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THZ Imaging of the Electron Distribution in Plasmas

A New Diagnostic for Electrical Breakdown Phenomena

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Breakdown Phenomena

- Many observations and measurements
- Few predictive models and explanations
- Nature finds the weakest link
- Potentially many components to any predictive model

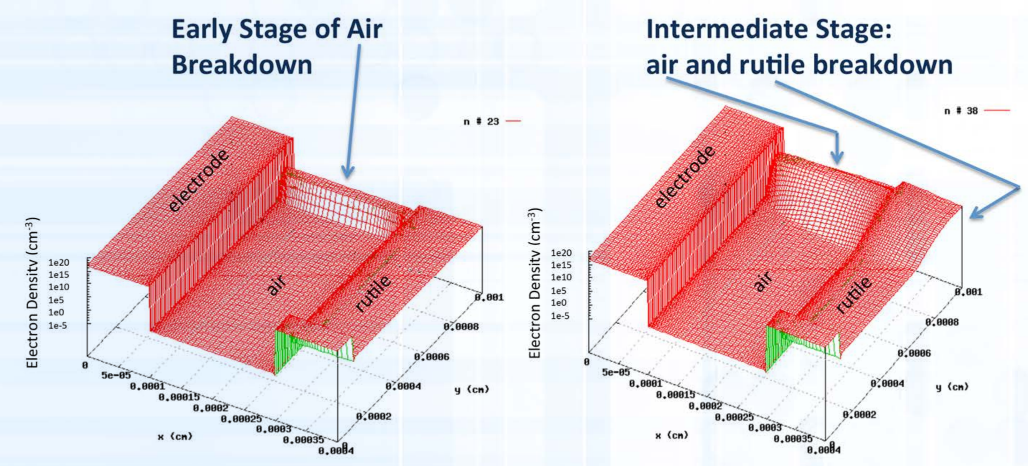
Questions

1. What's happening during the time delay from the start of a high voltage pulse to light initiation and to complete breakdown?
2. Why do breakdown paths hug the surface near the top and leave the surface part way down?
3. How does the initial static field change to the dynamic field during breakdown?
4. What are the relative roles of electrons and ions?

Recombination radiation from electrical breakdown with rutile in air a high dielectric material used in lightning arrestor connectors (Zac Wallace & Jane Lehr)

Example: Electron flow in bulk Rutile, TiO^2

Ensemble Monte Carlo Calculations, H. Hjalmarson



Optical radiation from air breakdown, but space charge limited electron flow in Rutile won't radiate

Information Needed to Continue/Advance the Development of Breakdown Models

- Free electron densities
- Surface electron densities
- Field emission sites
- Space charge limited emission
- Dynamic field enhancements
- Time evolution of everything

SNL Interests in Breakdown and Electronic Plasmas

- Threat of lightning strikes on NW components
- Predicting operation of lightning arrestor connectors
- Electrical breakdown on insulators and components in high voltage systems (firesets, lasers, power industry, materials science)
- High energy density science experimental facilities
- Plasma formation in accelerators, beam tubes, and pinches
- Plasma formation in diodes, switches, capacitors, and inductors
- Optically induced plasma radiation (RF-THz regime)

Why Use Terahertz to Image Electron Distributions?

1. Ultra short pulse laser-induced electron densities of 10^{12} to 10^{18} cm^{-3} radiate in the 10 GHz-10 THz (very wide band THz regime).
2. Efficient radiators are also strong absorbers.

Wide band THz radiation will interact strongly with these electron densities. It is the right part of the electro-magnetic spectrum to image electron densities.

Laser induced plasma radiation (LIPR) in the "THz regime"

$$\omega_{pe} = \sqrt{\frac{n_e e^2}{m^* \varepsilon_0}}, [rad/s] \quad \text{(SI units)}$$

$$f_{pe} \approx 8980\sqrt{n_e} \quad (\text{Hz, cm}^{-3})$$

Frequency (GHz)	Free electron density (cm^{-3})
10,000	1.240×10^{18}
1,000	1.240×10^{16}
100	1.240×10^{14}
10	1.240×10^{12}

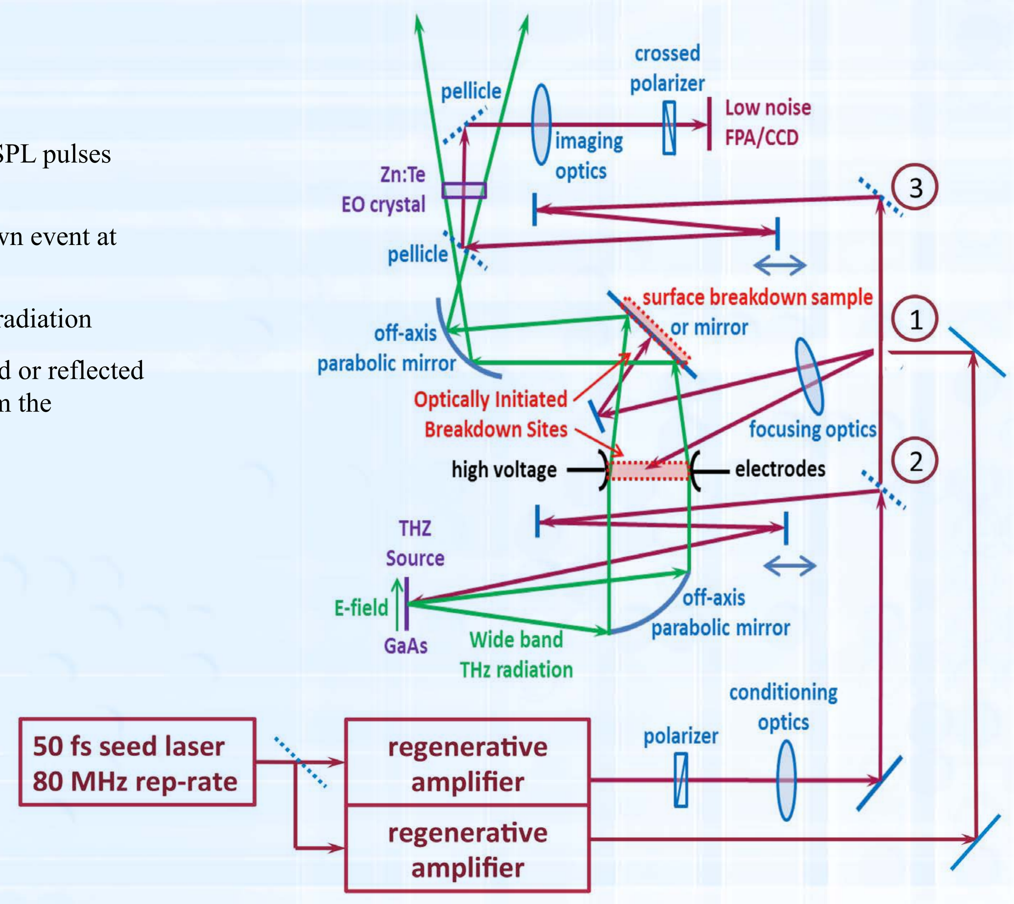
THz Imaging of Breakdown

Three synchronous USPL pulses are used to:

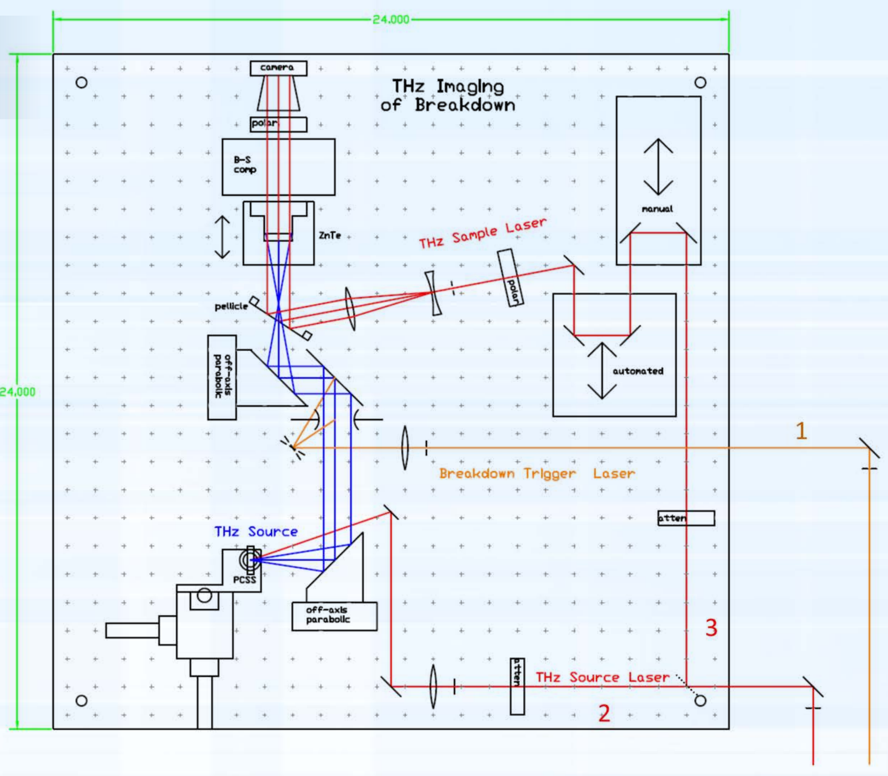
(1) initiate a breakdown event at one of 2 locations

(2) generate the THz radiation

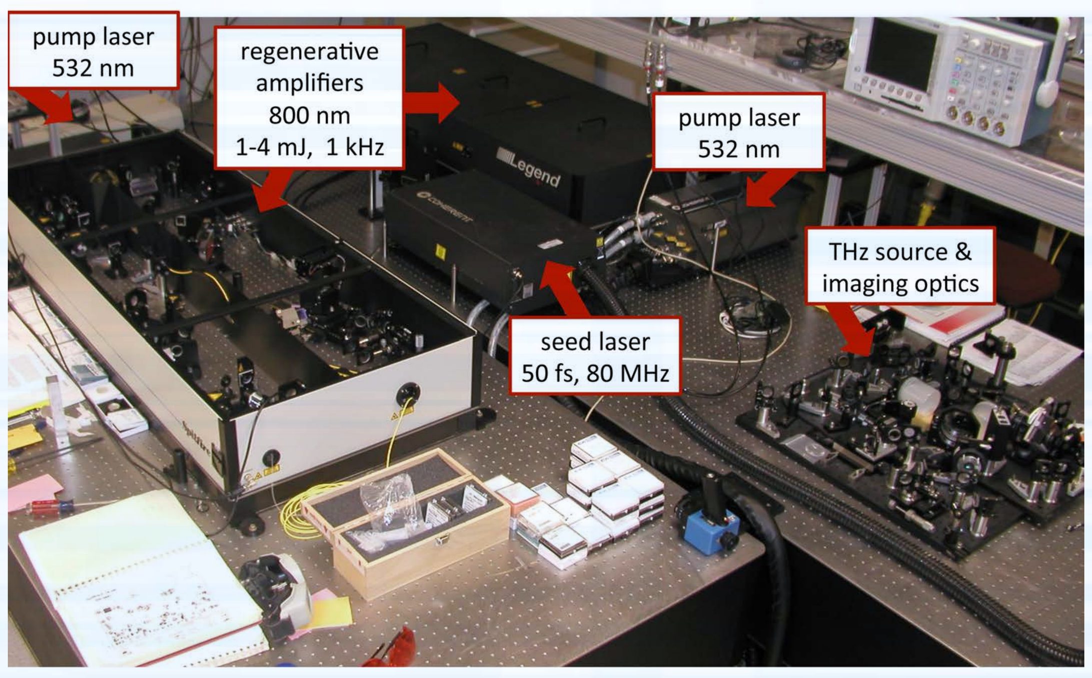
(3) image the scattered or reflected THz radiation from the breakdown event.



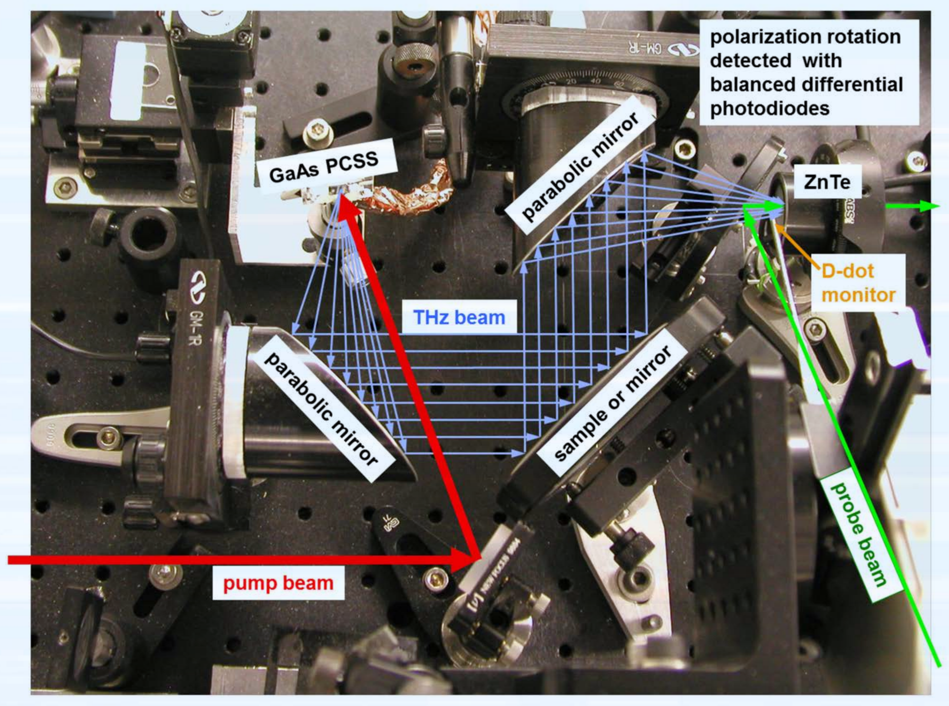
Optics Layout



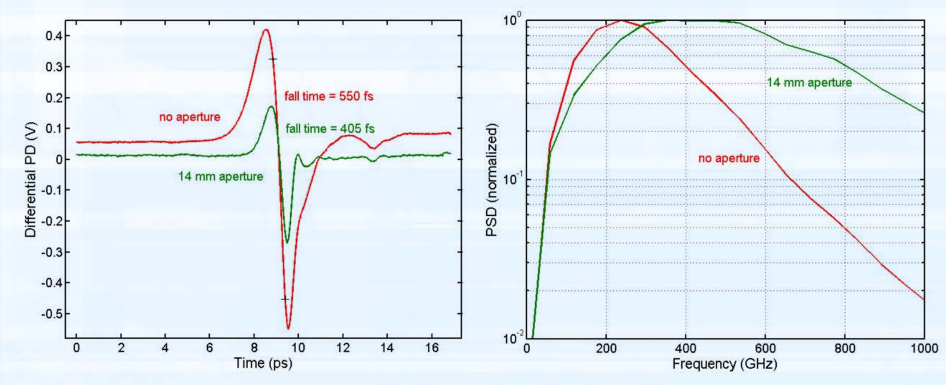
Electro Optical Imaging (Under Construction)



Electro-Optical Sampling – Similar to Electro-Optical Imaging

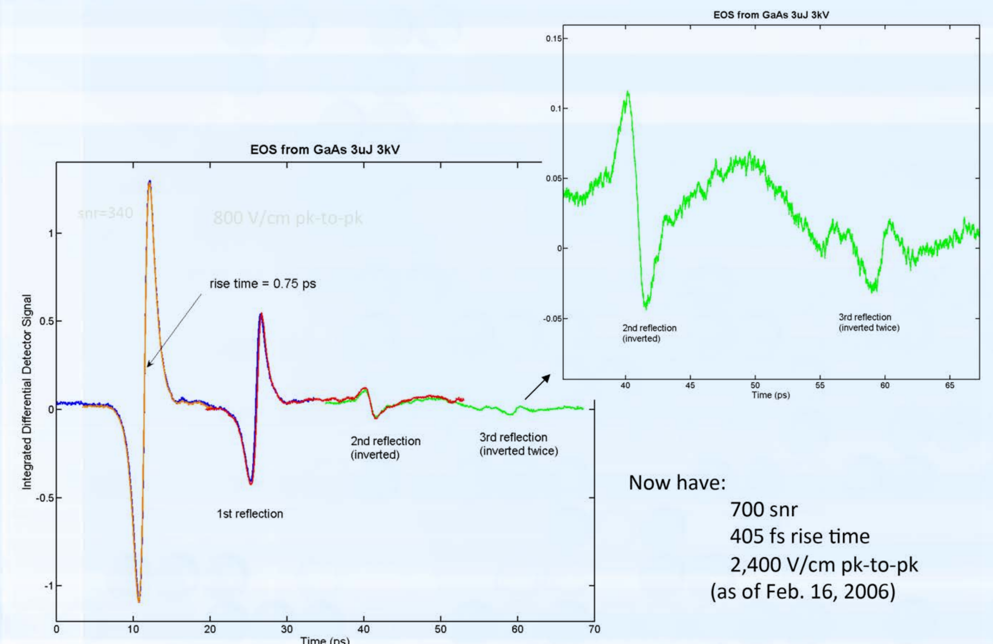


Electro Optical Sampling Results



A comparison of EOS signals on and their power spectral densities (PSD)on is shown. Bandwidth was improved (3 dB point is increased from 400 GHz to 800 GHz) by inserting a 14 mm aperture between the 50 mm diameter parabolic THz mirrors used to collect and focus the THz beam into a ZnTe electro-optic crystal.

EOS from Optically Pulsed GaAs at 12 kV/cm



A composite of 4 EOS scans of the radiation from a GaAs e-h plasma biased to 12 kV/cm and created with a 3 μJ, 50 fs optical pulse is shown. The electric field, 800 V/m, emitted by the e-h plasma is detected as a polarization rotation on a co-propagating optical pulse in a ZnTe crystal. The polarization change is measured with a pair of balanced photo-diodes (PD) and is proportional to the electric field in the ZnTe

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