Light Triggering of Thyristors

Pulse Power for Kicker Systems workshop at CERN

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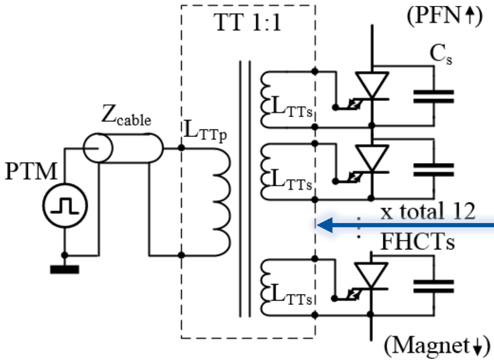
Outline

- Solid-state devices challenges in segmented extraction kicker systems
- Basics of Optical Absorption
- Few examples of light activated pulsed power devices:
  - Light-Triggered Thyristor (LTTs © Infineon)
  - Laser Pumped Silicon Thyristor (LPST © APP Inc.)
  - Laser Gated and Pumped Thyristor
- About the investigations at CERN

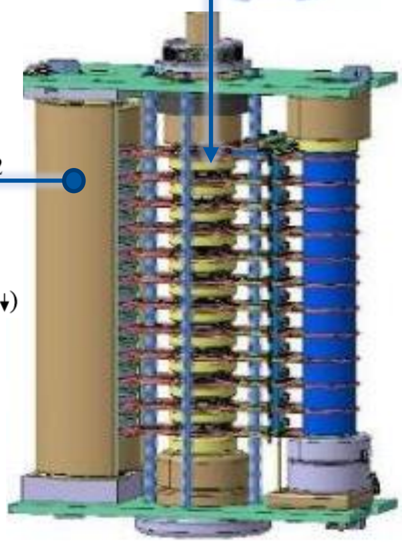
Solid-state switches challenges in segmented extraction kicker systems

- **Low turn-on delay –** The necessity of immediate switch re-triggering and asynchronous beam abort requests from switch a low turn-on delay as during this time the uncontrolled beam energy can damage the accelerator downstream equipment;
- **Easy maintenance/accessibility** aseptically in replacements of thyratron/ ignitron based systems, regular cables can not be used to connect the PTM;
- **Extremely stringent requirements** reliability, availability and fault-tolerance;
- **Gate pulse requirements** most of pulsed power semiconductors (bipolar technologies) follow the trend of increasing request on gate current, FHCT: $2e^3$A in peak and rise rate of $5e^3$ A/µs;
- **Triggering system robustness to EMI- erratic coupling**, the noise of less than 1% of the nominal gate pulse can set the switch into an uncontrolled conduction, possibly destructive. Case aseptically of easy-triggerable devices.
- **Operating voltage de-rating** limited radiation hardness of semiconductor switches implies the necessity of stacking of multiple switches;
- **Sourcing aspect** of selected switch;

Discrete Fast High Current Thyristor (FHCT)



Simplified view of the power triggering circuit (Power Triggering Module (PTM), triggering cable and Triggering Transformer (TT)

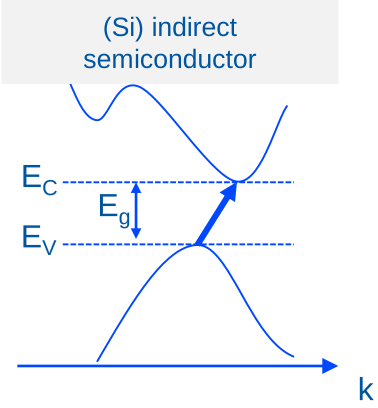


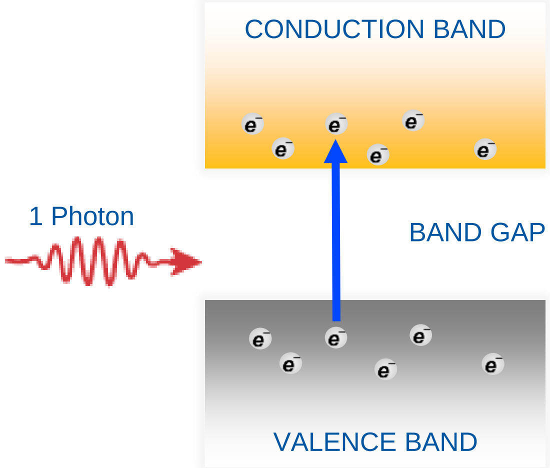
Main switch of future SPS Beam Dumping System, 3D Model

Basics of Optical Absorption

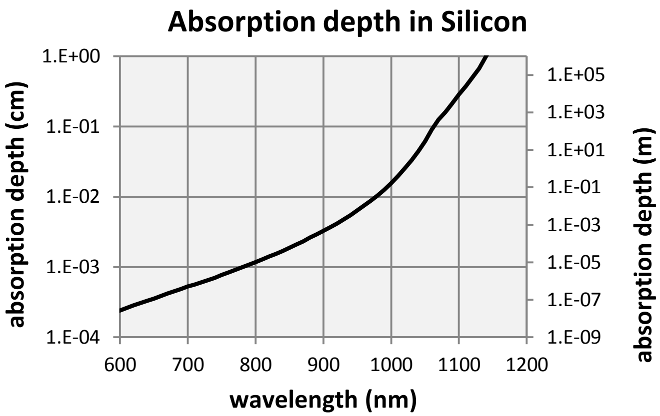
Optical absorption is fundamental process which is exploited when optical energy is converted into electrical energy.

- The energy has to be conserved
- The momentum has to be conserved





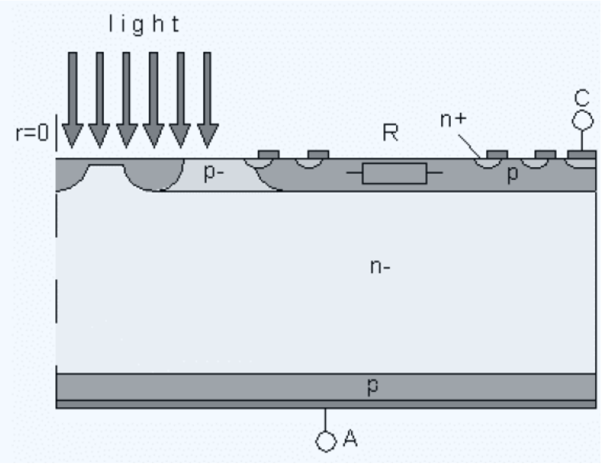
Wavelengths **over 1100nm are ineffective** because photon energy is insufficient for the electron-hoe pair generation. Light **effectiveness goes down** too, when wave length becomes **less than 1000nm** due to low light penetration into silicon and electron-hole pair recombination close to surface.



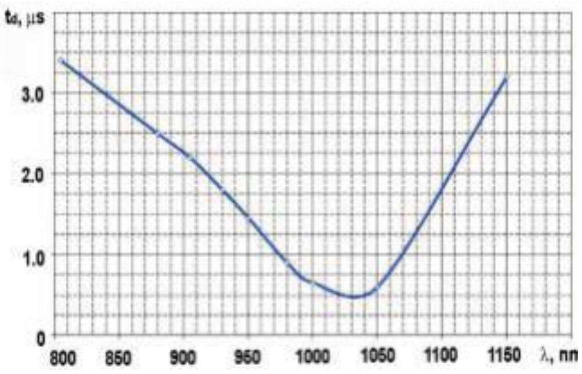
Light-Triggered Thyristor (LTTs)

Light pulse parameters example:
40mW, 10us long, 0.4uJ,
850nm-1000nm wavelength

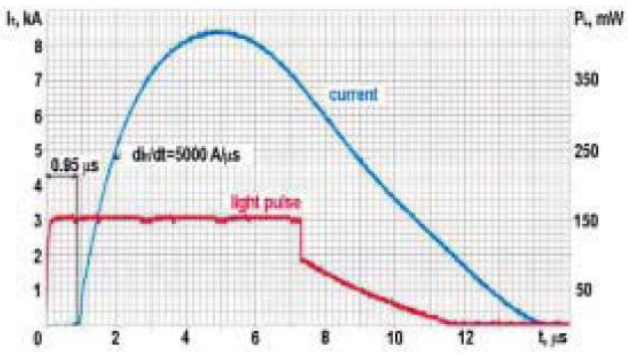
- The central area of the LTT consist of a Break-over Diode (BoD) and a multiple Amplifying Gate structure.
- The BoD is located inside the light sensitive area.



Cross-section of the center of the light-triggered thyristor.



Simulated LTT turn-on delay time versus laser diode wave length (P_{LM} = 200 mW, V_A = 100 V)

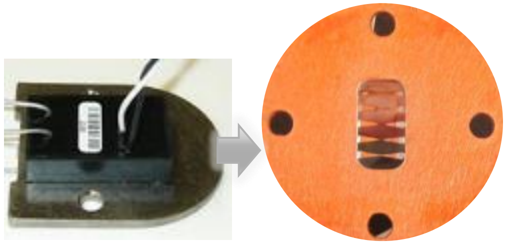


Anode current turn-on example waveforms.

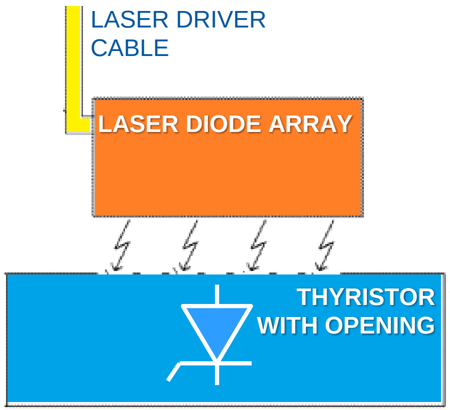
Laser Pumped Silicon Thyristor © APP Inc.

Light pulse parameters example:
650W in peak, 170uJ, 400ns FWHM, 1000nm wavelength

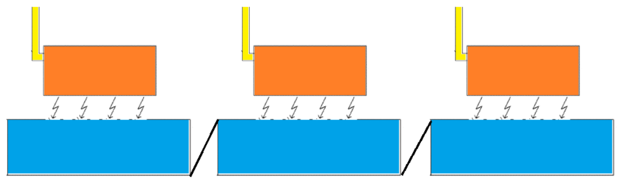
Demonstrated performance:
2500A in less than 40ns



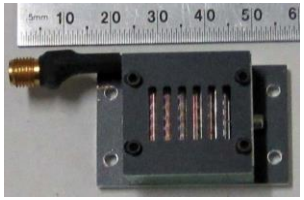
Commercially available APP Inc. switch modified for laser pumping – with openings windows patterned in the anode metallization.



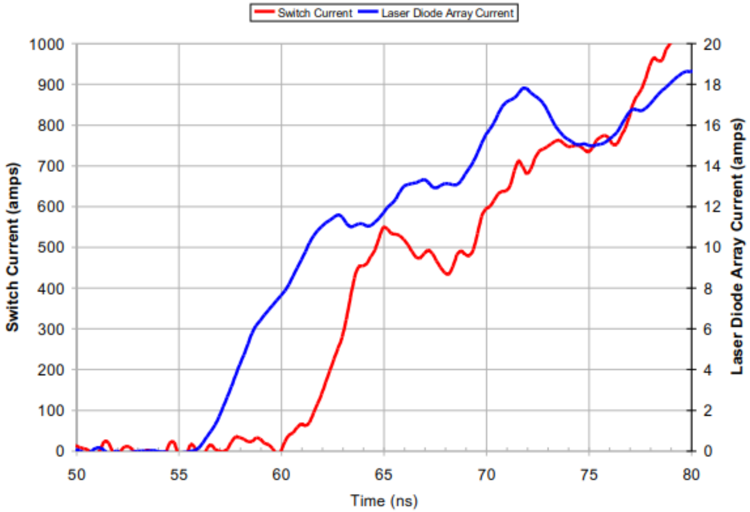
One switch embodiment view.



Series connected stacks, each device has it separate photon source. Each of the thyristors are coupled together with stage to stage connection.



1kW Laser diode array

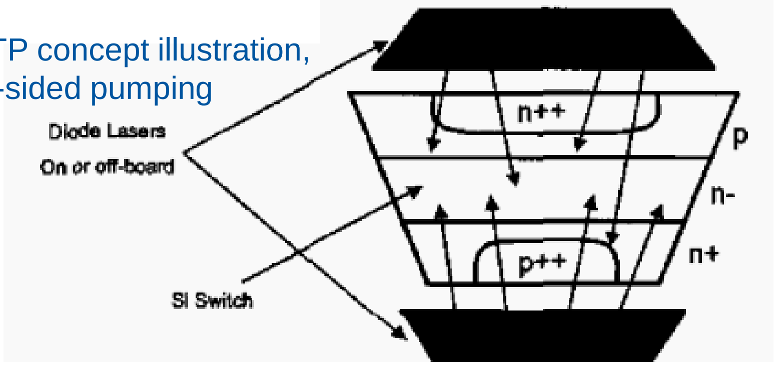


5ns of turn-on delay measured between the switch current and laser driver current.

Laser Gated and Pumped Thyristor

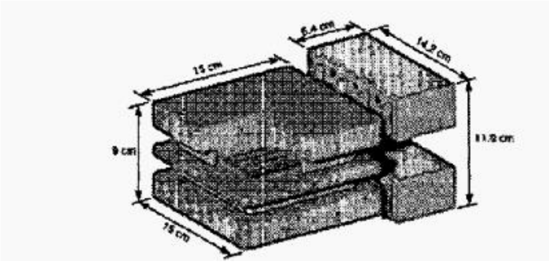
First developed for Electra, a Krypton Fluoride (KrF) laser.
Primary energy transfer time of 800 us for a
Marx-charged one-stage magnetic pulse compressor

LGTP concept illustration,
two-sided pumping

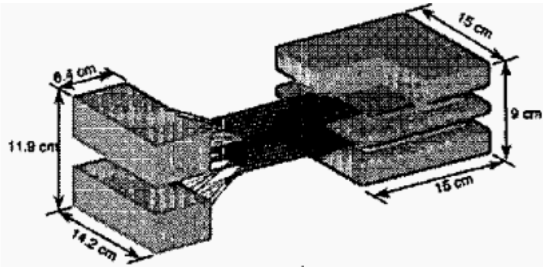


Light pulse parameters example:
5kW/cm^2 over 50ns followed by continuous illumination levels 500, 1000, 2000, 5000 W/cm^2 in order to reduce forward dissipation.

Demonstrated performance of 16.4kV devices:
Single shot operations at 3kA/cm^2 , 30kA/µs/cm^2



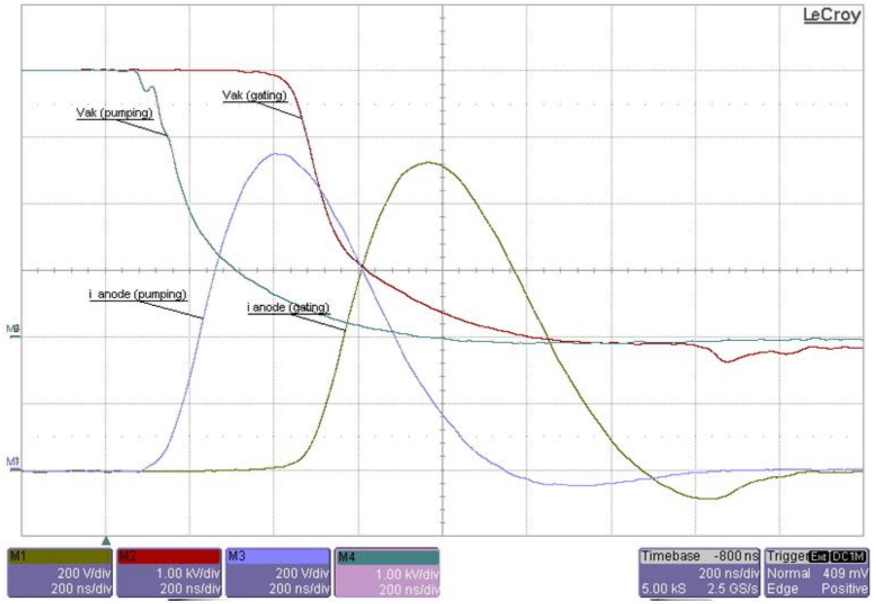
On-Board (Direct Illuminating)
Conceptual Embodiment.

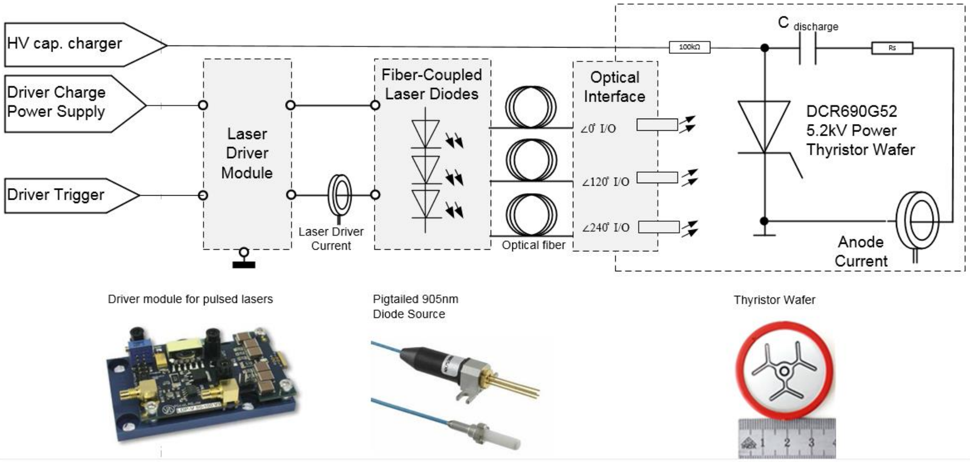


Off-Board (Indirect Illuminating)
Conceptual Embodiment.

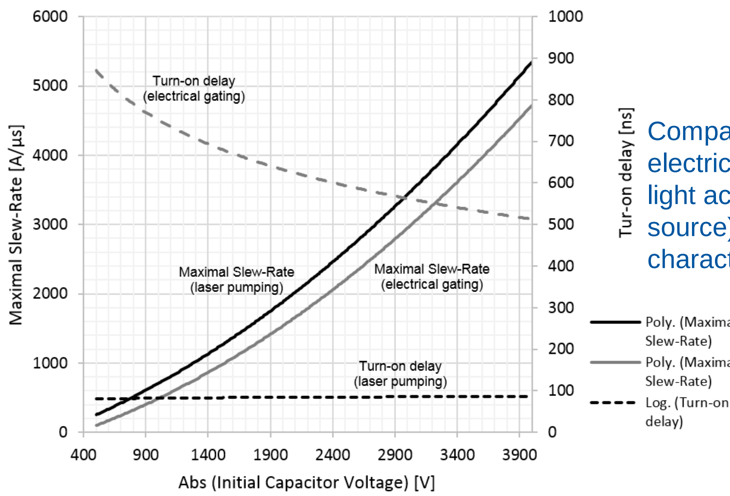
Investigations at CERN

So far in our investigations we use market available Low Cost SCR Phase Control Thyristors. Activation is being achieved through gate distribution illumination with an appropriate light source.



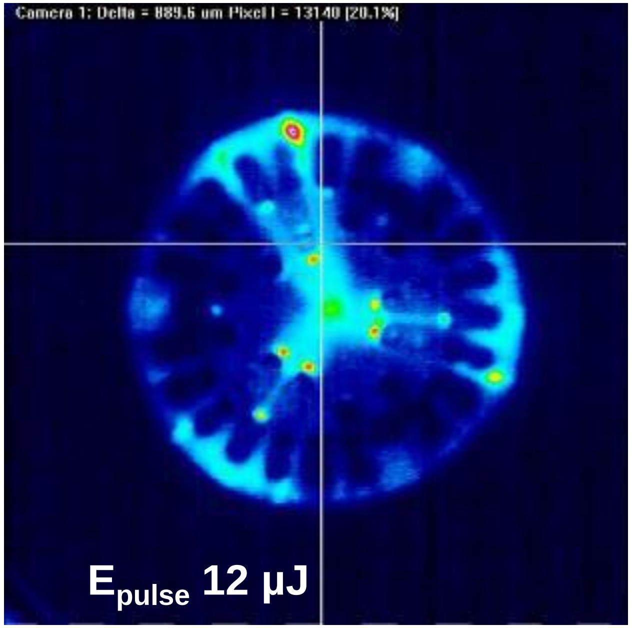


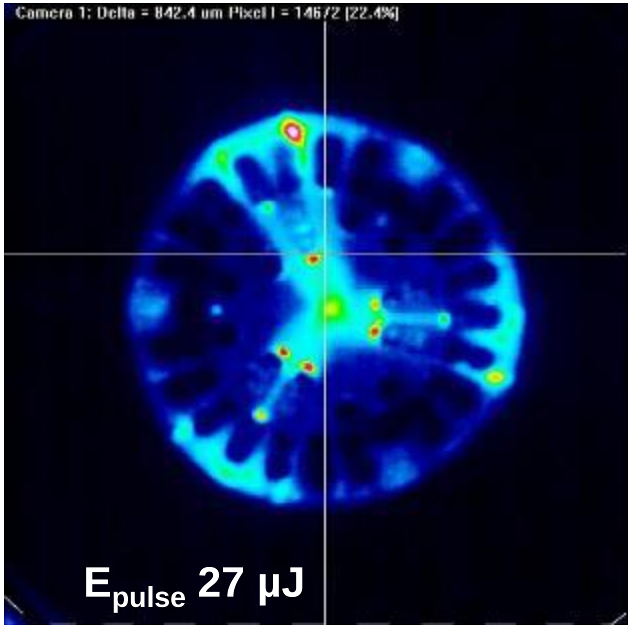
Example view of electrical test setup.

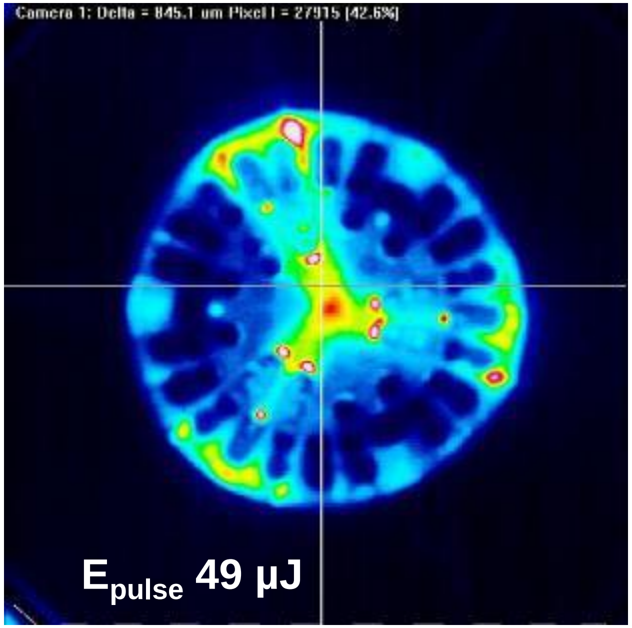


Comparison of electrical gating and light activation (1µm source) methods characteristics.

Wafer illumination profile imaging with a CCD camera, 905nm light source

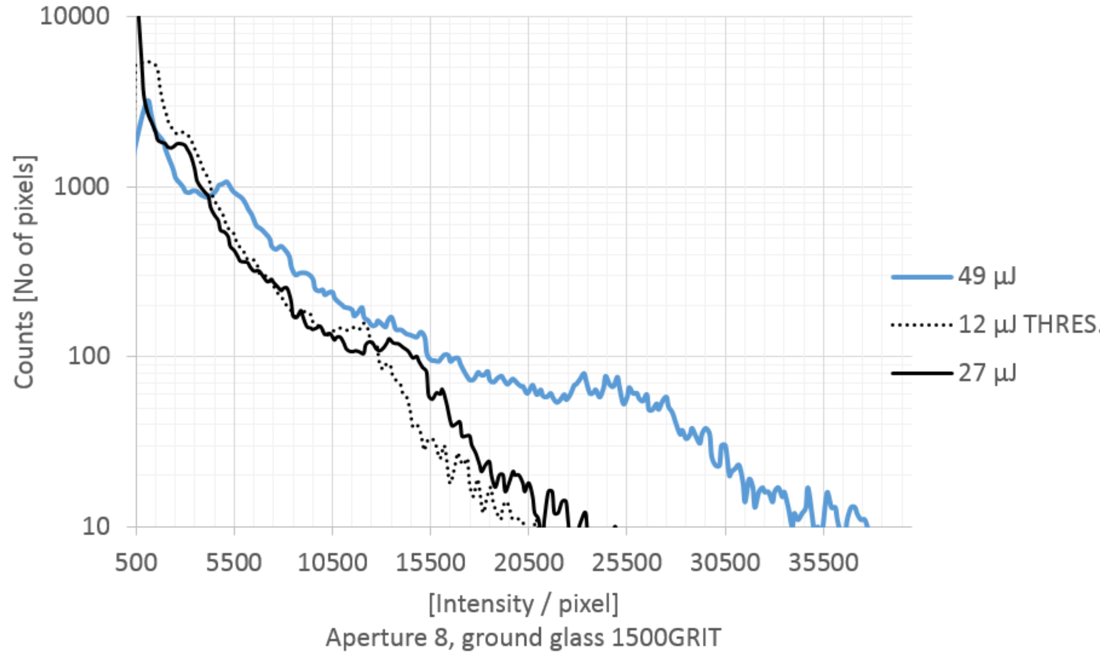




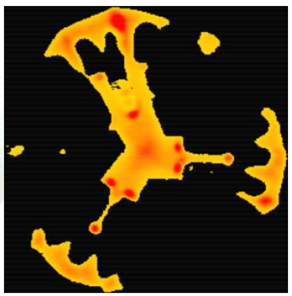


Wafer illumination profile imaging with a CCD camera, 905nm light source

- In electrical test 12µJ pulse energy defines a threshold where the SCR thyristor starts turning-on (very slowly)
- If the threshold intensity is known, one can rad-out the initial conductive area A(t) at the very beginning of the thyristor turn-on. This area is directly linked to maximum allowable di/dt capability of the device. Cv is the specific heat of silicon, t_f is the falling time of the blocking voltage.

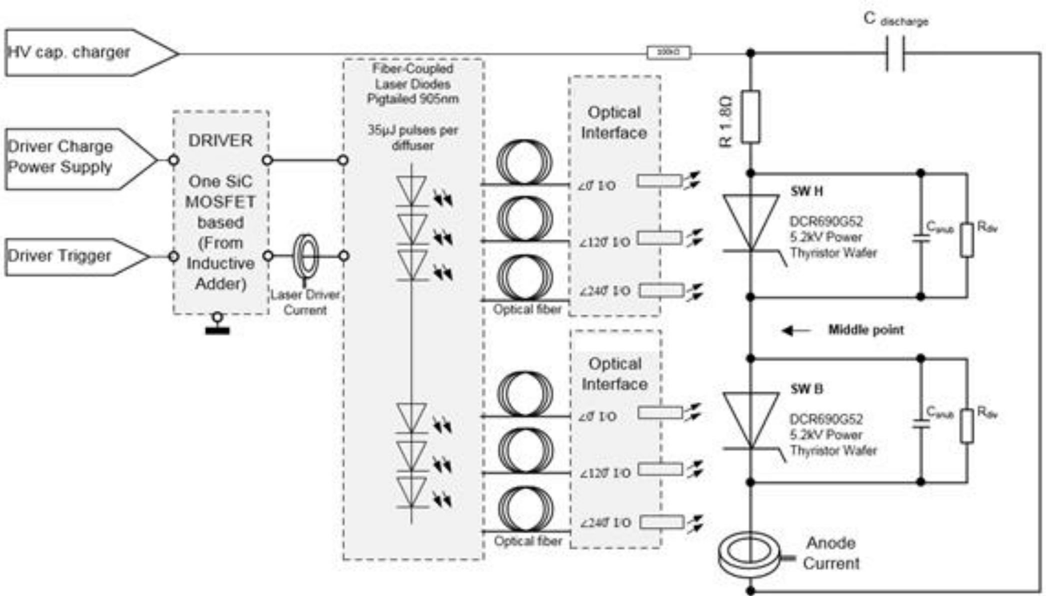


$$\Delta T_{j\max} = \frac{1}{C_V} \int_0^{t_f} \frac{V_{AK}(t)\,\frac{di}{dt} \times t}{A(t)}\,dt$$



Mapping of the area illuminated above the threshold intensity. 49uJ light pulse.

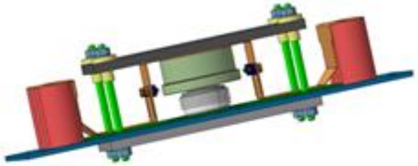
Tests with a series of two connected SCR thyristor devices

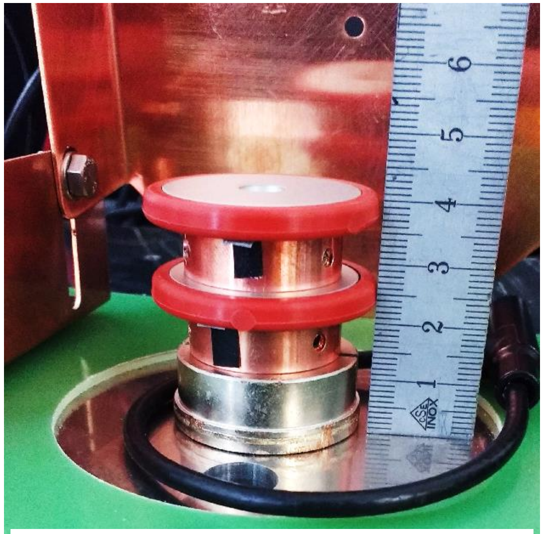


Pigtailed 905nm diode source

Thyristor wafer

Low inductance clamp





Two stacked wafers placed in the low inductance clamp

- Fiber-coupled light source limitation;
- A correct balance of the total voltage between series connected switches is curtail for the performance;
- Small differences in commutation characteristics between the switches can be compensated by means of a snubber circuit

Thank you for your attention

Questions ?

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