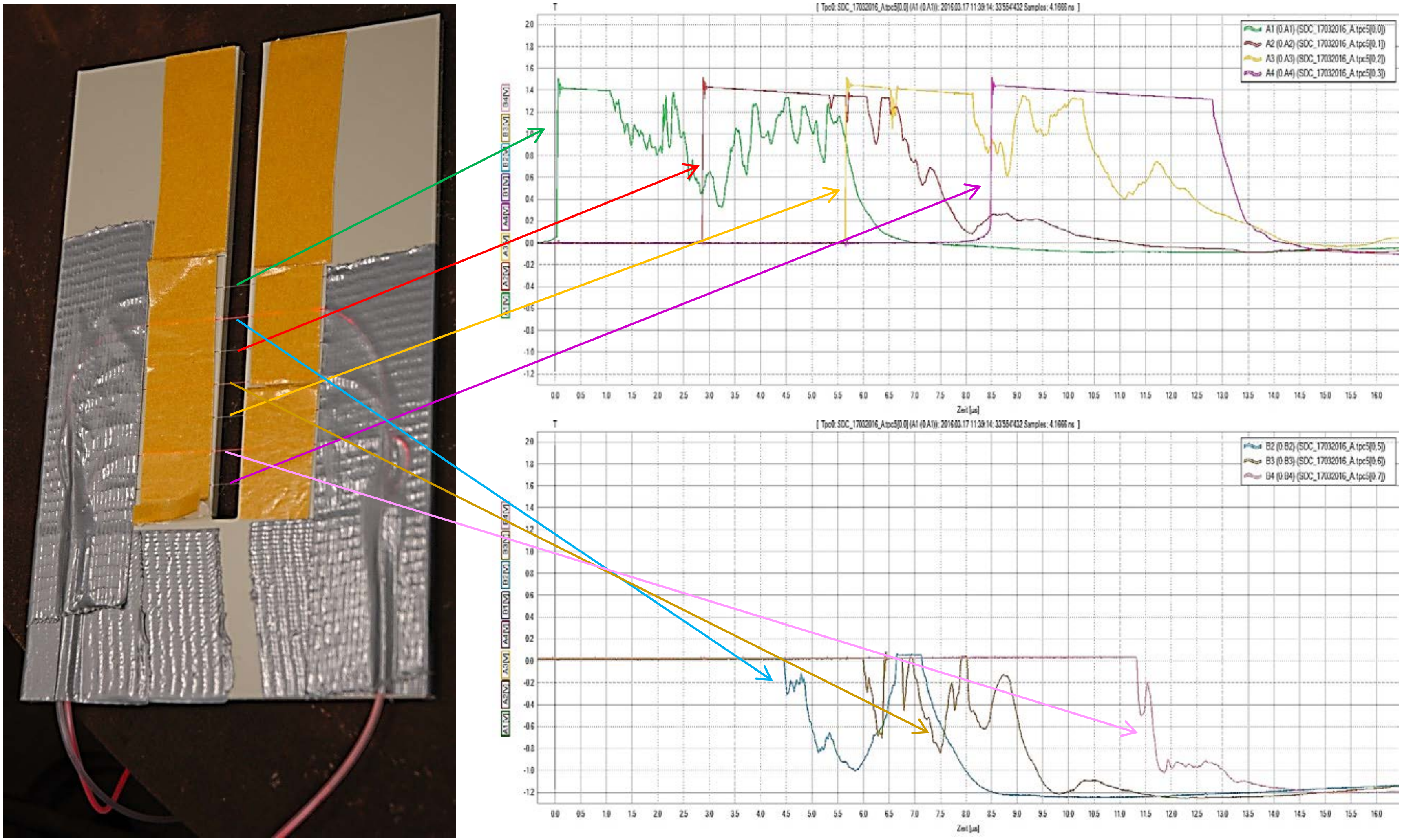
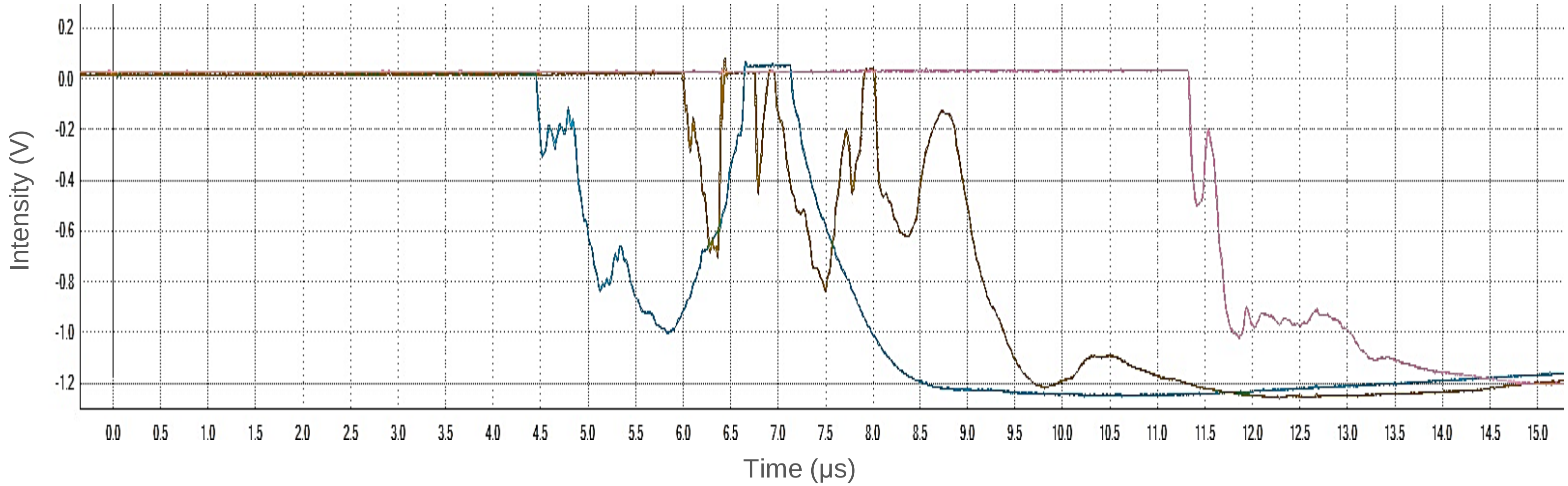
Metrology – First Experiment



Metrology – First Experiment

Lasers Signals



Problems:

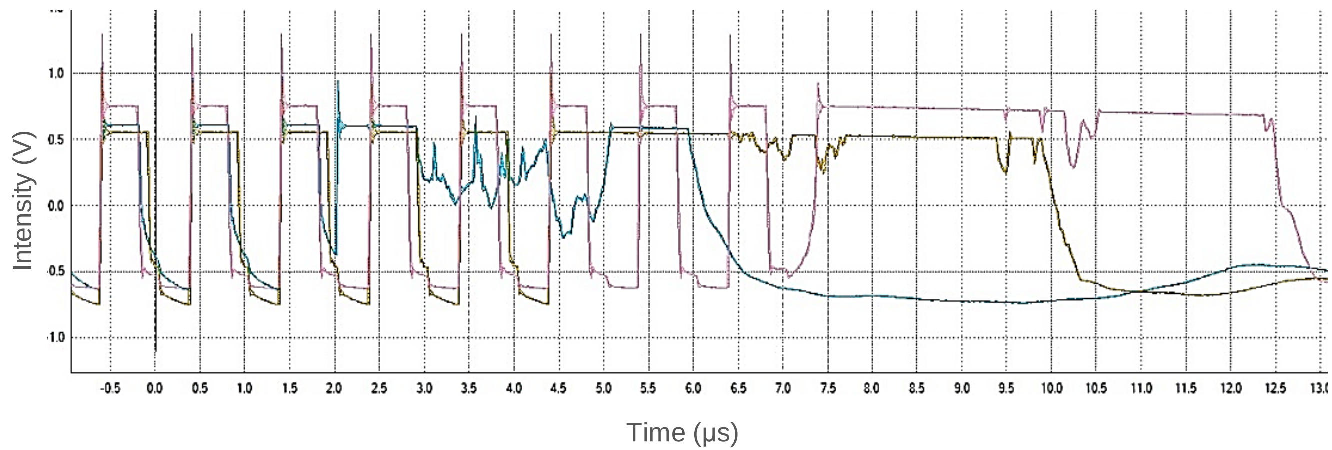
- The falling down of the signals are not precise in time. Why?
  - o Are the fibers receiving light before being broken?
  - o Is the detonation light that keeps the sensors saturated?

Metrology – Experiments

Lasers Signals

Solution:

- Modulate the lasers signals with squared shapes and 1 MHz of bandwidth



It was proved that :

- The laser lights saturate the sensors, as well as the detonation light.

Problem:

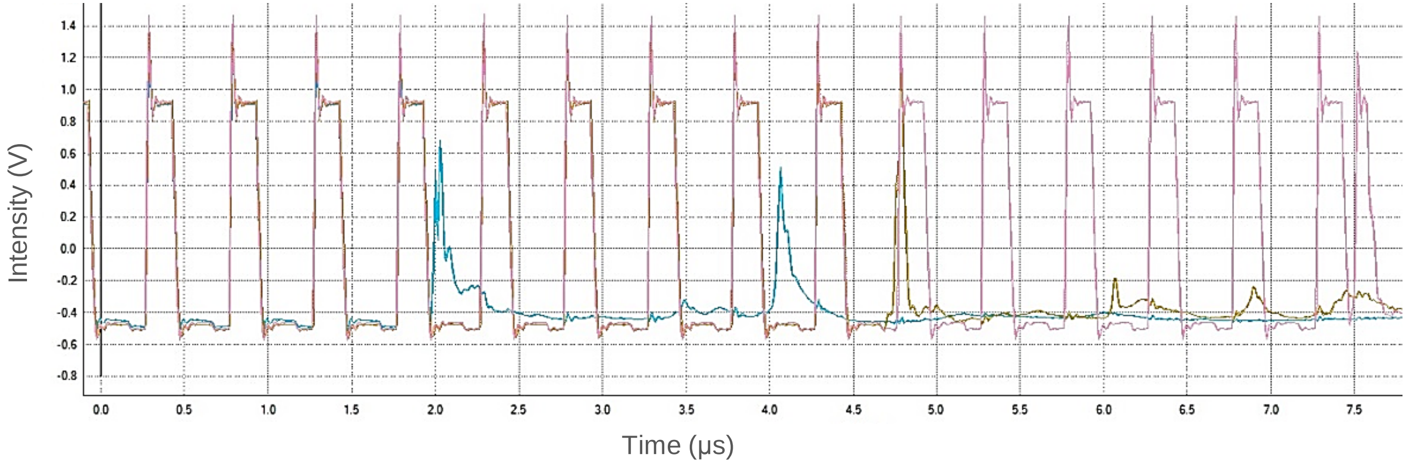
- If the fibers are broken when the sensors are saturated (positive plateau), there is no precision in time

Metrology – Experiments

Lasers Signals

Solution:

- Modulate the lasers signals with squared shapes , 2 MHz of bandwidth and add filters (range between 635 and 675 nm)



It was proved that :

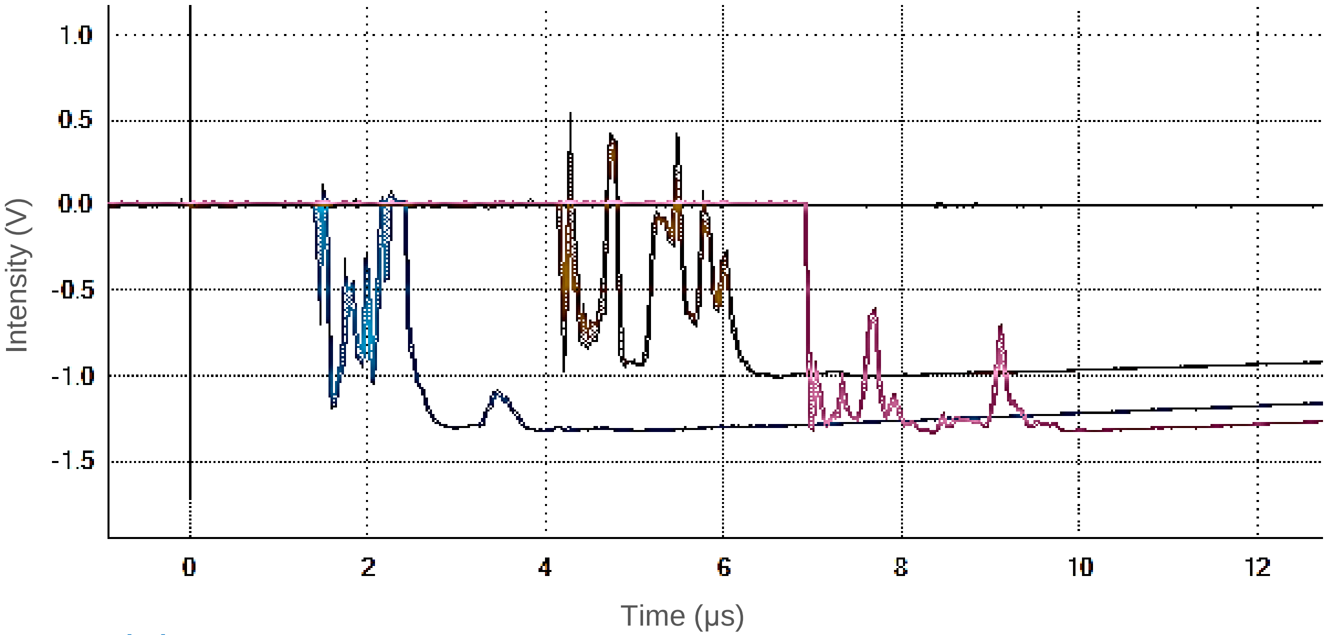
- The fibers, when transversally, just receive light when they break, otherwise the interruption of laser light would not be so drastic.
- **With filters is possible to determine precisely the breaking time and identify the different radiations: from the laser and from the detonation**

Metrology – Experiments

Lasers Signals

Challenge:

- Determine the breaking of the fibers without modulation



It was proved that :

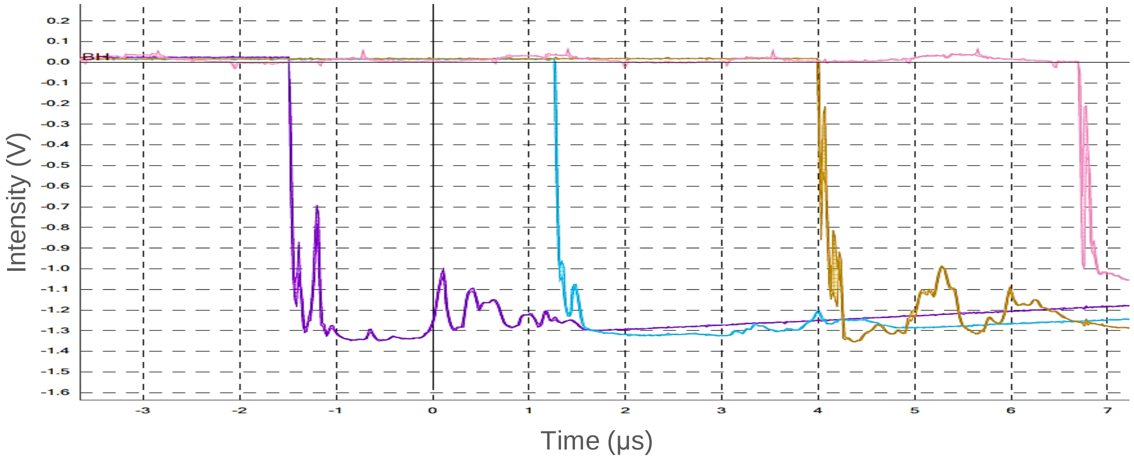
- It is possible to determine precisely the time when the fiber breaks without modulation

Metrology – Experiments

Lasers Signals

Challenge:

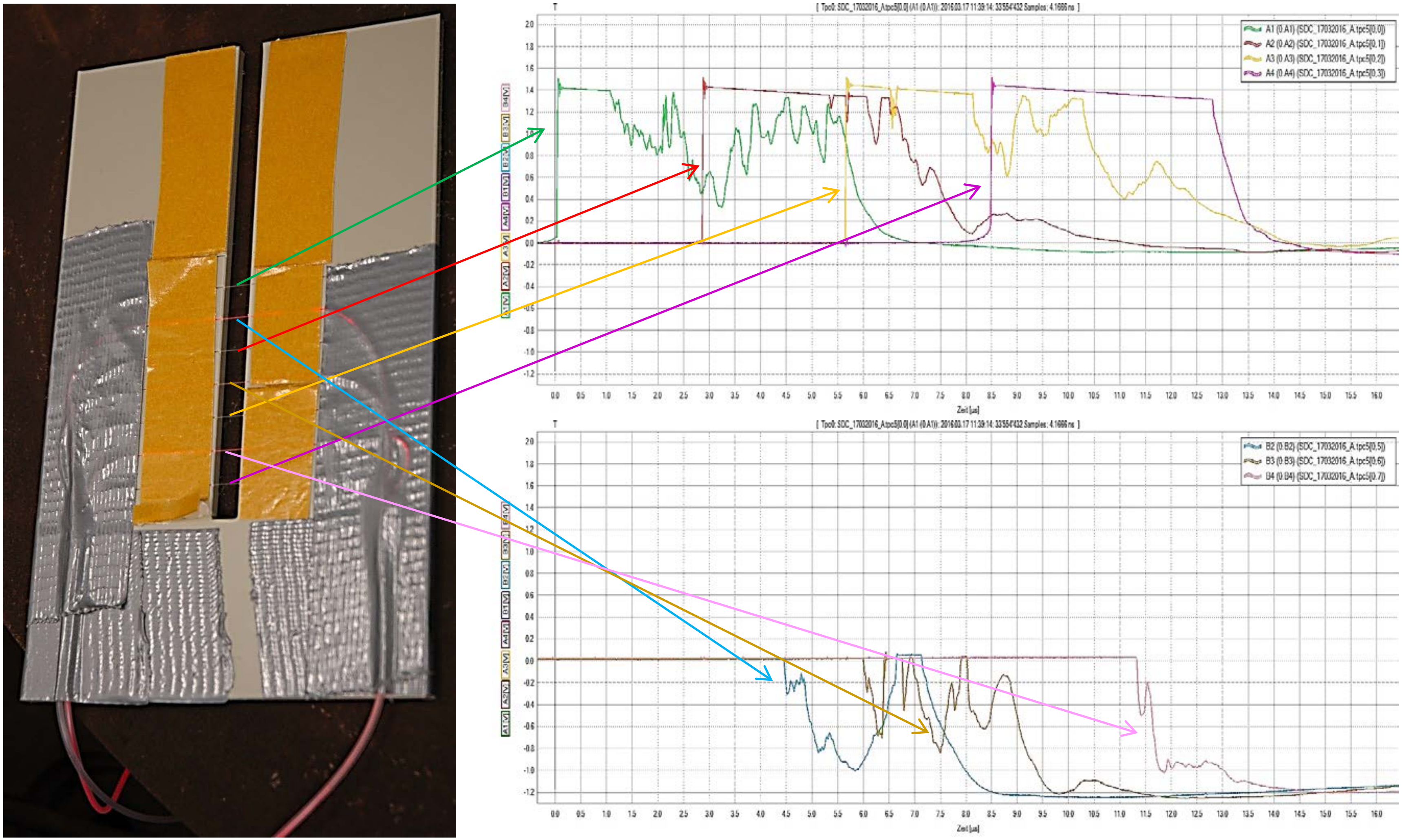
- “Clean” the signals. How?
    - o Use filters with a sharper wavelength (between 635 and 660 nm)



It was proved that :

- The use of the sharper filters improve the falling down of the signal, avoiding undesirable peaks very near to it

Metrology – First Experiment



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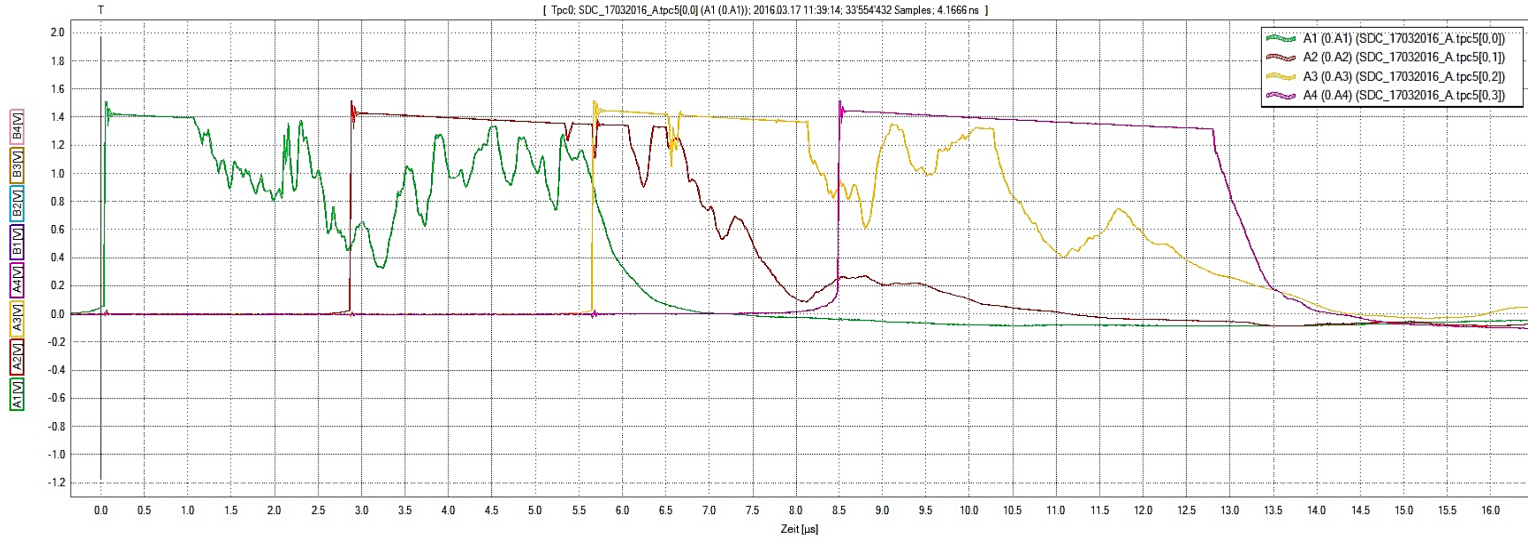
Metrology – Remembering First Experiment

Open Fibers Signals



Problem:

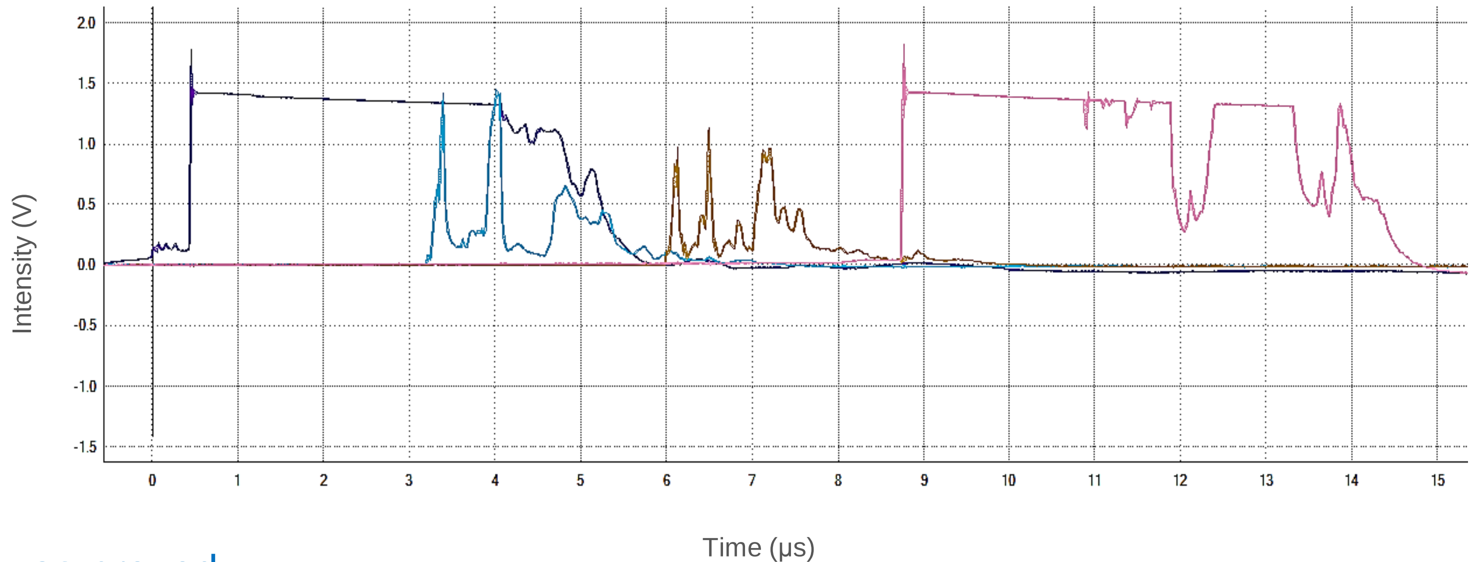
- All the signals are saturated

Metrology – Experiments

Open Fibers Signals

Solution:

- Use filters on these fibers



It was proved :

- **The use of filters avoids the signal saturation**

Challenge:

- Use a single open optical fiber for acquiring the same four signals

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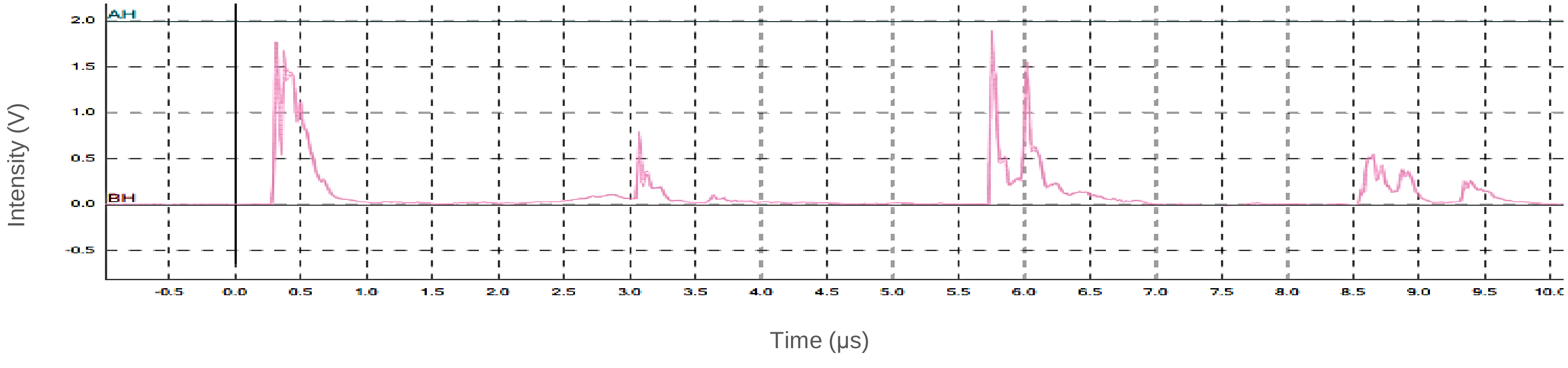
Metrology – Experiments

Open Fibers Signals

Challenge:

- Use a single open optical fiber for acquiring the same four signals. How?
    - o Make an “S” shape with the fiber
    - o Join a filter on it

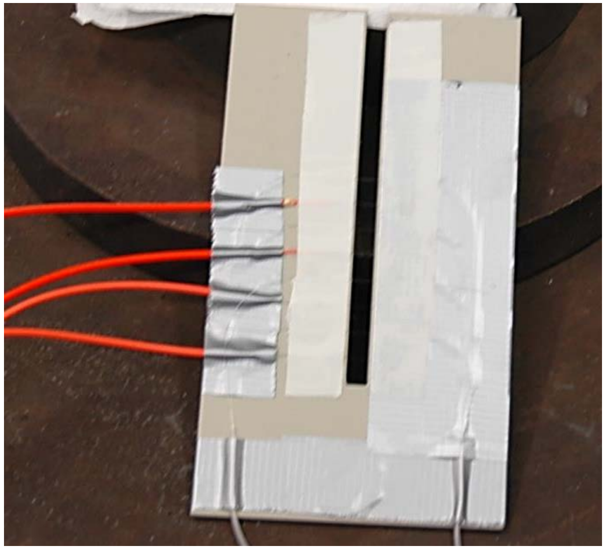


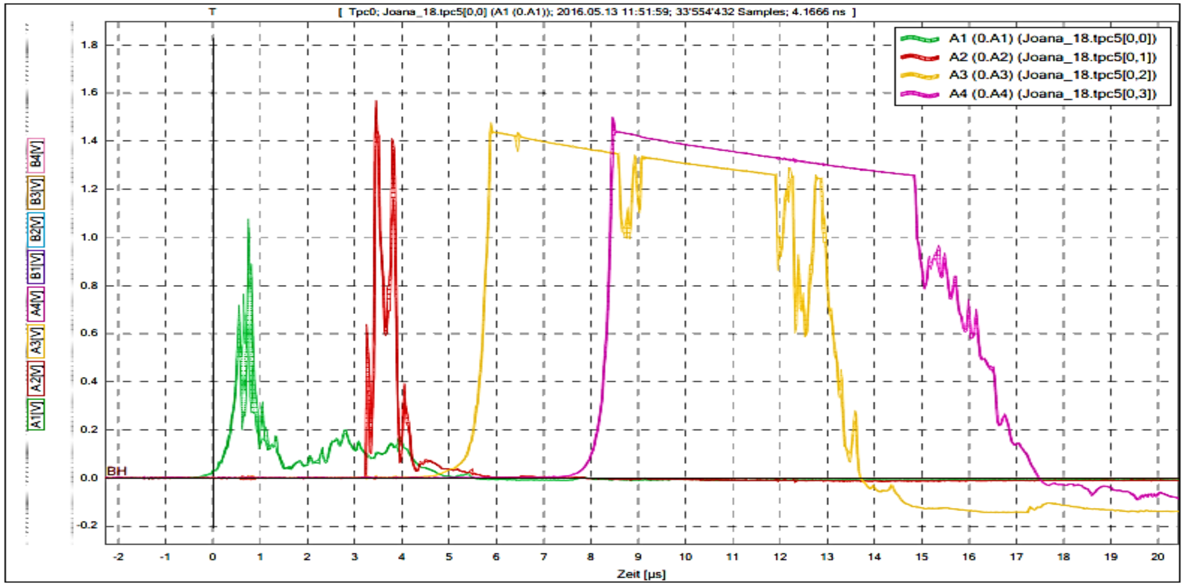
Metrology – Experiments

Open Silica Fibers Signals

Challenge:

- Use silica fibers with different diameters (50 and 200 µm) to see the influence of the acquired signals





Problem:

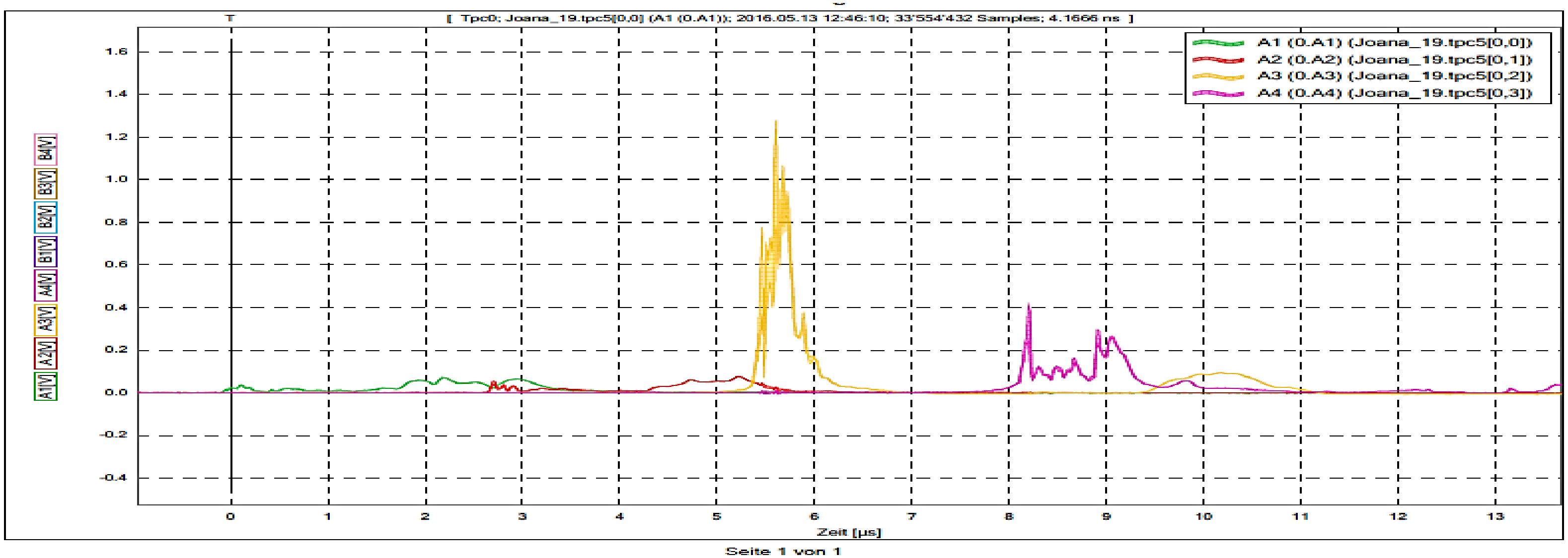
- **The signals of the silica fibers with bigger diameters are saturated**

Metrology – Experiments

Open Silica Fibers Signals

Solution:

- Use filters on the fibers with bigger diameter

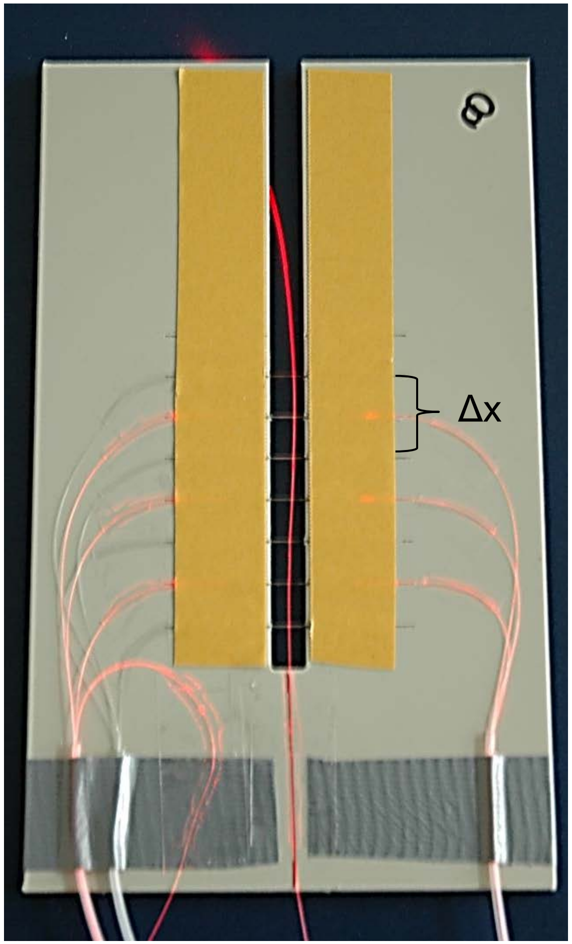


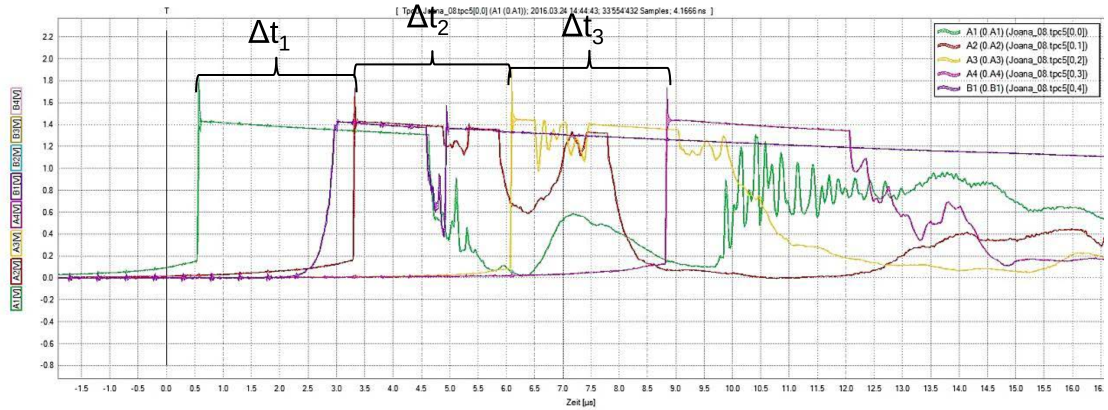
It was proved that :

- The signals of silica fibers with bigger diameter (200 µm) have the same behavior (saturation) as PMMA fibers (250 µm)
- **To have unsaturated signals we always need filters**

Metrology – Data Analysis

Detonation velocity - Open Fibers Signals





$$D = \frac{\Delta x}{\Delta t}$$

	Δx (m)	Δt (s)	D (m/s)
1	0,02	$2,754 \times 10^{-6}$	7261,637
2	0,02	$2,771 \times 10^{-6}$	7218,132
3	0,02	$2,750 \times 10^{-6}$	7272,727

$$\bar{D} = 7250,832 \ \pm 23,56 \ m/s$$

$$\% \ error = \frac{\bar{D}}{\sigma} \times 100 = 0,32$$

Metrology – Data Analysis

Detonation velocity - Open Fibers Signals

Experiment	D (m/s)	$\bar{D}$ (m/s)	σ (m/s)	Error (%)
	7132,413			
1	7294,744	7237,003	74,09	1,02
	7283,852			
	7069,14			
2	7185,71	7097,63	69,57	0,98
	7038,04			
	7741,736			
3	7111,111	7256,478	352,199	4,85
	6916,586			
	7283,727			
4	7441,86	7147,752	175,097	2,45
	7017,544			
5	Failed detonation			
	7430,249			
6	7153,588	7413,133	205,26	2,77
	7655,502			

Experiment	D (m/s)	$\bar{D}$ (m/s)	σ (m/s)	Error (%)
	7007,217			
7	6703,986	7074,313	333,16	4,71
	7511,737			
	7261,637			
8	7218,132	7250,832	23,56	0,32
	7272,727			
	7361,873			
9	7283,852	7313,49	34,5	0,47
	7294,744			
	7283,857			
10	7272,727	7233,057	63,94	0,88
	7142,857			
11	7135,806			
	6818,027			
12	7396,176	7241,98	303,47	4,19
	7511,737			

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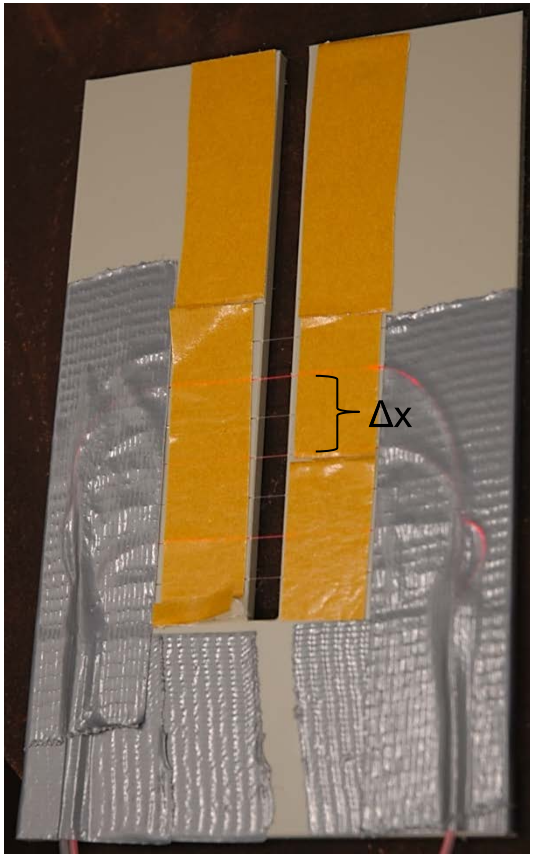
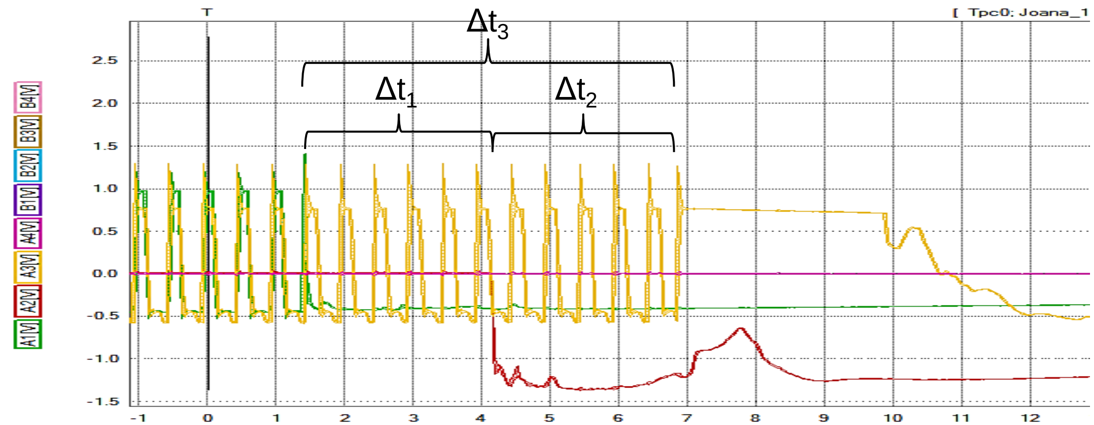
Metrology – Data Analysis

Detonation velocity - Laser Fibers Signals





$$D = \frac{\Delta x}{\Delta t}$$

	Δx (m)	Δt (s)	D (m/s)
1	0,02	$2{,}729\times10^{-6}$	7328,155
2	0,02	$2{,}733\times10^{-6}$	7317,162
3	0,04	$5{,}463\times10^{-6}$	7322,654

$$\bar{D} = 7322{,}657 \pm 4{,}49\ m/s$$

$$\%\ error = \frac{\bar{D}}{\sigma} \times 100 = 0{,}06$$

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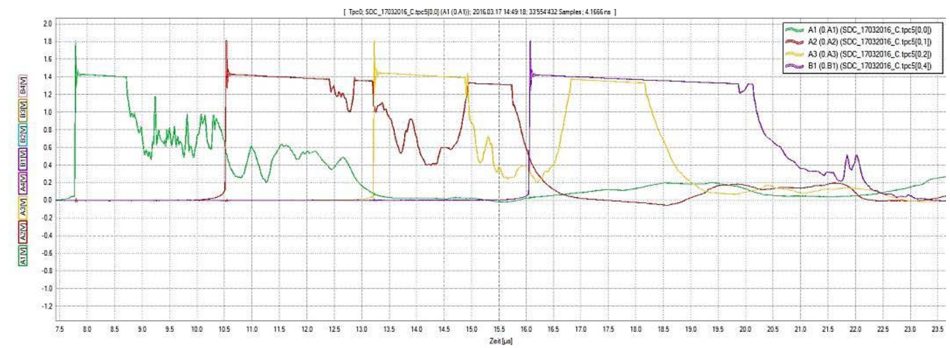
Detonation velocity - Laser Fibers Signals

Experiment	D (m/s)	$\bar{D}$ (m/s)	σ (m/s)	Error (%)
1	6886,815			
	6906,316			
2	12972,69			
	3750,02			
3	3108,776			
	20253,17			
4	5251,549			
	6722,689			
5	Failed detonation			
6	7630,966	7472,966	128,12	1,71
	7317,162			
	7470,771			

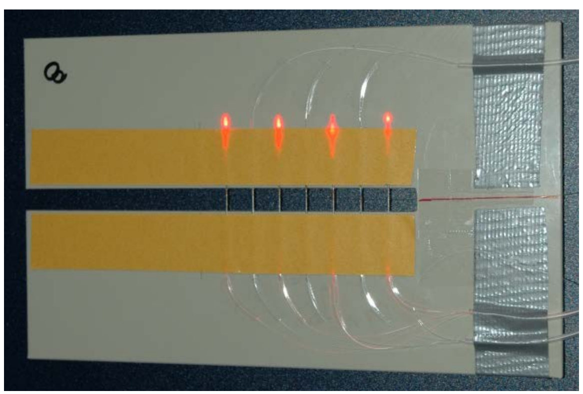
Experiment	D (m/s)	$\bar{D}$ (m/s)	σ (m/s)	Error (%)
7	7228,829	7076,541	123,47	1,74
	6926,407			
	7074,387			
8	7261,637	7294,845	27,16	0,37
	7328,155			
	7294,744			
9	7373,272	7214,821	128,45	1,78
	7058,657			
	7212,535			
10	7328,155	7322,657	4,49	0,06
	7317,162			
	7322,654			
11	7339,45	7283,999	45,16	0,62
	7228,829			
	7283,719			
12	7121,746			
	3619,91			

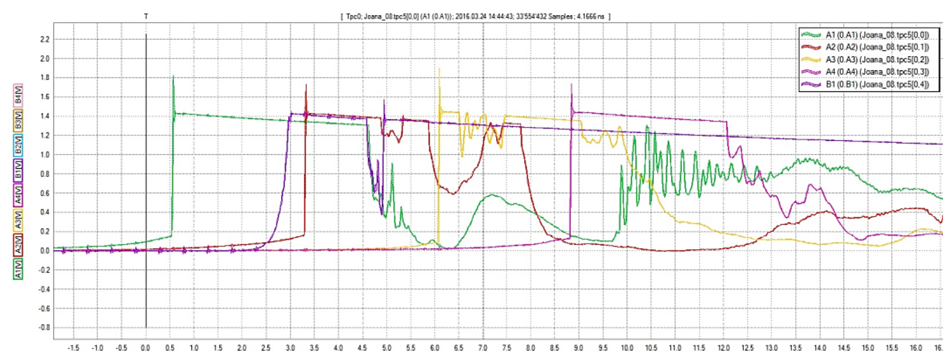
Metrology – Data analysis

Influence of using needles



Experiment 4





Experiment 8

Metrology – Data Analysis

Detonation velocity - Influence of using needles

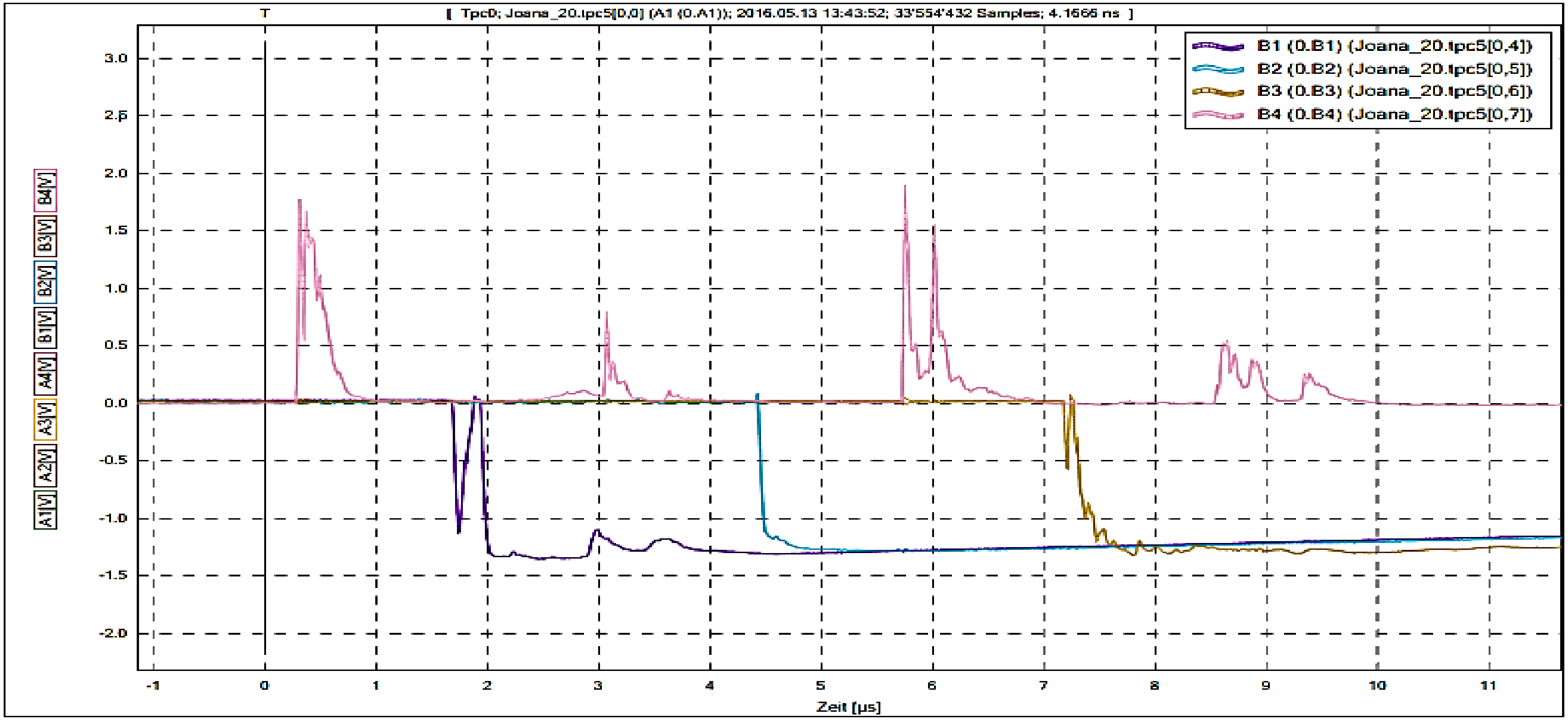
Experiment	D (m/s)	$\overline{D}$ (m/s)	σ (m/s)	Error (%)
1	7132,413 7294,744 7283,852	7237,003	74,09	1,02
2	7069,14 7185,71 7038,04	7097,63	69,57	0,98
3	7741,736 7111,111 6916,586	7256,478	352,199	4,85
4	7283,727 7441,86 7017,544	7147,752	175,097	2,45
5	Failed			
6	7430,249 7153,588 7655,502	7413,133	205,26	2,77

Experiment	D (m/s)	$\overline{D}$ (m/s)	σ (m/s)	Error (%)
7	7007,217 6703,986 7511,737	7074,313	333,16	4,71
8	7261,637 7218,132 7272,727	7250,832	23,56	0,32
9	7361,873 7283,852 7294,744	7313,49	34,5	0,47
10	7283,857 7272,727 7142,857	7233,057	63,94	0,88
11	7135,806			
12	6818,027 7396,176 7511,737	7241,98	303,47	4,19

The use of needles on open fibers increase the precision of the results

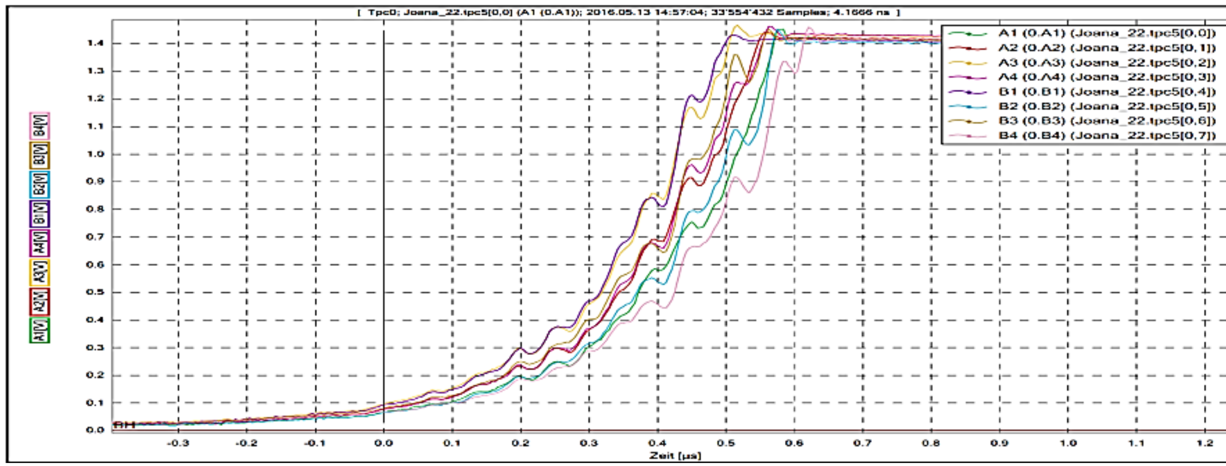
Metrology – Data Analysis

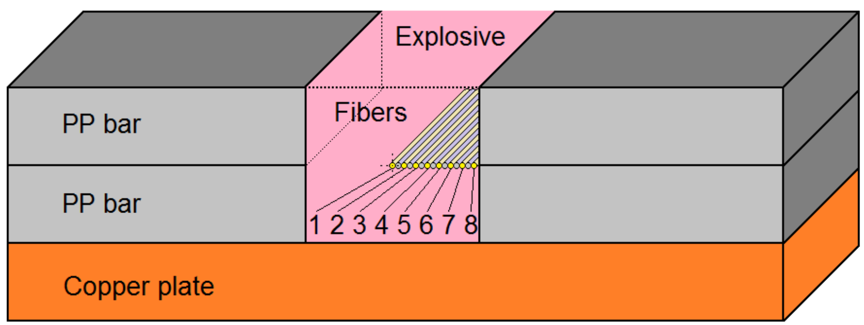
Coordination between laser and open fibers signals



Metrology – Data Analysis

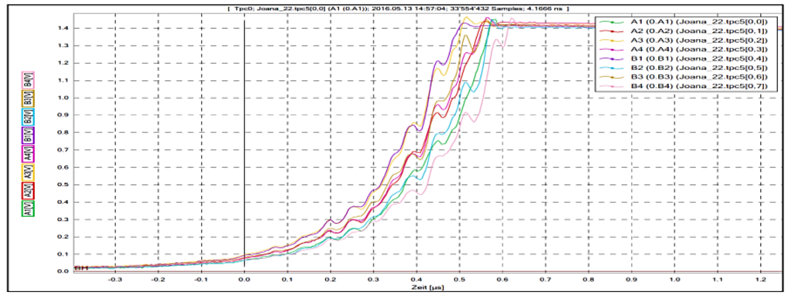
Detonation Front

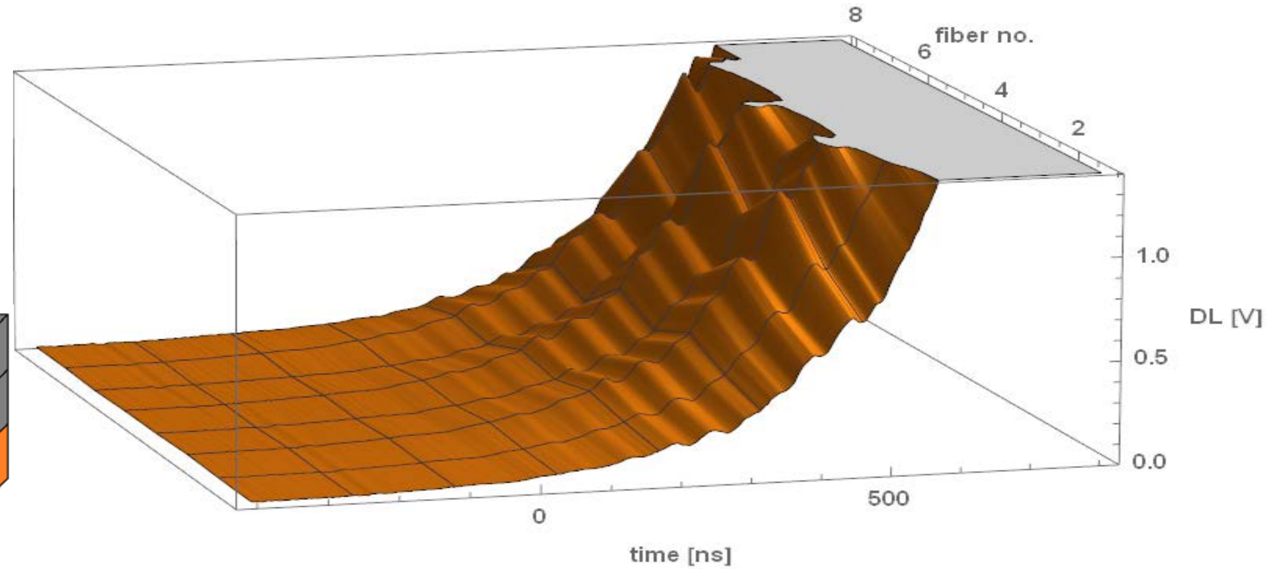


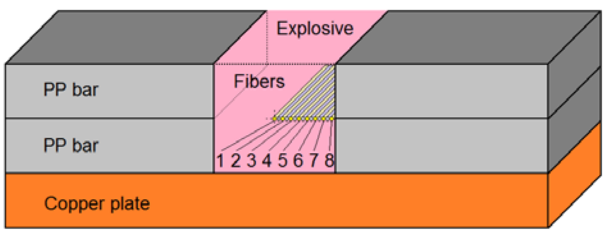


Metrology – Data Analysis

Detonation Front

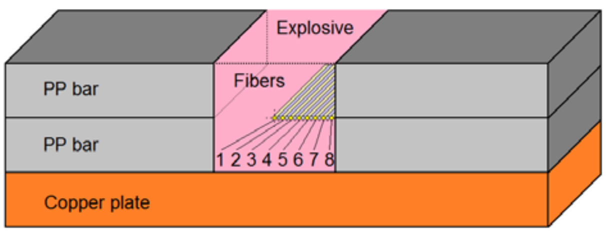


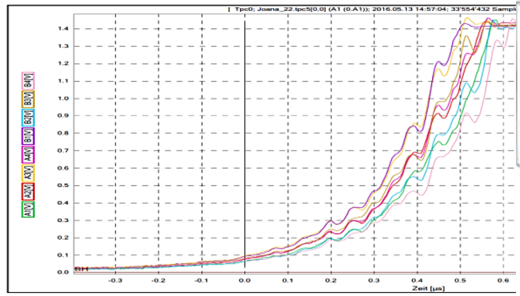


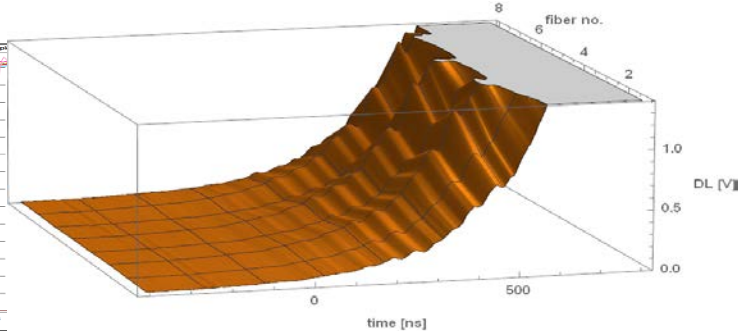


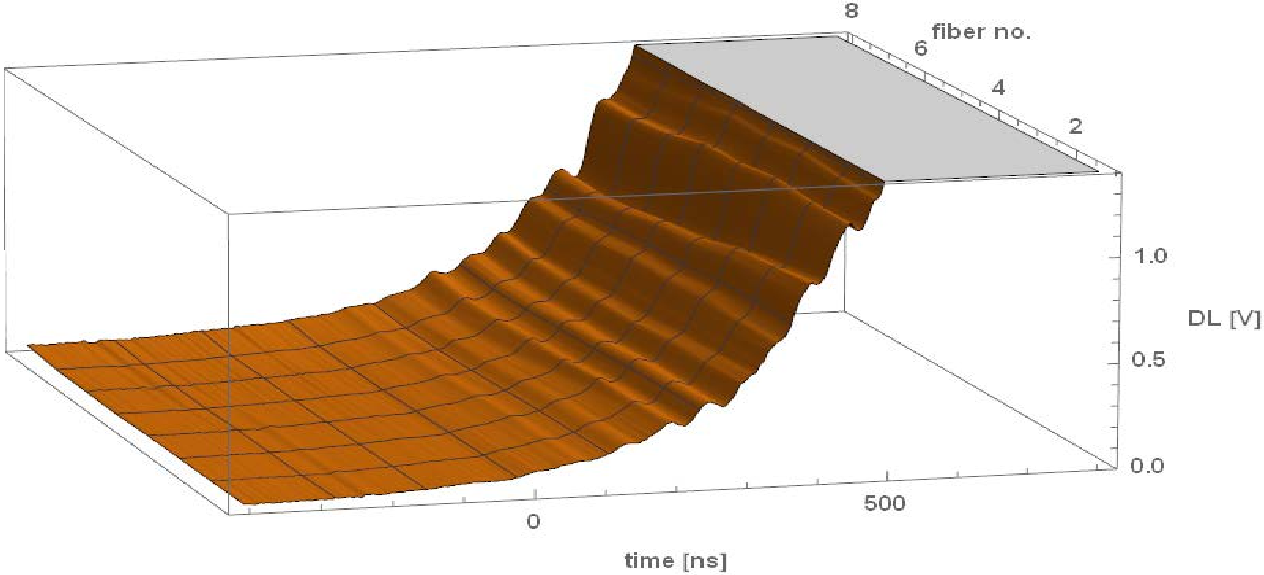
Metrology – Data Analysis

Detonation Front



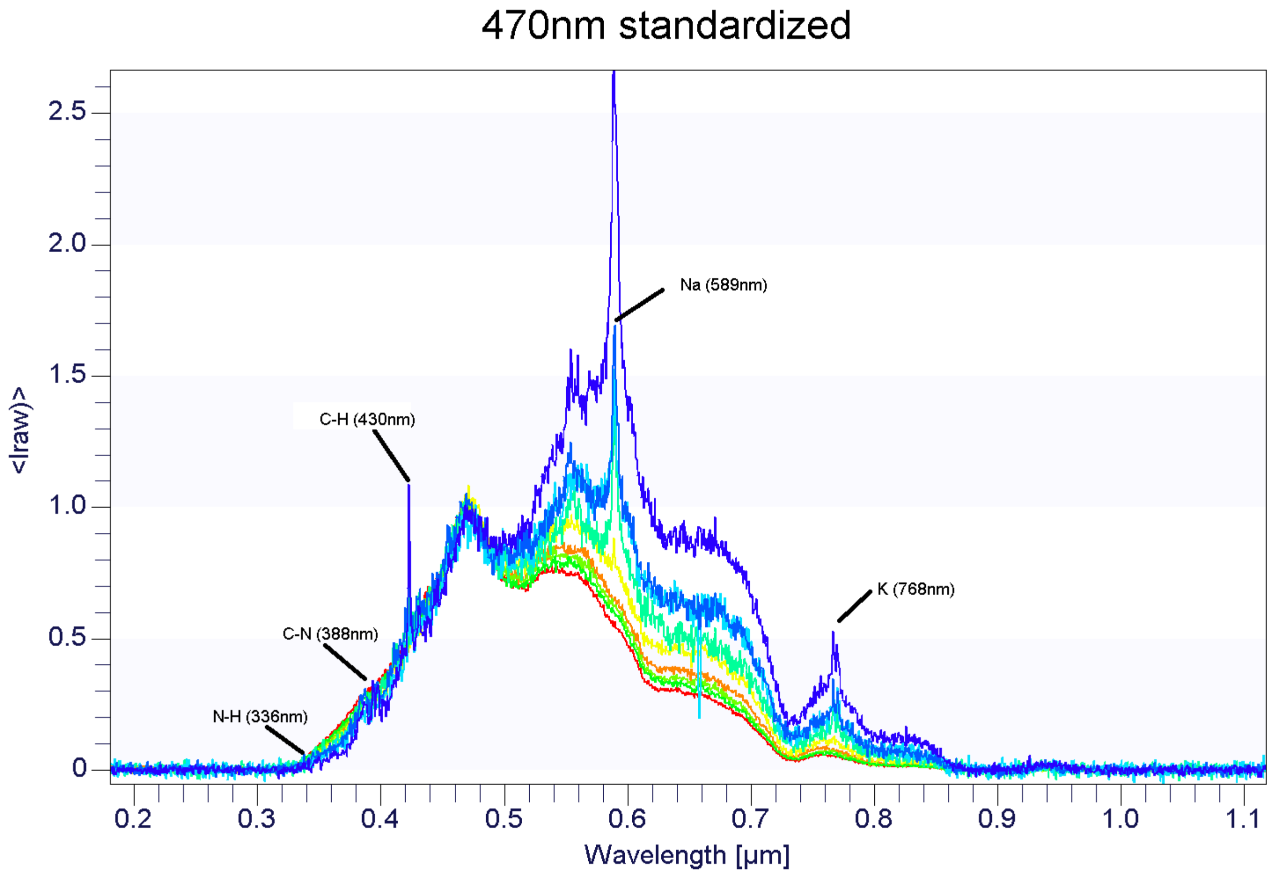






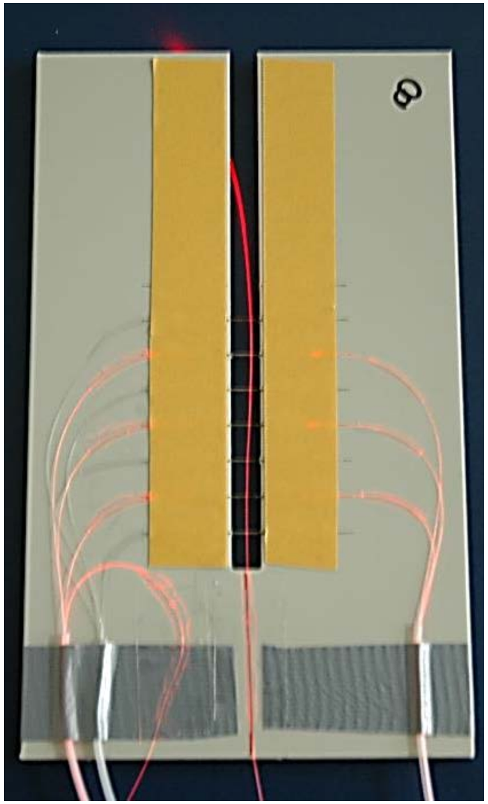
Metrology – Data Analysis

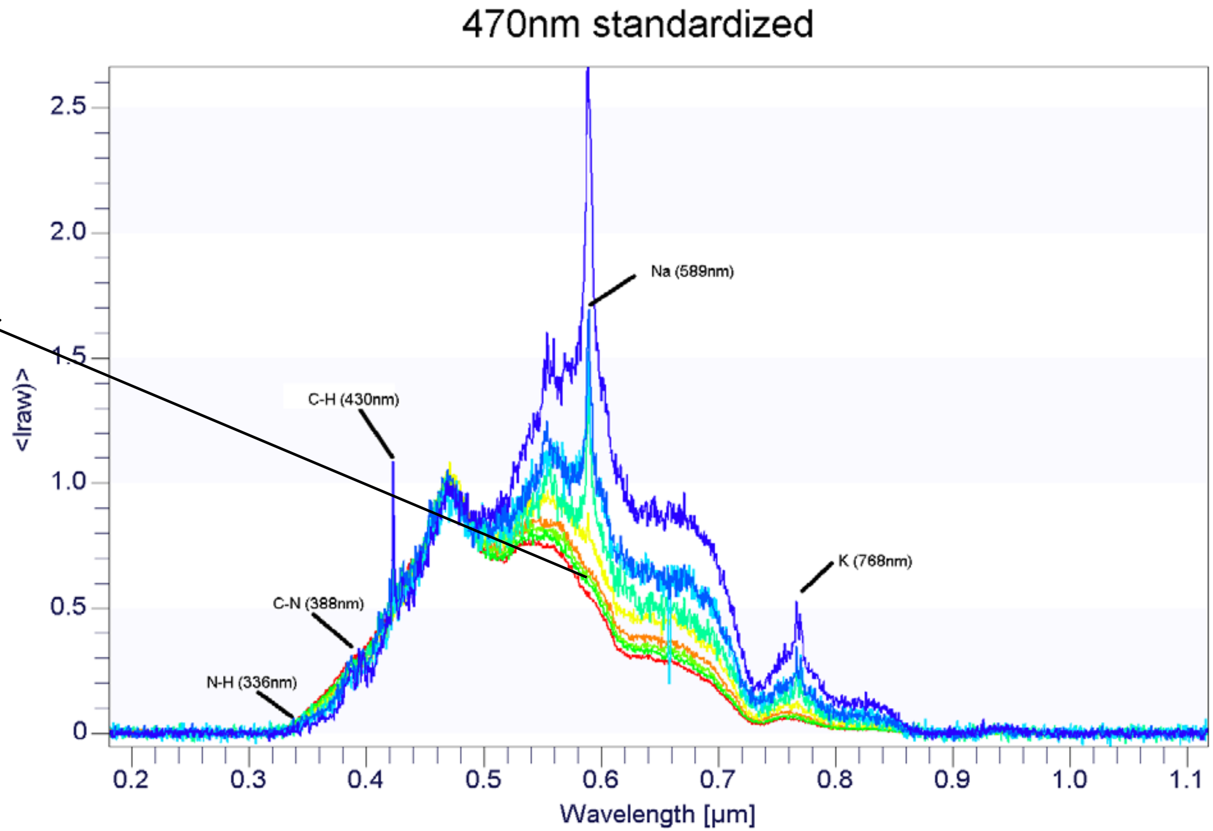
Spectrometric Analysis



Metrology – Data Analysis

Spectrometric Analysis



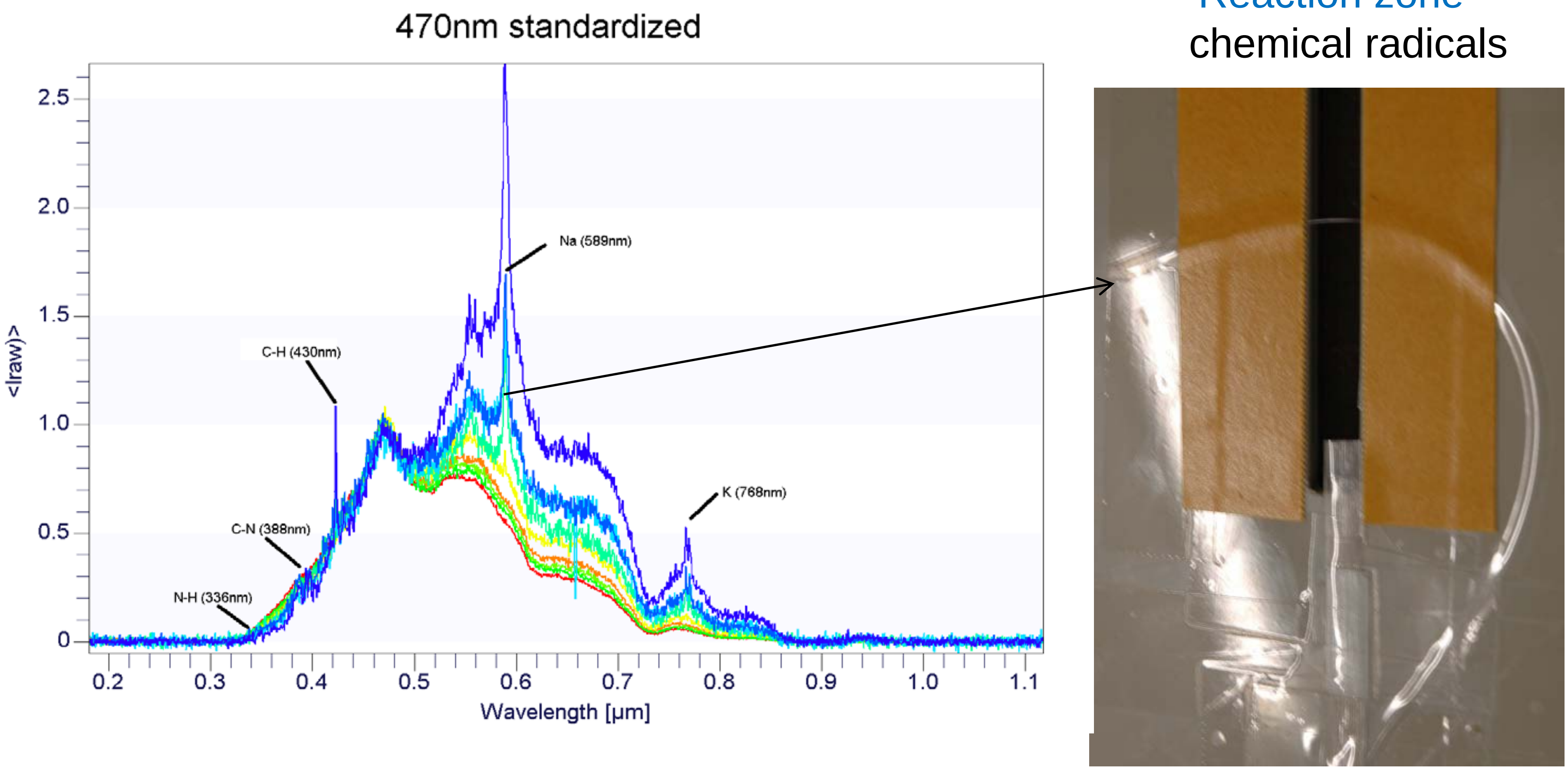


Detonation Products
– thermal radiation

Metrology – Data Analysis

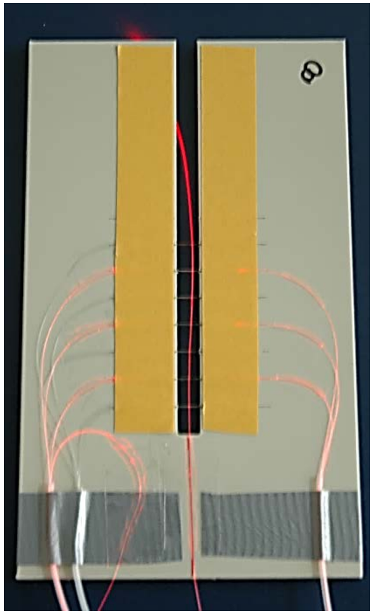
Spectrometric Analysis

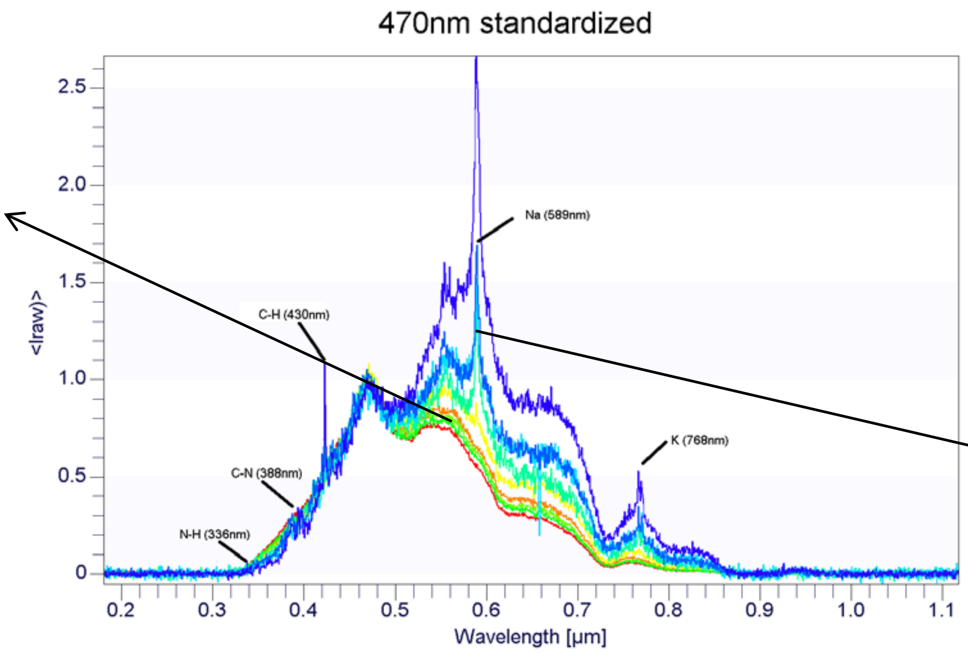
Reaction zone – chemical radicals



Metrology – Data Analysis

Spectrometric Analysis





Reaction zone – chemical radicals

Detonation Products – thermal radiation

Summary

- It was proved that:
  - The laser lights saturate the sensors, as well as the detonation light.
  - The fibers, when transversally, just receive light when they break, otherwise the interruption of laser light would not be so drastic.
  - **With filters is possible to determine precisely the breaking time and identify the different radiations: from the laser and from the detonation**
  - It is possible to determine precisely the time when the fiber breaks without modulation
  - The use of the sharper filters improve the falling down of the signal, avoiding undesirable peaks very near to it
  - **The use of filters avoids the signal saturation**
  - The signals of silica fibers with bigger diameter (200 µm) have the same behavior (saturation) as PMMA fibers (250 µm)

Summary

- The detonation velocity was achieved with very good accuracy. With open fibers the errors were always below 5% and, with lasers, always below 2%.
- The use of needles, on open fibers, increase the precision of the measurements.
- It was possible to have an idea about the behavior of the detonation front.
- The spectroscopic analysis showed it is possible to distinguish the radiation of the detonation products from the radiation of the reaction zone
- The expectations about the future work is to measure the detonation pressure

End

Thank you very much for your attention ☺

Questions?