CERN

Laser Triggering of Thyristor Switches

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Special Technologies session ‘Injection and Extraction II

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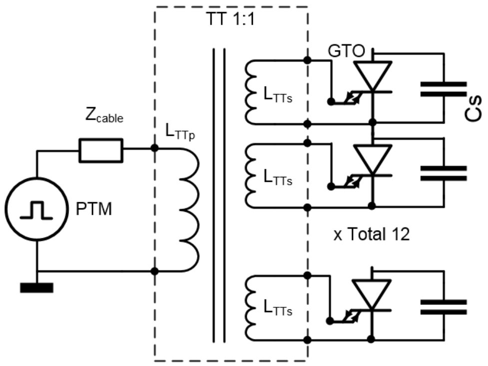
Plan

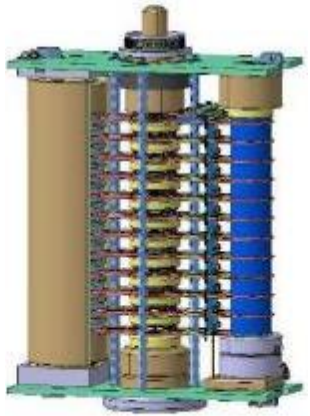
- How we currently trigger thyristor stacks and possible improvements
- Motivation for other triggering technology for FCC
- Principle of laser triggering
- Firsts test of laser-triggering of thyristor
- Laser optical diffuser, developments and measurements
- Triggering of two thyristors in series with diffuser
- Future developments

How We Currently Trigger Thyristor Stacks



Triggering of FHCT stack using:
- Power Trigger Module (PTM)
- Trigger Transformer (TT)
- Power Trigger Cables

Fast High Current Thyristor (FHCT) stack 3D drawing



Discrete Fast High Current Thyristor (FHCT)

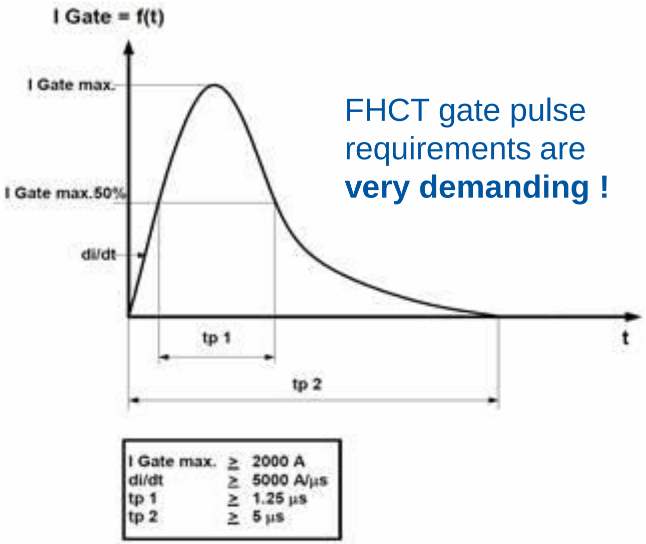
Challenges:

- **Low turn-on delay:** Parasitic inductance in triggering circuit. It's a basic parameter of solid state switches, directly linked to the re-triggering time requirement of the FCC.
- **Easy maintenance/accessibility:** Distributed PTMs near each GTO is difficult to implement, diagnosis is difficult.
- **Extremely stringent requirements** in reliability, availability and fault-tolerance => Redundancy in triggering circuit is needed.
- **Gate pulse requirements:** Very demanding gate current requirements;
- **Triggering system robustness to EMI- erratic coupling:** Small noise current on gate can set the switch into an uncontrolled conduction, possibly destructive.
- **Operating voltage de-rating:** Limited radiation hardness => stack of multiple switches;
- **Sourcing aspect**: Difficult to find GTO providers, long delivery time, not a very common component.
- Etc…

Improvement of Triggering System for LBDS

Improvements of triggering for LHC Beam Dump System (LBDS) extraction kickers:

- Higher current PTMs
- Lower inductance cables from PTM to TT
- Lower inductance TT



FHCT gate pulse requirements are **very demanding !**

Measurements using 2 PTM in parallel per TT / stack:

	LBDS PTM x2	New LBDS PTM x2	FHCT spec.
PTM voltage	3.5 kV	3.4 kV	-
Gate peak current	520 A	2 kA	2 kA
Gate dI/dt	460 A/us	2.9 kA/us	5 kA/us
Retriggering delay	~800 ns	~600 ns	
GTO turn-on alone	>500 ns	~400 ns	

FHCT triggering improved a lot: 4x Ip / 6x dI/dt
Improvement of trigger turn on delay is limited (150-300 ns depending on stack voltage)

From our FHCT triggering measurements, it is difficult to achieve better turn on delay of GTO stack

Motivations for new Triggering Technology for FCC

Avoid EMC problems, coupling between HV generators => Multiple erratics

- Problems seen at LBDS: One HV generator triggered its neighbour HV generator during erratic (Problem of common mode coupling mitigated using ferrite)
- Risk of partial triggering of GTO stack in case of EMI noise on the gates (Could yield in destruction of the GTO stack due to poor turn-on)

<u>FCC extraction system baseline requirements:</u>

See talk E. Renner: **<u>FCC-hh injection and extraction: insertions and requirements</u>**

- FCC extraction system needs **>150 HV generators** deployed over **long distance (~120m)** (Increased risks of EMI noise and EMC coupling)

⇒ **Optical trigger distribution improves insolation between generators and EMI sensitivity**

- Retriggering delay requested by FCC extraction system is very low **(< 400 ns**)
  Present electrical triggering system cannot reach such low triggering delay time

⇒ **GTO stack turn-on delay must be reduced**

⇒ **New triggering technology should be evaluated**

Principle of Laser Pumping Triggering

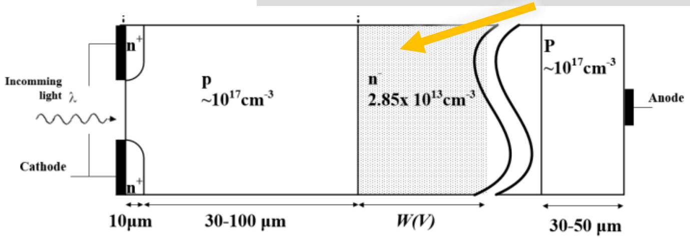
Electrical triggering:
- Carriers generated by gate current diffuse very slowly to drift region, were they are accelerated by strong electric field

=> turn-on limitation

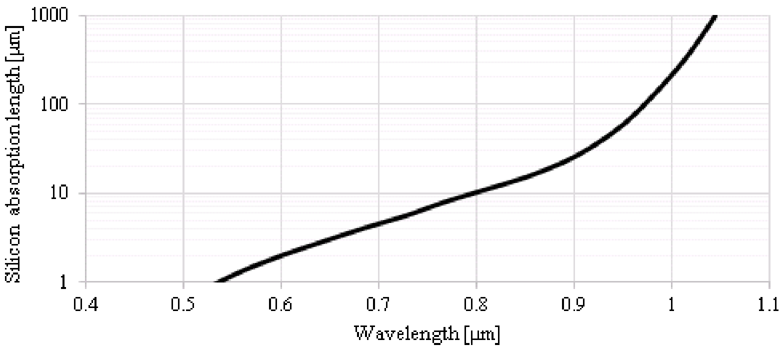
Optical triggering:
- Photons injected on gate can penetrate to depletion zone directly to photo-generate carriers

⇒ Carriers travel time to depletion region is eliminated= **Faster turn-on**

Depletion zone situated in the device drift region



View of thyristor in bloking state (Vak>0). Typical dim.



Photons penetration in silicon depends on wavelength:
For photons to reach directly depletion zone (~100um typical)
⇒ Device absorption length thresh. : Wavelength must be **bigger than ~970 nm**

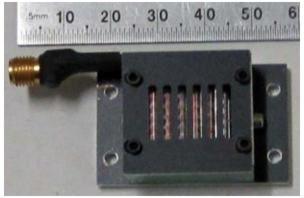
Also carrier generation needs a minimum of photon energy:
⇒ Silicon bandgap thresh. : Wavelength must be **lower than ~1100 nm**

⇒ **Optical triggering can be much faster than electrical**

⇒ **Optimal laser wavelength around 1um**

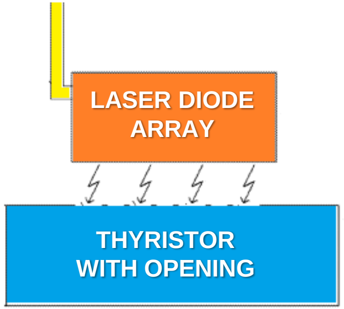
Test Bench for Laser-Triggering of Low Cost SCR

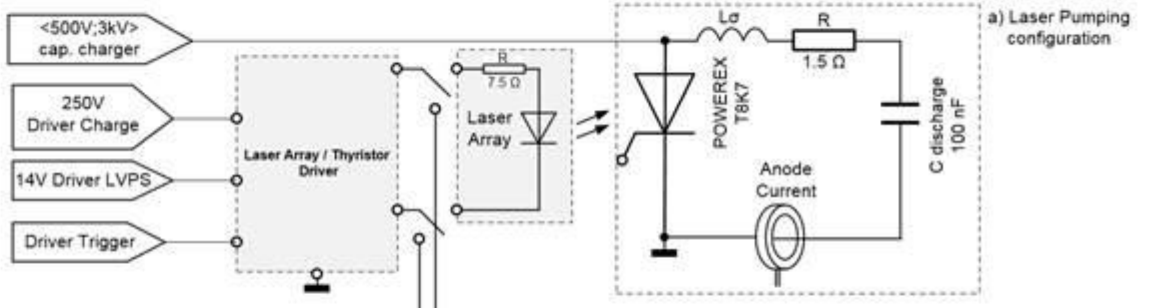
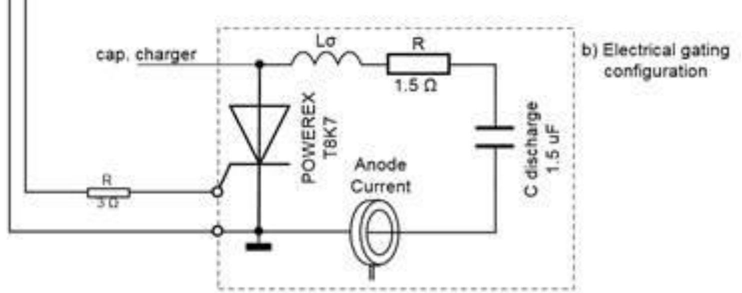
1um Laser Source. *Copyright APP Inc. LPST*



Capsule of a Low Cost SCR Off-the-Shelf

Wafer cathode and gate distribution view example

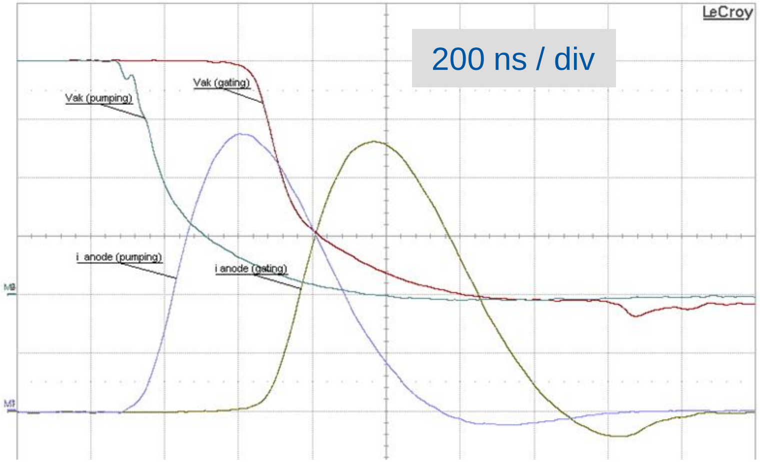


Comparison between Electrical and Optical triggering

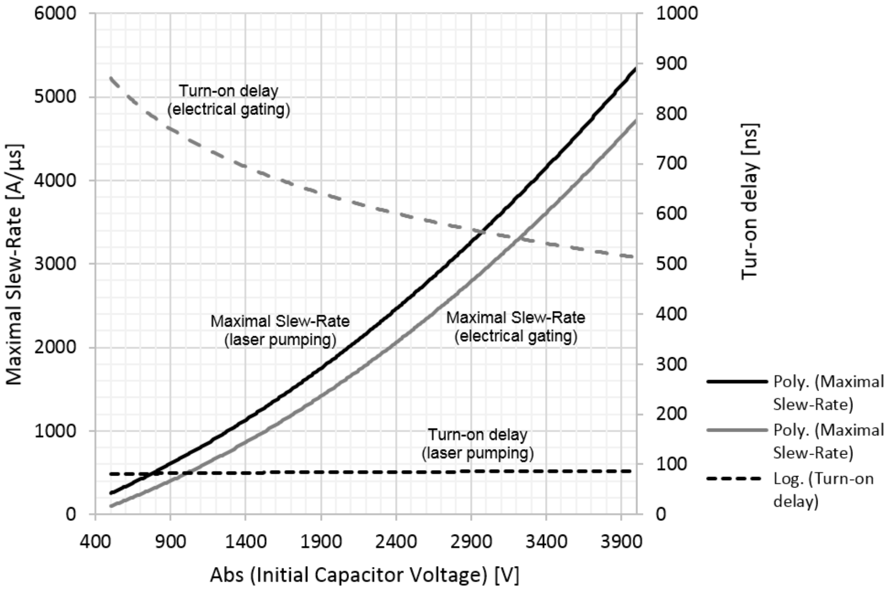
Using APP LPST 1um laser source directly mounted on SCR

Firsts Test for Laser-Triggering of Low Cost SCR



	Turn on delay	Max Slew-Rate (4 kV)
Electrical	> 500 ns (variable)	~ 4.6 kA/us
Optical	< 100 ns (constant)	> 5.4 kA/us

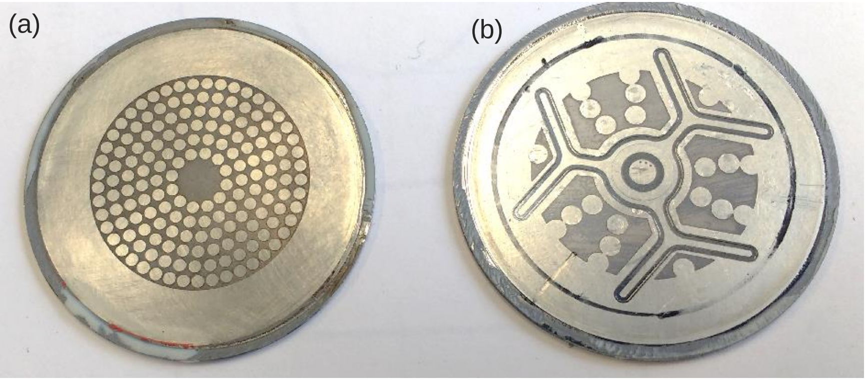
See: *Prospect for Laser Triggering of Large Arrays of Semiconductor Switches / FCC-Week16 / J.Rodziewicz*



Very promising results.

But impossible to stack thyristors using this approach
=> Series connection => increase inductance => lower turn on

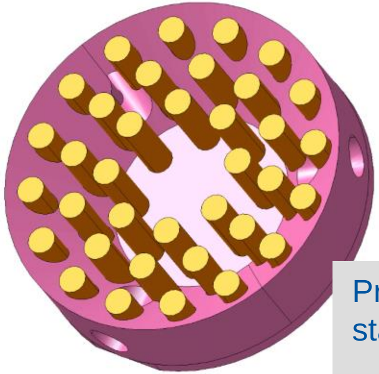
Light Diffuser Development



Etched SCR thyristor wafers anode side etching (a), cathode side etching (b)

To be able to stack, we need a light coupling system:

- **To diffuse the light in optimal way to silicon**
- **To have short anode-cathode connections in the stack**



Printed diffuser with inserted stainless steel pins

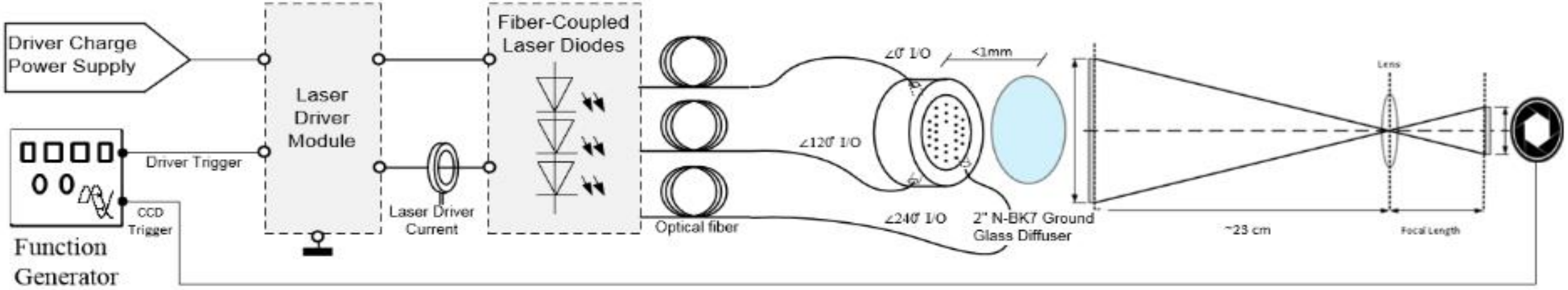
3 inputs for optical fibres

To increase illumination of silicon, anode and cathode can be etched to remove metallisation

Challenges for light diffuser:

- High homogenous illumination of silicon (photosensitive part)
- Incidence angle problem: penetration in silicon depends on angle
- Low inductive path for high current conduction

Light Diffuser Measurement Test Bench



Driver module for pulsed lasers

Pigtailed 905nm Diode Source

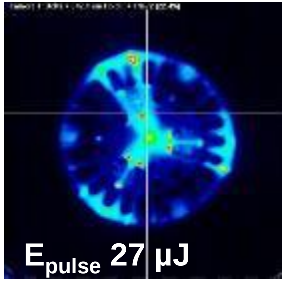
Printed diffuser with inserted INOX pins

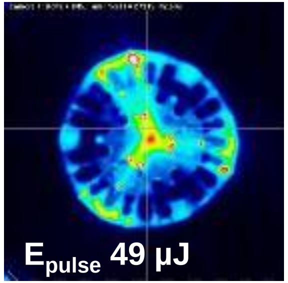
FUJI PHOTO OPTICAL FUJINON-TV 1:1.7/35

Gentec CCD23 Beamage USB 768px x 768px

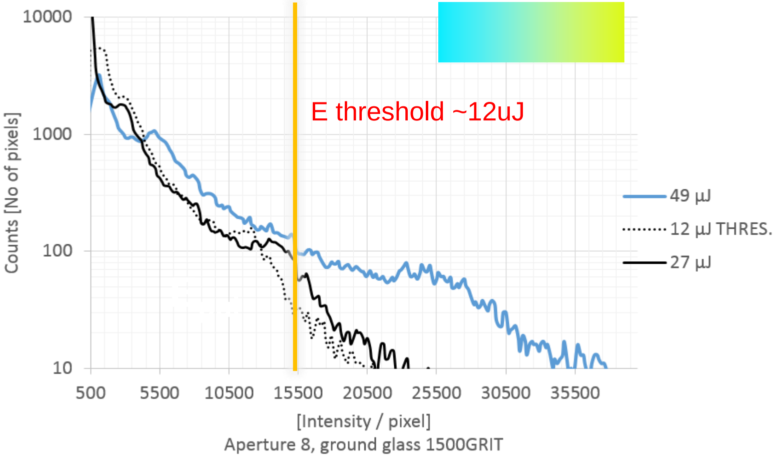
Using Beam Instrumentation optical test bench:
- Pigtailed 905nm diode laser source
- Measure optical coupler with 3 optical fibres

Light Diffuser Measurement

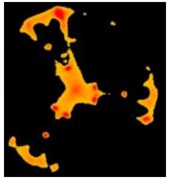




Electrical tests shows that thyristor starts turning-on (very slowly) at energy **min 12µJ**



Histograms show homogeneity of illumination



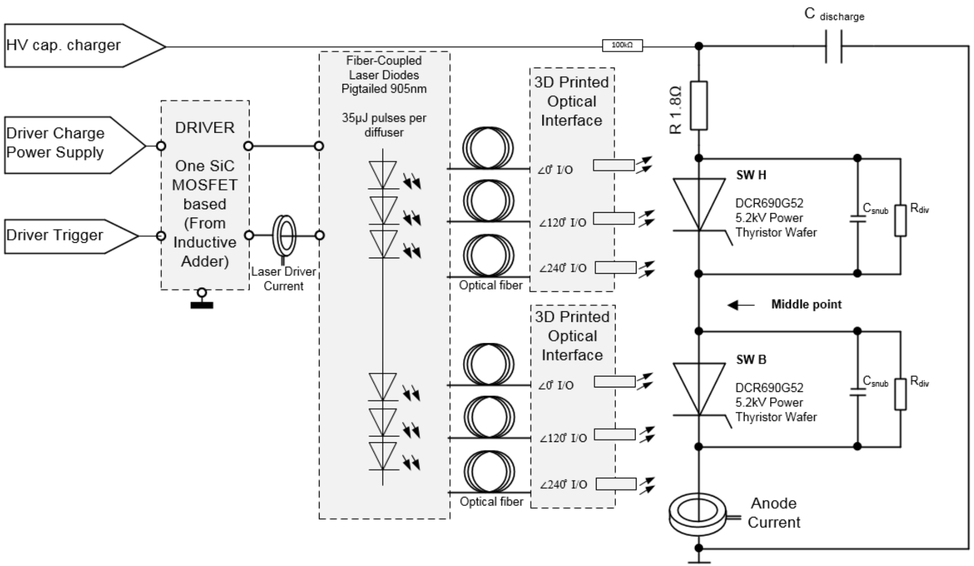
Illumination map above 12uJ threshold for 49uJ pulse

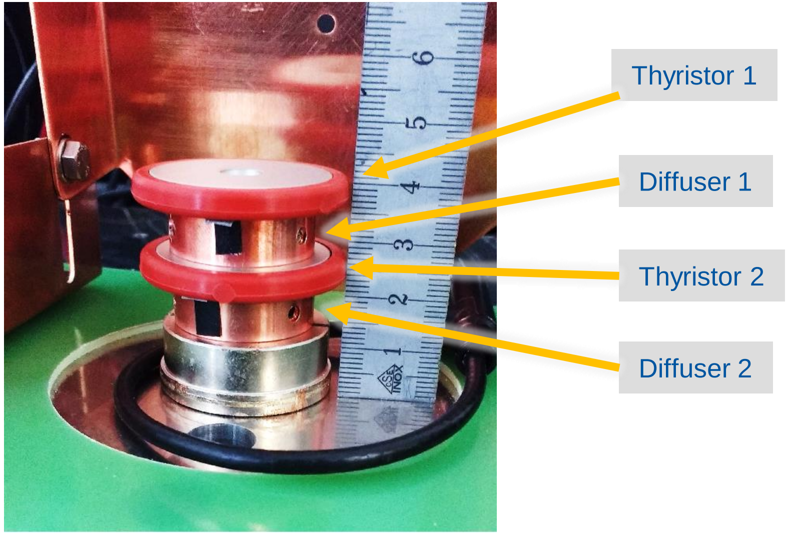
$$\Delta T_{j\,max} = \frac{1}{C_V}\int_0^{t_f} \frac{V_{AK}(t)\,\frac{di}{dt}\times t}{A(t)}\,dt$$

Max di/dt capability depends on initial conductive area

- Thyristor will not conduct below the **activation energy threshold**.
- Histograms can allow to quantify the homogeneity of the illumination and help to estimate the **initial conductive area** (area illuminated with intensity above the electrical threshold intensity).
- Thyristor **dI/dt max capability** depends on this initial area

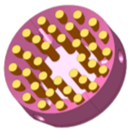
Test Bench for 2 Thyristors in Series with Diffuser





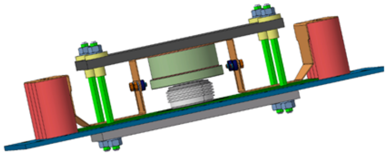
Pigtailed 905nm diode source

3D Printed diffuser with inserted INOX pins



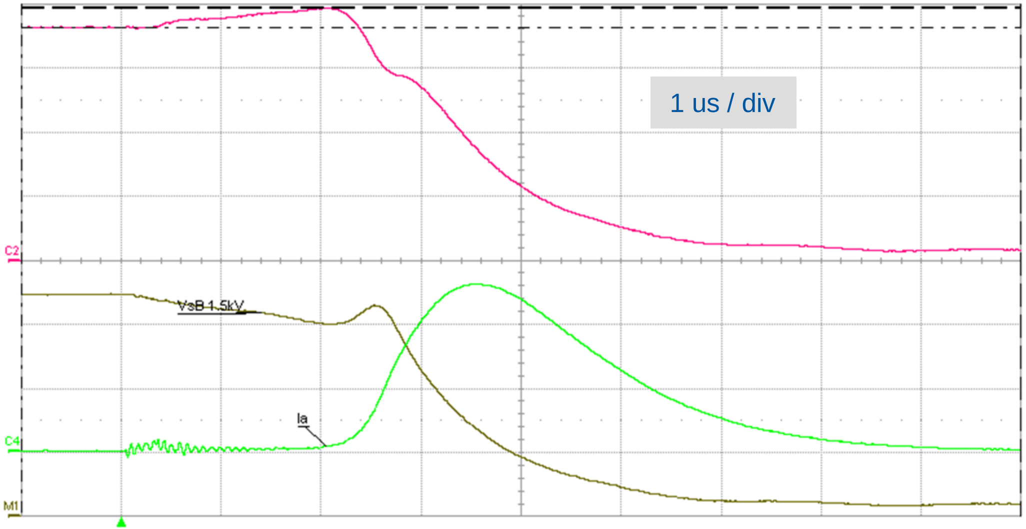
Thyristor wafer

Low inductance clamp



- Stack of 2 low cost SCR with 2 light diffusers
- A 905nm pigtail laser light source is used. (Difficult to find 1um laser source OTS)
- Laser transported using 3 optical fibres per diffuser.

Triggering of 2 Thyristors in Series with Diffuser



Purple (C2): High side switch voltage 200V/div, (1.5kV is the total initial voltage of $C_{discharge}$)
Brown (M1): Bottom switch voltage 200V/div, (1.5kV is the total initial voltage of $C_{discharge}$)
Green (C4): Anode current 100A/div

The two thyristors are operating in series...

But rather slow turn on (~2.5 us !)

- The activation is still relatively weak (**905nm** wavelength, absorption length 6x smaller at 900nm vs 1um)

Difference in turn on delay of both thyristors:

- Static voltage sharing to be adjusted with R_{div}.
- Slow turn-on increase the switching difference
- can be compensated by means of a **snubber circuit.**

Very encouraging results,
but new fibre-coupled source needed…

Future developments

- Better understanding of the turn-on state propagation across the device for a given light pulse parameters (wavelength / energy)
  - Collaboration with device manufacturer under a NDA
  - Simulations
- Continue development of light diffuser
  - Optimise initial conduction area
  - Optimise incidence angle
  - Optimise electrical connection between thyristors
- Find a better fibre-coupled laser source (~1um)
- With increased turn-on speed, and better diffuser, try to supress snubber circuit ?
- Influence of diffuser and/or thyristor on turn on delay ?
  (Two different thyristors with the same diffuser will have the same switching characteristics?)
- Performance measurements under different operational conditions to be done
  (voltage, peak current, di/dt, linearity, switching off…)

Thank you for your attention !

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