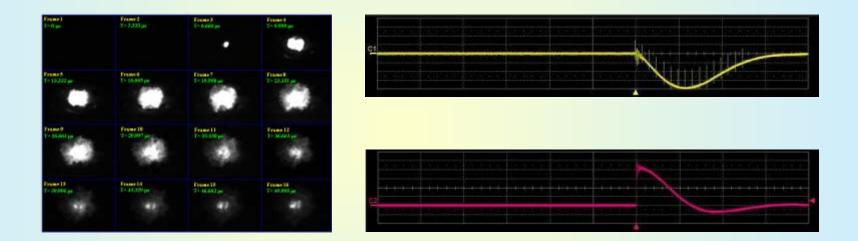


Nano second behavioral of Exploding Bridge Wire (EBW) using Ultra High Speed Imaging Technology



H. Muthurajan, Martin Yeo Kwee Liang, Low Chan Gee, Ang How Ghee

Energetic Materials Research Centre Nanyang Technological University, Singapore

For 58th Annual Fuze Conference, Baltimore



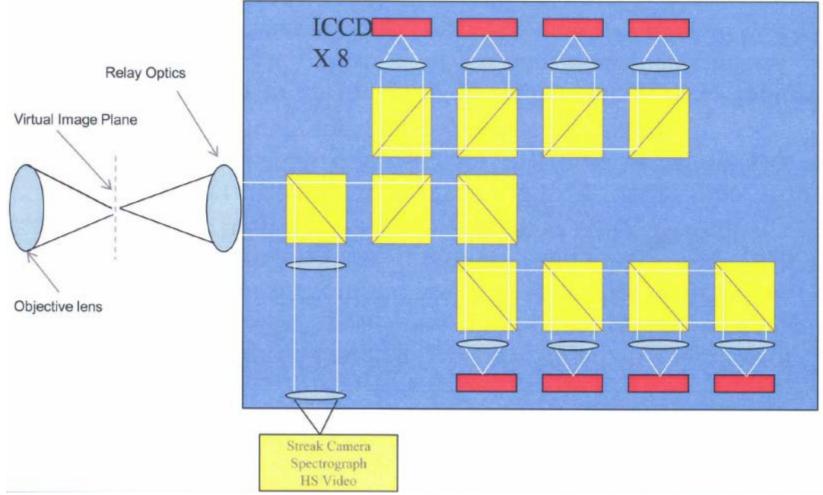
Overview of Presentation

1. Introduction

- a) Framing Camera for detonics
- b) Streak Camera for detonics
- c) Simultaneous Streak and Framing Camera
- 2. Al based EBW
 - a) Ultra high speed framing
 - b) Streak Record
 - c) Digital Storage Oscilloscope Analysis
- 3. Result and Discussion
- 4. Conclusion



High Speed Framing Camera Eight way beak splitter with additional optical port

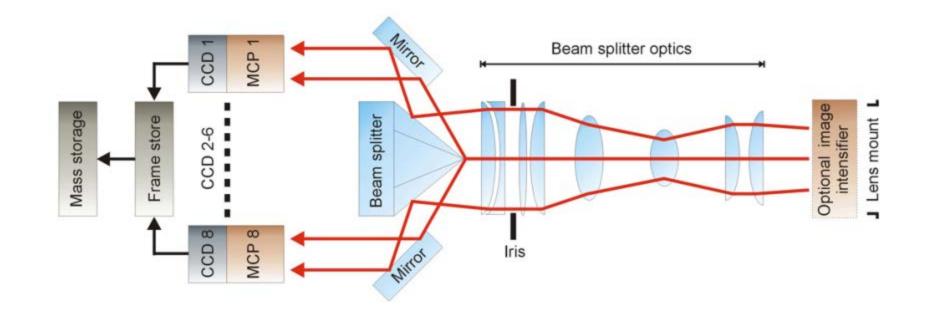


Disadvantages

Disadvantage of this technique is that **at each beam** splitter 50% light intensity is reduced (halve, i.e split in-to 50% and 50%) which is received by next subsequent beam splitter. Hence each ICCD receives different intensity of light



Framing Camera : Pyramid beam splitter

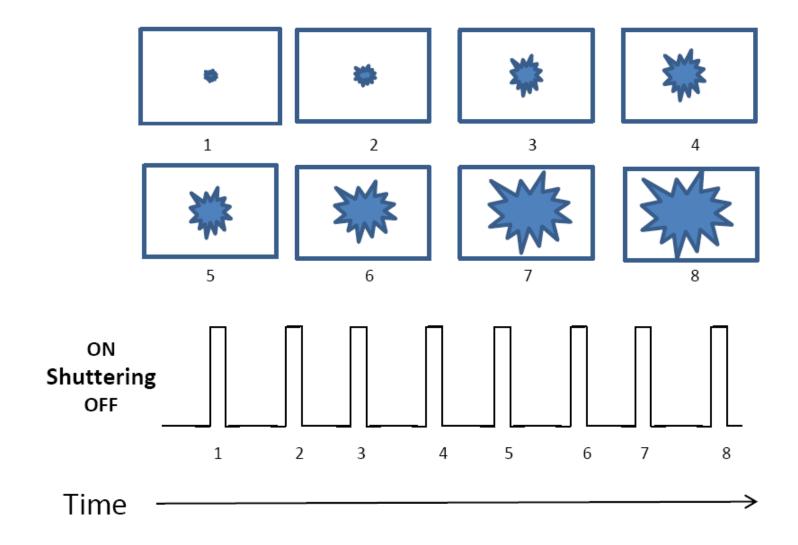


Each camera consists of eight individual CCD detectors. The signal is collected by a common optical system and is then split into eight identical copies that are relayed to the individual CCD detectors. The camera also has the option of double exposure for the CCDs thus giving 16 images.

The **pyramid mirror** has eight plane facets reflecting eight images of the object on to the faces of **eight image intensifier devices** for respective image sensor devices. In each case the respective image is reflected via an intermediate mirror

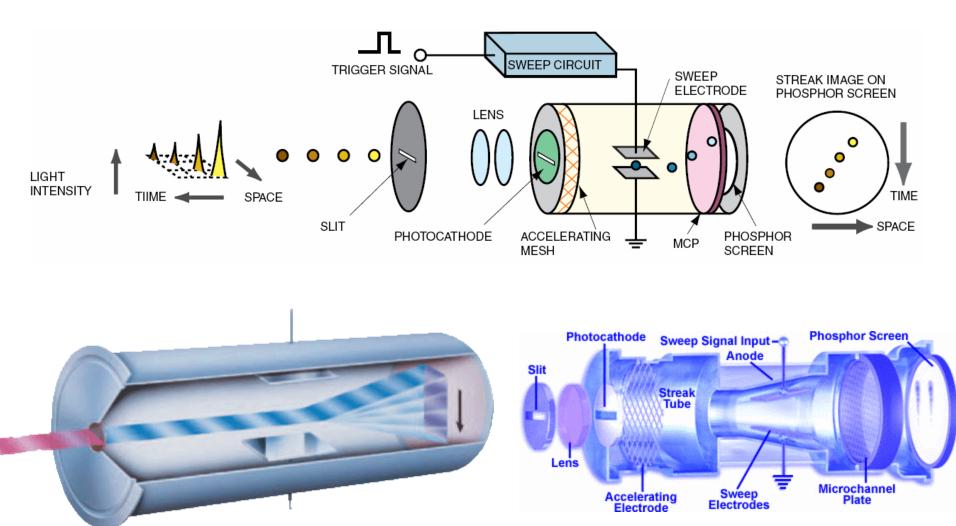


Framing Sequence





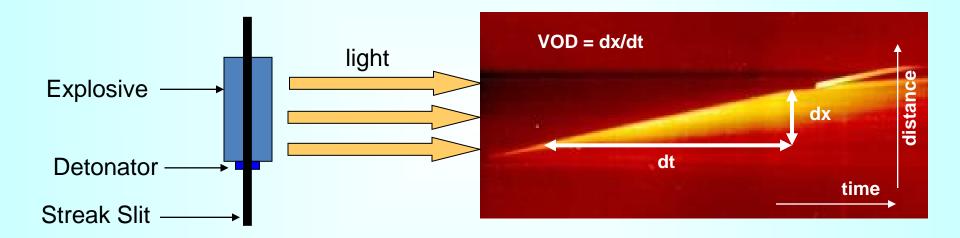
Operating Principle of Streak Camera for Detonics



Streak Tube



- Use to derive velocity of detonation (VOD)
- Event parallel to slit, perpendicular to optical axis



Setup

Typical streak image

Slope = m = tan
$$\theta = \frac{y_2 - y_1}{x_2 - x_1}$$
 θ = tan⁻¹ $\left(\frac{y_2 - y_1}{x_2 - x_1}\right)$
 $VOD = \frac{d_x}{d_y} * \frac{SF}{WR}$ $C_J = \frac{1}{4}\rho D^2$



Why nano seconds exposure for detonics?

"Freezing" Image Motion



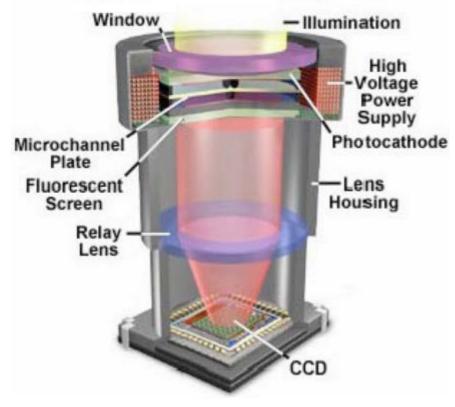
Image blur on the camera sensor.

Using a very short exposure time reduces blur.



ICCD (Intensified CCD) for Framing and Streak Camera

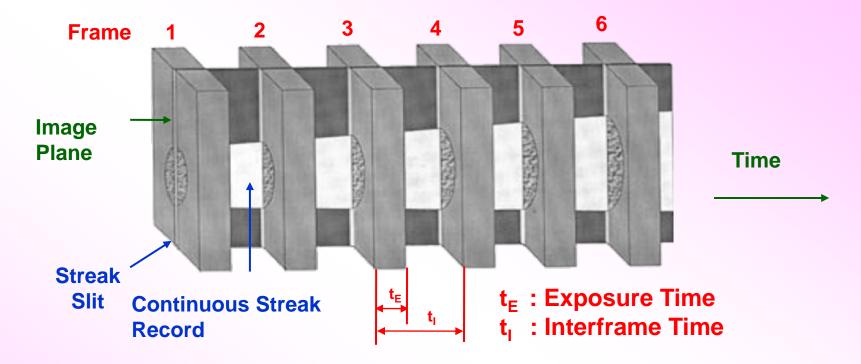
Image Intensifier with Relay Lens



- Photocathode: Generation of photoelectrons
- Microchannel plate (MCP): Multiplication of electrons
- Phosphor Screen: Conversion of electrons back into highly increase (x10⁴ - 10⁶) number of photons
- High numerical aperture lens-coupling for superior distortion free image quality
- CCD: Conversion of the very high number of photons to charge, readout and digitization



Simultaneous Streak-Framing Record



Streak : Continuous imaging, difficult to interpret

Framing : "what you see is what you get", but only at certain time-intervals Simultaneous Streak and Framing

- Allows recording of entire phenomena (with streak) + easier interpretation (with framing)
- Prevent misinterpretation of images

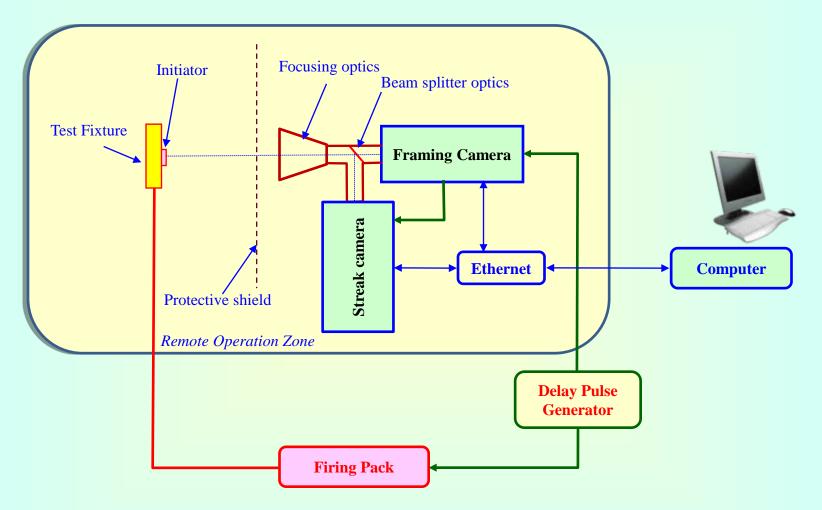


Advantages of Simultaneous Streak and Framing Records

Parameter	Frames	Streak
Spatial picture	+	—
Space resolution	_	+ (but only in 1 plane)
Time resolution	-	+
Full-time observation	_	+
Interpretation	\rightarrow	\leftarrow
Velocities	\rightarrow	\leftarrow



Experimental setup of Simultaneous Streak and Framing Imaging



Experimental setup of Simultaneous Streak and Framing Imaging for performance evaluation of AI based EBW

Simultaneous Framing and Streak Imaging of AI - EBW

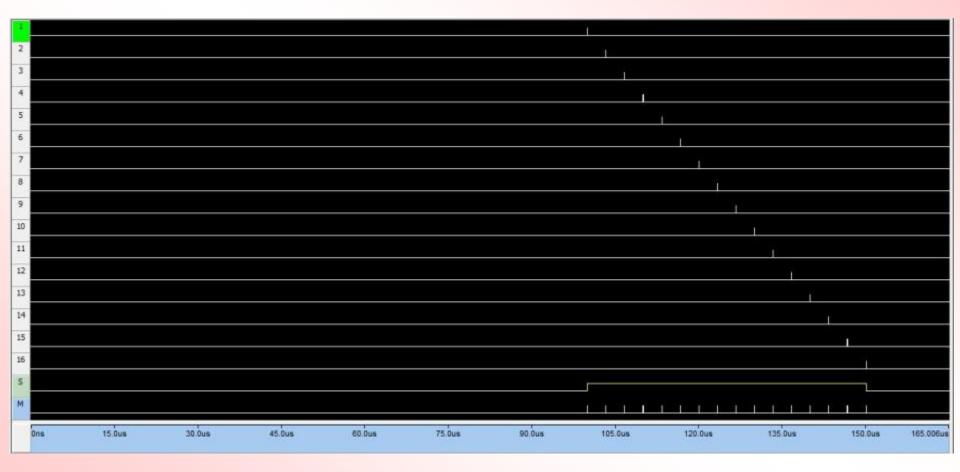
Parameters of Experiment – Synchronization CDU and Imaging System

NTU - EnRI Software to Control Delay / Pulse Generator					
ïle Trigger Delay Output Tools Help					
È: E: E: E: E: C: ?					
Trigger	Delay				
C Internal Rate 1000 Hz, t= 100 μs	A = T • + 0 μs •	Read Delay			
○ External Level 1 V, Slope Rising ▼ HI Z ▼	B = A • + 1 μs •	Read Trigger			
Single Shot <u>Execute </u> ■ ARM Window C Line	C = Β • + 100 μs				
C <u>B</u> urst Rate 10000 Hz. t = 100 μs	D = C • + 101	<u>D</u> ownload to Instrument			
Pulses per burst 10 Periods per burst 20 Duration (Period) of a burst = 2 ms	A .□L B = 1 μs				
Output	Info Experimental Remarks				
$T_0 = HIZ \cdot TTL \cdot Normal \cdot$	5mil Al based Exploding Bridge Wire 5kV CDU, 100 Joules	*			
A = HIZ · TTL · Normal ·					
$B = 50 \Omega \bullet TTL \bullet Normal \bullet$					
$C = 50 \Omega \cdot VAR \cdot Amplitude 4 V, Offset 0.50 V$		~			
$D = 50 \Omega \cdot TTL \cdot Normal \cdot$	☐ Instantaneous download of delay and text				
AB -AB = 50 Ω • TTL •	LCD Display LCD Text EnRI_Welcomes				
$CD_{-CD} = 50 \Omega \cdot TTL \cdot$	C Static Display C Time C Date C Day C Flash C Roll C Loop C Clear Text Timer 25				
Pop-up Error Messages					
EnRi		2:17 PM			



Simultaneous Framing and Streak Imaging of AI - EBW

Parameters of Experiment – Imaging Systems



Exposure Time : **10 ns** Inter-frame Time: 3.323 µs Iris: f2.8 Gain: 1 Total Recording Length: 50.005 μs

Ultrahigh Speed Framing Imaging of AI - EBW

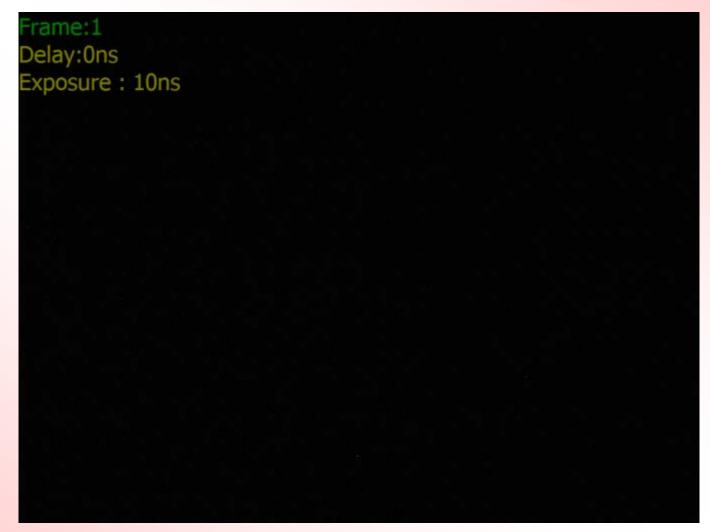
Frame 1	Frame 2	Frame 3	Frame 4
T= 0 μs	T= 3.333 μs	T= 6.666 μs	T= 9.999 μs
		•	
Frame 5	Frame 6	Frame 7	Frame 8
T= 13.332 μs	T= 16.665 μs	T= 19.998 μs	T= 23.331 μs
Frame 9	Frame 10	Frame 11	Frame 12
T= 26.664 μs	T= 29.997 μs	T= 33.330 μs	T= 36.663 μs
Frame 13	Frame 14	Frame 15	Frame 16
T= 39.996 μs	T= 43.329 μs	T= 46.662 μs	T= 49.995 μs

Observed Function Time : 6.666 μs Exposure Time : **10 ns** Inter-frame Time: 3.323 μs

Iris: f2.8 Gain: 1 Total Recording Length: 50.005 μs



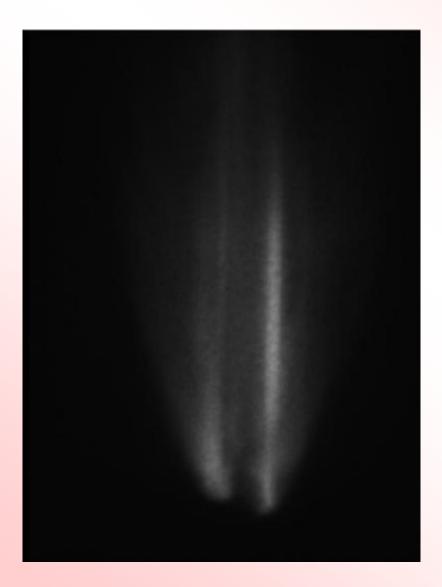
Ultrahigh Speed Framing Imaging (Video) of AI - EBW



Observed Function Time : 6.666 µs Exposure Time : 10 ns Inter-frame Time: 3.323 µs Iris: f2.8 Gain: 1 Total Recording Length: 50.005 μs



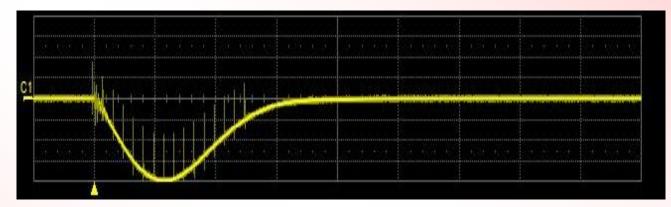
Streak Imaging of AI - EBW



Sweep Speed : 2.5 μ s/mm Sweep Duration : 50 μ s Slit Size : 50 μ m Gain : 608 Volt Iris : f2.8

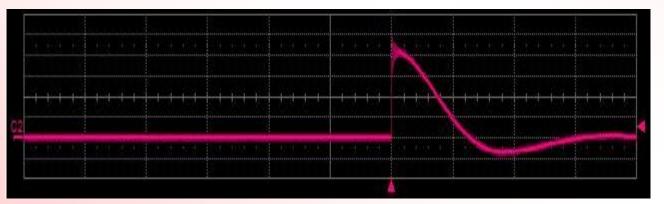


Digital Storage Oscilloscope (DSO) Data on AI EBW



Y axis : 1 Volt/div X axis : 20µs/div Offset : 0 mV

Pulses from Framing camera corresponding to the frames acquired



Y axis : 1.0 kV/div X axis : 20µs/div Offset : -2.0 kV

Voltage across the AI based EBW



Simultaneous Framing and Streak Imaging of AI - EBW

Parameters of Experiment

1							1				
2											
3											
4											
5											
6								8			
7											
8											
9											
10									1		
11									31		
12											
13									1		
14										1	
15										1	
16											
s											
м								1.1.1			
	Ons 15.0us	30.0us	45.0us	60.0us	75.0us	90.0us	105.0us	120.0us	135.0us	150.0us	165.0us

Observed Function Time : 6.656 μs Exposure Time : **5 ns** Inter-frame Time: 3.323 μs

Iris: f2.8 Gain: 1 Total Recording Length: 49.925 μs



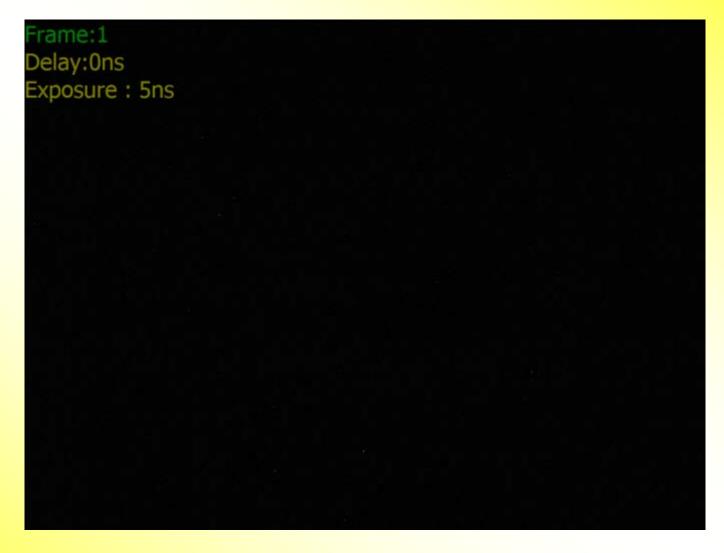
Ultrahigh Speed Framing Imaging of AI - EBW

Frame 1	Frame 2	Frame 3	Frame 4
T= 0 μs	T= 3.328 μs	T= 6.656 μs	T= 9.984 μs
		•	
Frame 5	Frame 6	Frame 7	Frame 8
T= 13.312 μs	T= 16.640 μs	T= 19.968 μs	T= 23.296 μs
Frame 9	Frame 10	Frame 11	Frame 12
T= 26.624 μs	T= 29.952 μs	T= 33.280 μs	T= 36.608 μs
Frame 13	Frame 14	Frame 15	Frame 16
T= 39.936 μs	T= 43.264 μs	T= 46.592 μs	T= 49.920 μs

Observed Function Time : 6.656 μs Exposure Time : **5 ns** Inter-frame Time: 3.323 μs Iris: f2.8 Gain: 1 Total Recording Length: 49.925 μs



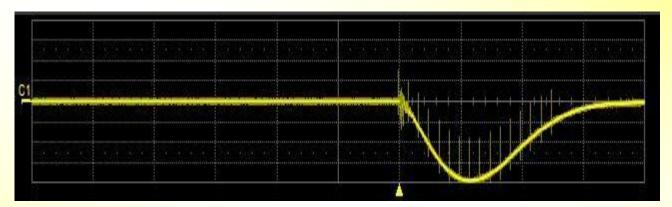
Ultrahigh Speed Framing Imaging (video) of AI - EBW



Observed Function Time : 6.656 μs Exposure Time : **5 ns** Inter-frame Time: 3.323 μs Iris: f2.8 Gain: 1 Total Recording Length: 49.925 μs

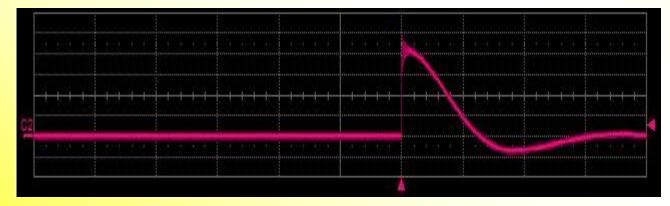


Digital Storage Oscilloscope (DSO) Data on AI EBW



Y axis : 1 Volt/div X axis : 20µs/div Offset : 0 mV

Pulses from Framing camera corresponding to the frames acquired



Y axis : 1.0 kV/div X axis : 20µs/div Offset : -2.0 kV

Voltage across the AI based EBW



CONCLUSION

a) Simultaneous streak and framing camera technique synergizes the advantages of the two methods and at the same time indicates whether the streak record had actually been taken in the expected or predetermined planes of observation.

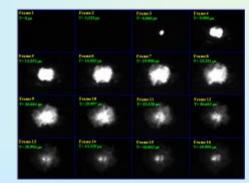
In this manner, faulty analysis and wrong interpretation, which were frequent problems in the early days of streak recording, can be eliminated completely.

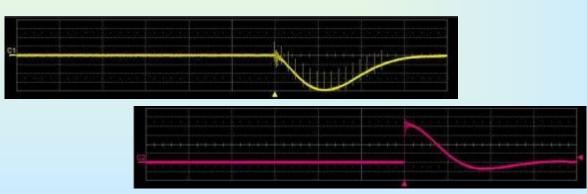
b) Due to simultaneous streak and ultra high speed framing camera we are able to evaluate the performance of Al based EBW

(1) The observed Function time AI - EBW is 6.66 µs for 5kV / 16µF CDU

(2) Ten or Five nano second exposure is sufficient for ICCD based ultra high speed framing camera to capture AI-EBW events

c) Demonstrated the repeatability of AI-EBW









THANK YOU

from

Energetics Research Institute Nanyang Technological University Singapore



Name : Harries Muthurajan Phone : +65-6513 8172 Company: Energetics Research Institute Nanyang Technological University, Singapore - 639 798 Email: mharries@ntu.edu.sg Abstract Reference number: 13745