The nanosecond diagnostic and analysis of microwave-driven window breakdown

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Content

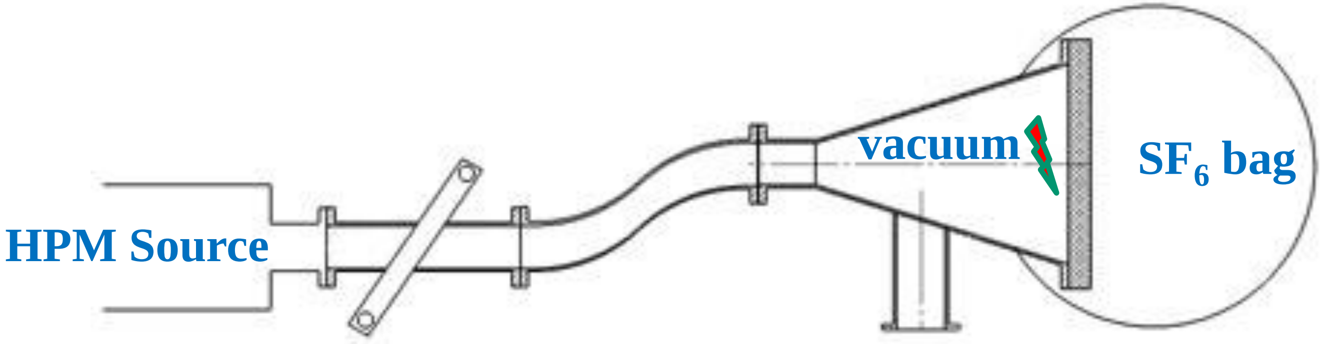
1 **Background**

2 **Discharge at dielectric/vacuum interface**

3 **Discharge at dielectric/air interface**

Background

Breakdown at vacuum/dielectric interfaces of HPM window have been major limitation of power radiation [1]. Methods of improving breakdown threshold become key issues of HPM system [1].

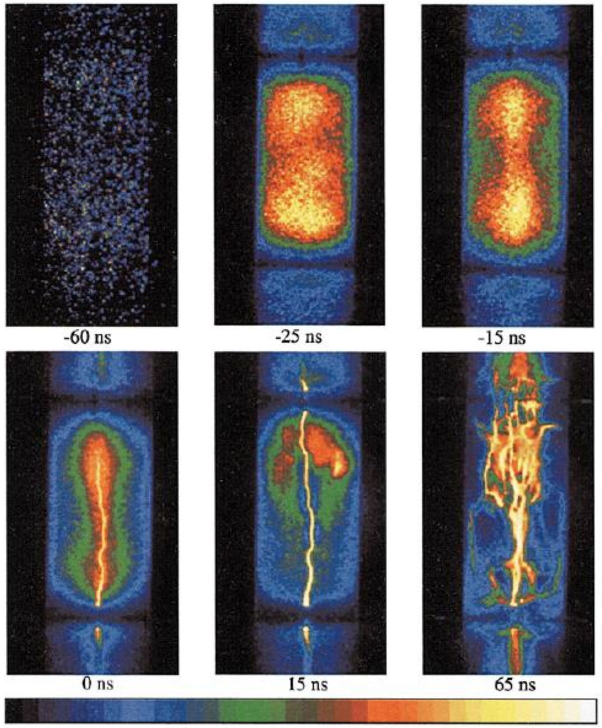


Breakdown is triggered by multipactor and finally realized by plasma avalanche in ambient desorbed or evaporated gas layer above dielectric.

[1] R. Barker, E. Schamiloglu, High power microwave source and technology, 2001.

Background

Dr. Neuber and other scientists in TTU had experimentally diagnosed the optical light during microsecond HPM pulse in S-band rectangular waveguide.



Light evolution in front view

Intense E-field at triple junction, final stream arc along central line

A. Neuber, et al., IEEE Trans. Plasma Sci. 1999, 27: 138.

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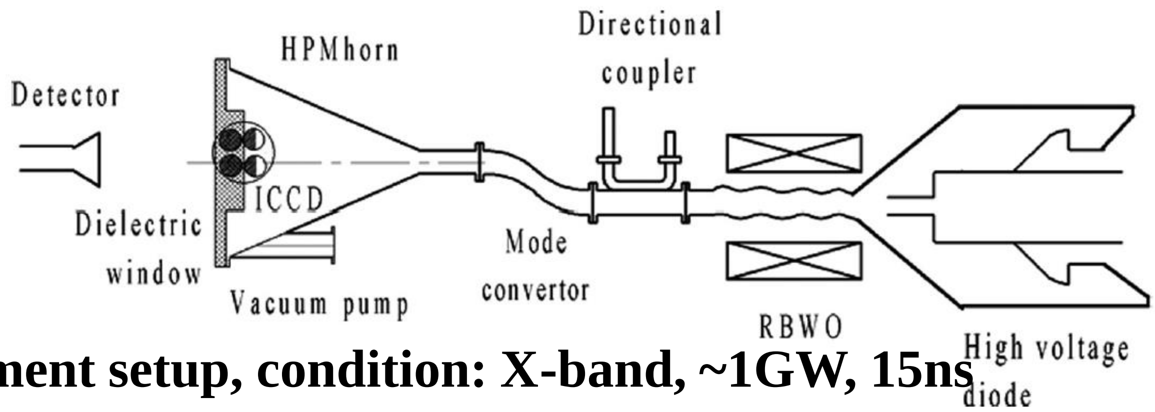
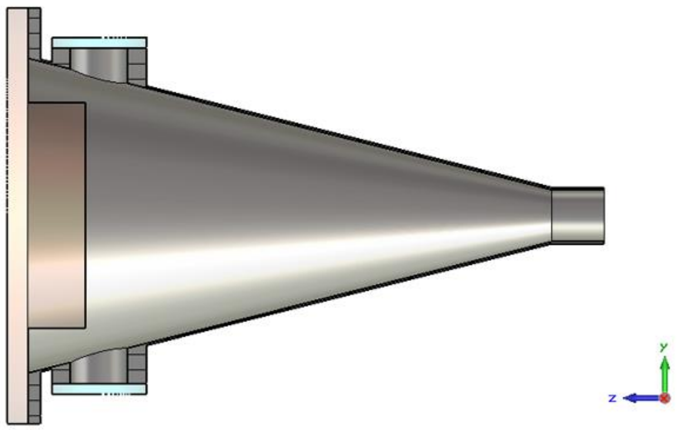
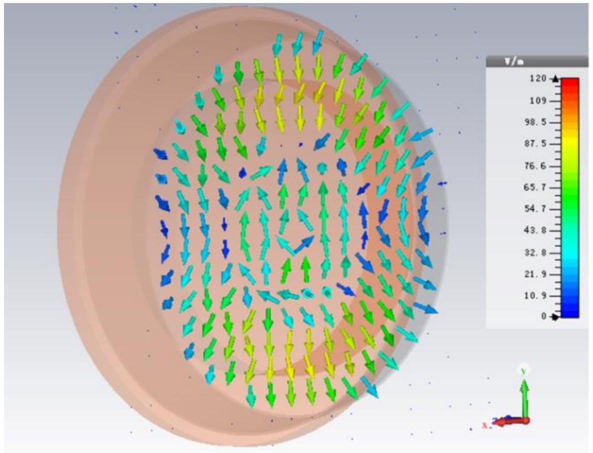
Detecting discharge at dielectric/vacuum interface



Experiment setup, condition: X-band, ~1GW, 15ns

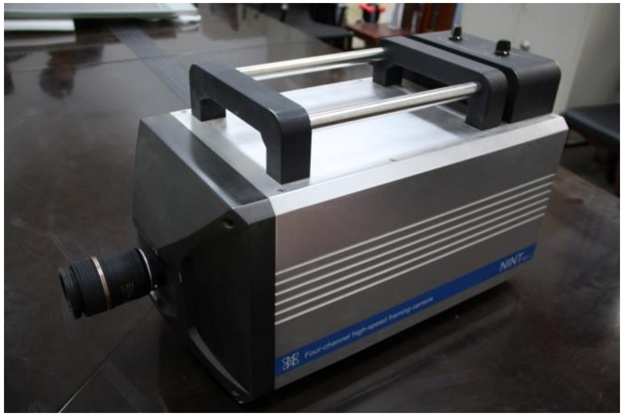


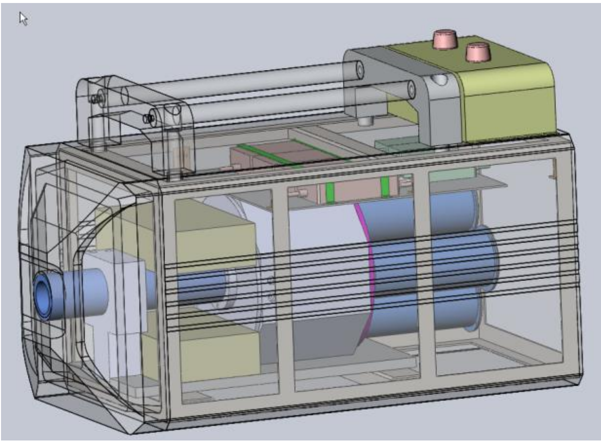


(Left) Schematic of HPM feed horn **with side view windows.** (Right) Transient E-field vector distribution near dielectric/vacuum interface

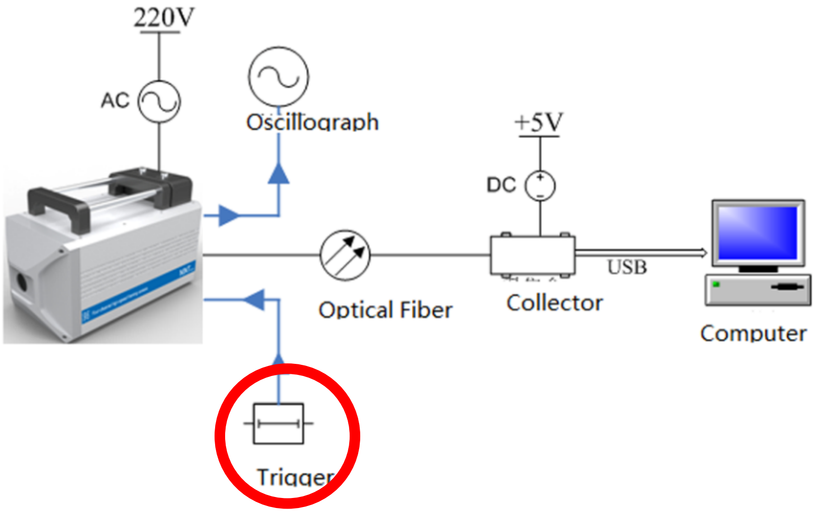
To laterally observe light emission on dielectric/vacuum interface, PE window has a protrudent hat shape, double sides of horn punctured according to interface position

Schematic of the four-frame ICCD and data collection



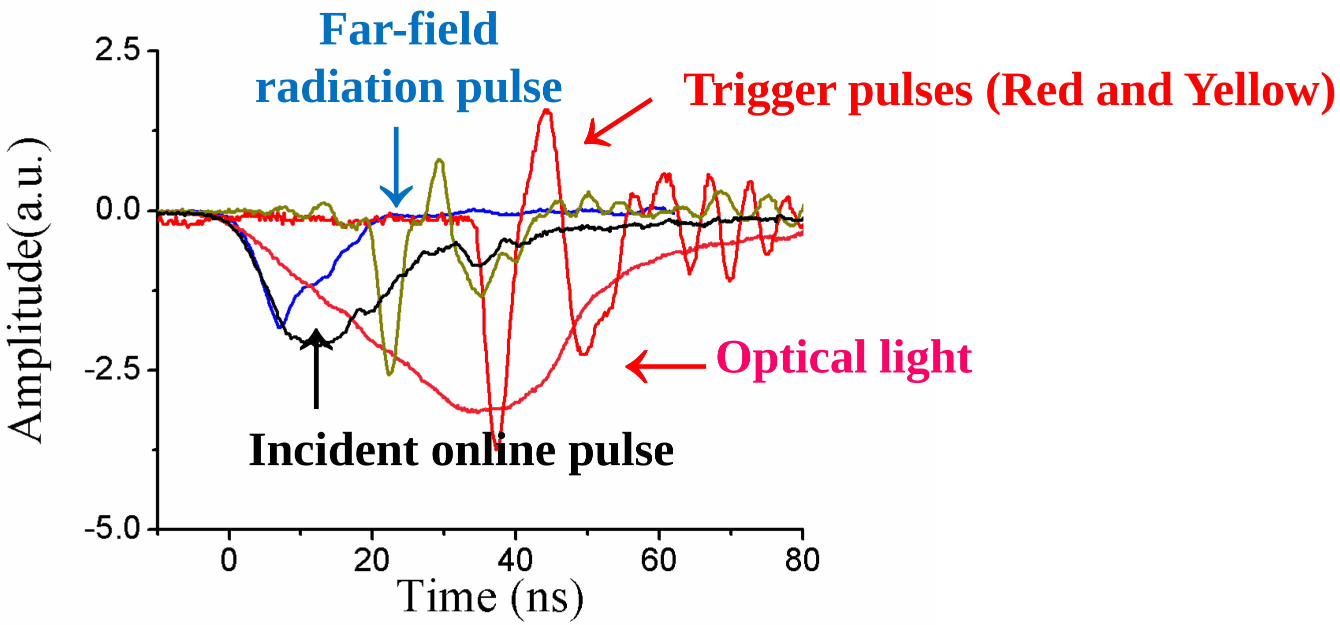


Photos of four-frame ICCD with nanosecond response



The time synchronization between ICCD and nanosecond microwave pulse is realized by using voltage signal (+65V) monitoring high-voltage vacuum diode to trigger fast shutter of ICCD.

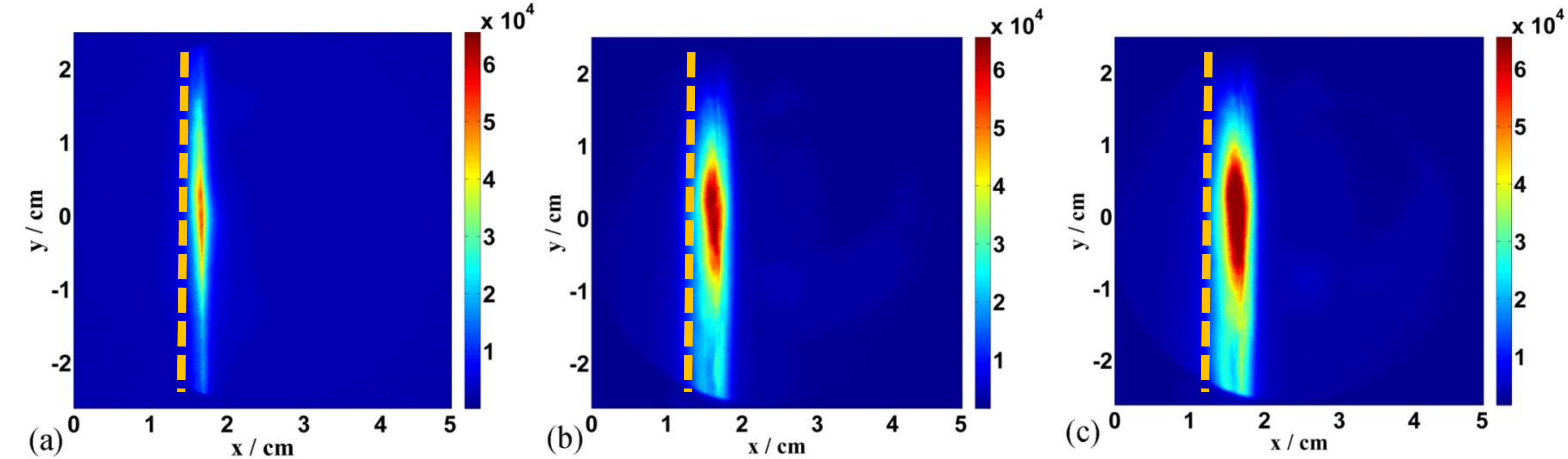
Typical waveforms



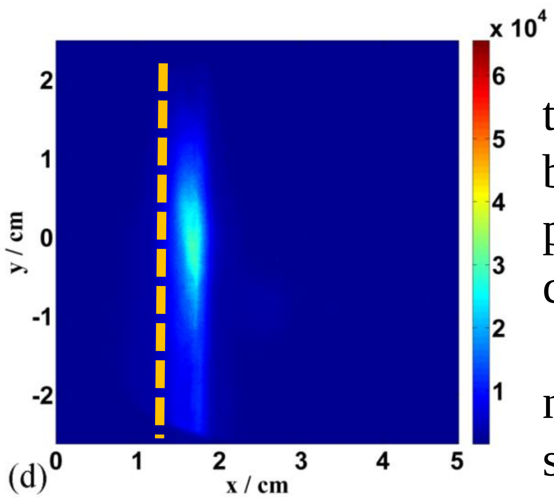
Typical pulse waveforms and detected optical intensity.

Light emission firstly becomes stronger after HPM pulse; rising edge of light emission detected by optical probe (pink) lasts for 40ns, much longer than HPM pulse width, and duration of whole light emission > 80 ns.

Development and evolution of HPM breakdown



For a 9.9GHz, 1GW, and 15ns pulse. (a) t0, (b) t0+15ns, (c) t0+30ns, (d) t0+60ns.

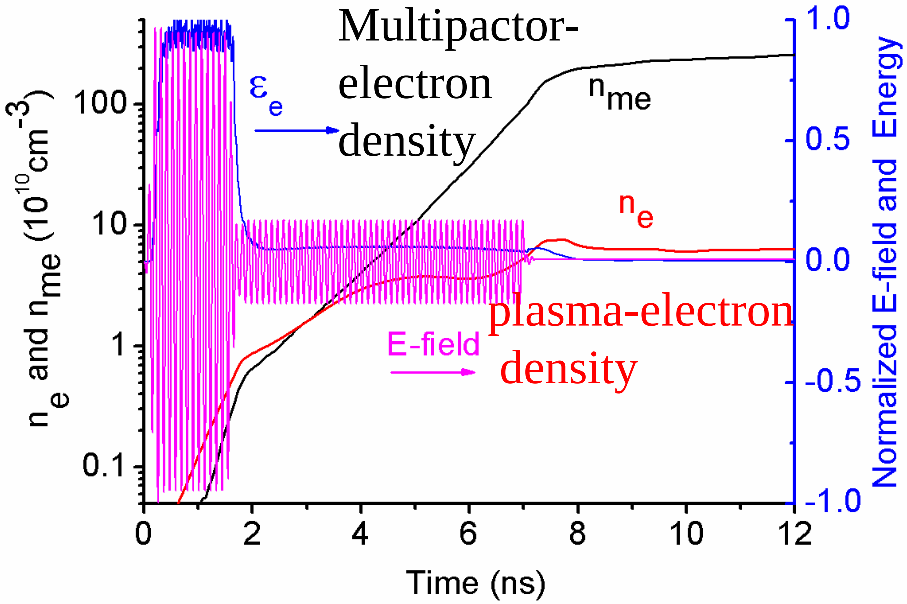


The light intensity and emission area increased during (b) flat top and (c) trailing edge of HPM pulse. The light emission layer became thicker to sub-centimeter and got brighter after HPM pulse, then intensity quickly decayed before whole area completely dark.

Thus, plasma discharge at dielectric/vacuum interface under nanosecond HPM pulse, initially starts at ambient gas layer above surface; the intense light emission in surface layer has a thickness of several millimeters and becomes brighter after HPM pulse.

Temporal evolution of plasma and multipactor electrons

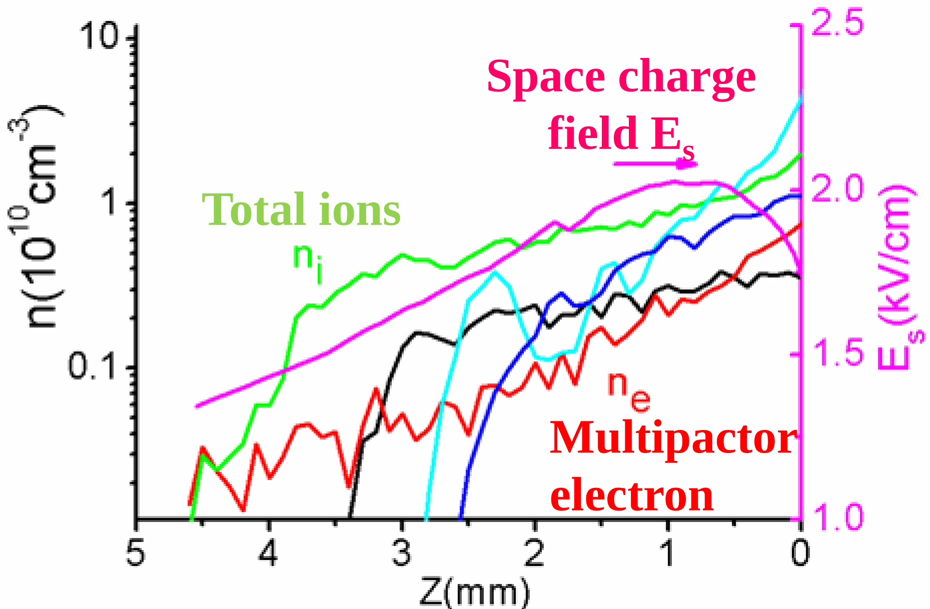
Particle-in-cell simulation



ε_e about 400eV during short HPM pulse (E_{rf0}~40 kV/cm, Blue), and ε_e decreases to ~15eV during tail pulse, sufficiently high to ionize gases and closer to peak of excitation cross section (about 10-20 eV for N_2 and O_2).

Thus, intense excitation emission together with further increased electron density (Red and Black) during tail pulse results in brighter light emission after main HPM pulse until tail ending, observed in experiment.

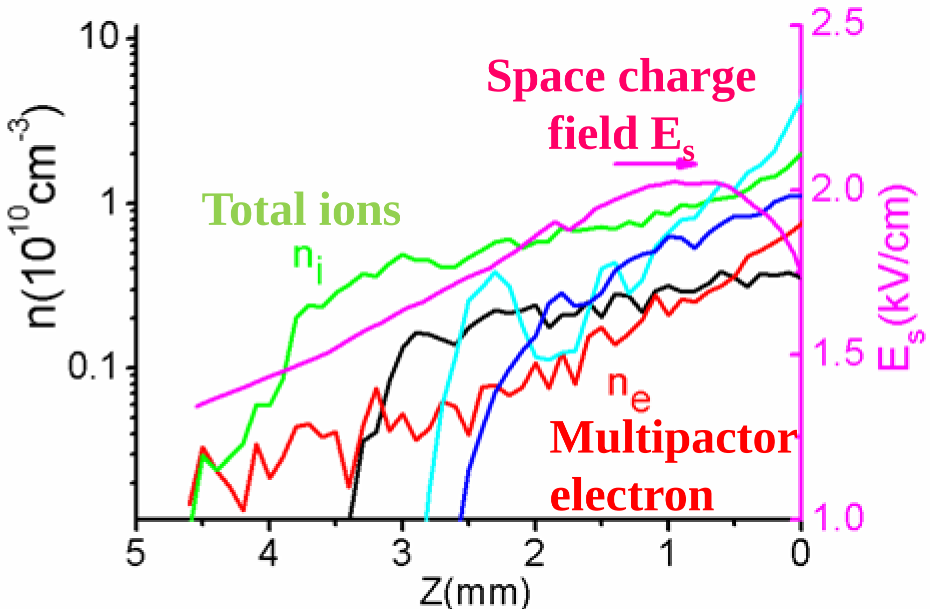
Temporal evolution of plasma and multipactor electrons



Plasma electrons (Black, t=1.5ns, Blue at t=3ns, Cyan t=7ns).

The plasma and multipactor coexist in ambient gases above dielectric surface with a thickness of several millimeters, and multipactor electrons near dielectric surface have a higher density compared with plasma electrons. Accumulated positive surface charge due to multipactor is much higher than negative charge from collided plasma; dielectric surface is positively charged.

Temporal evolution of plasma and multipactor electrons



Plasma electrons (Black, t=1.5ns, Blue at t=3ns, Cyan t=7ns).

After main HPM pulse, **space charge field together with low E_{rf}-field of tail-pulse elevates electron energy,** leading to a larger ionization rate and higher electron density above dielectric surface (Blue and Cyan) compared with other area. This ambient density grows further faster until whole pulse ends.

C. Chang,M. Zhu, J. Verboncoeur et al. **Appl. Phys. Lett.** 104, 253504 (2014)

Content

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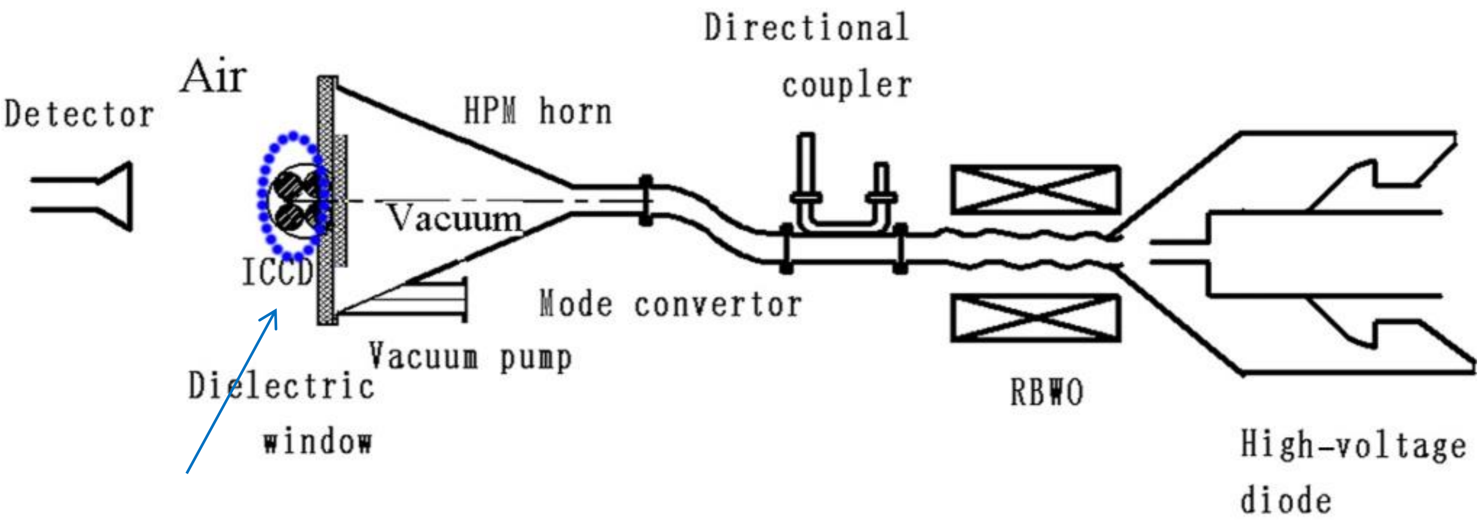
3 Discharge at dielectric/air interface

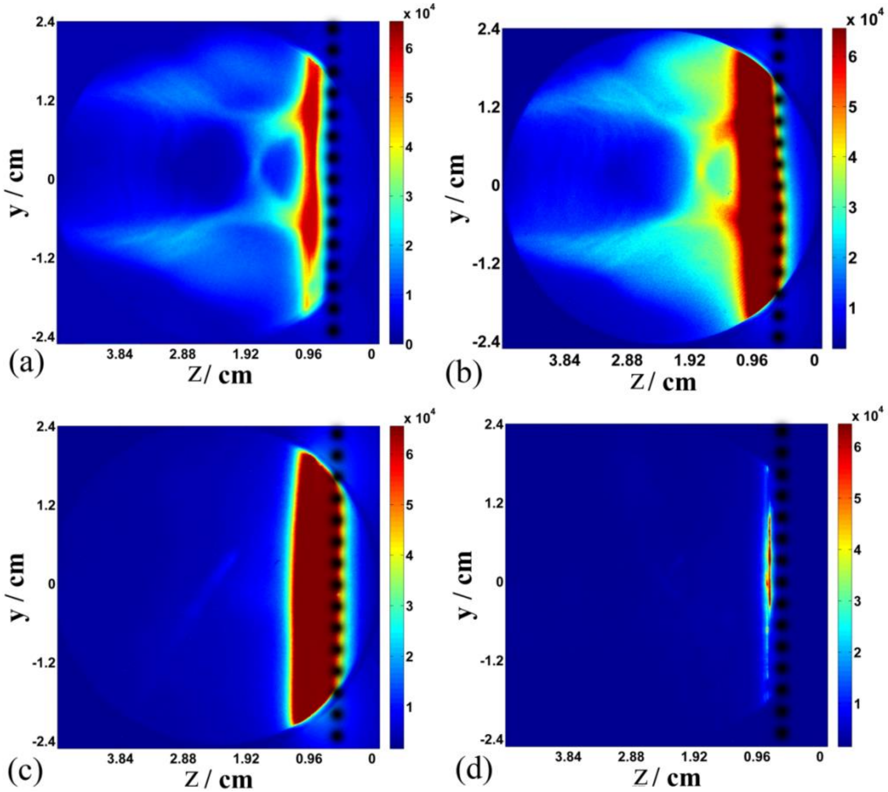
Detecting discharge at dielectric/air interface

For the same condition: X-band, 1-GW power , 15-ns pulse.

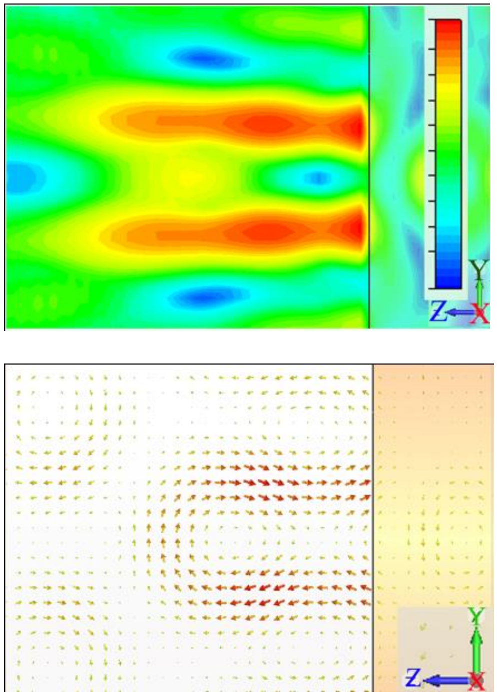


Discharge region marked by blue dotted ring.
In air at 760 Torr

Detecting discharge at dielectric/air interface



Evolution of HPM window surface breakdown.

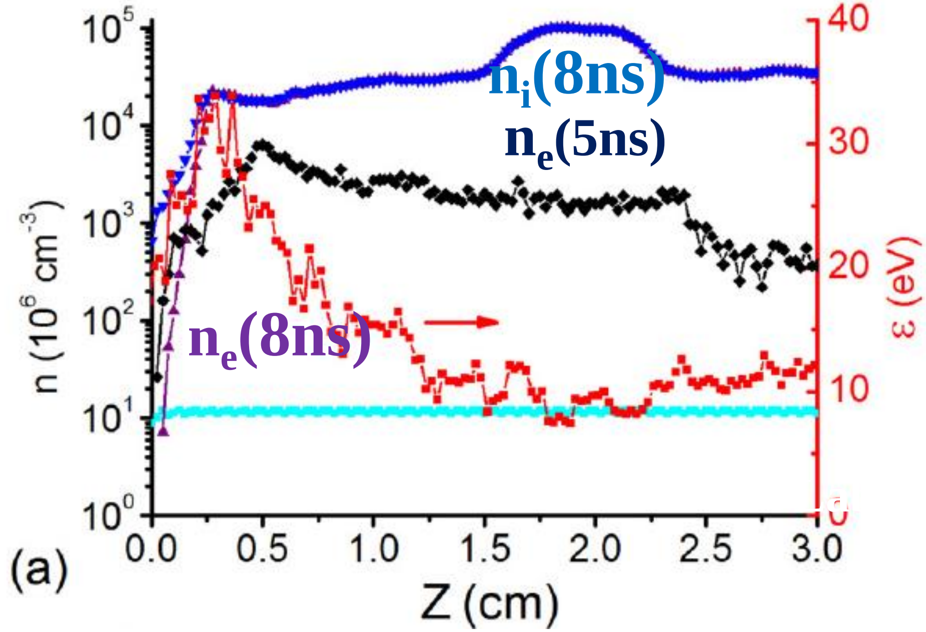


Two intense peaks of normal E field in upper and lower regions by CST

(a-c) Plasma developed more intensely at dielectric/air interface than at free-space region with a higher electric-field amplitude. (d) A thin layer of intense light emission above dielectric was observed after microwave pulse.

Detecting discharge at dielectric/air interface

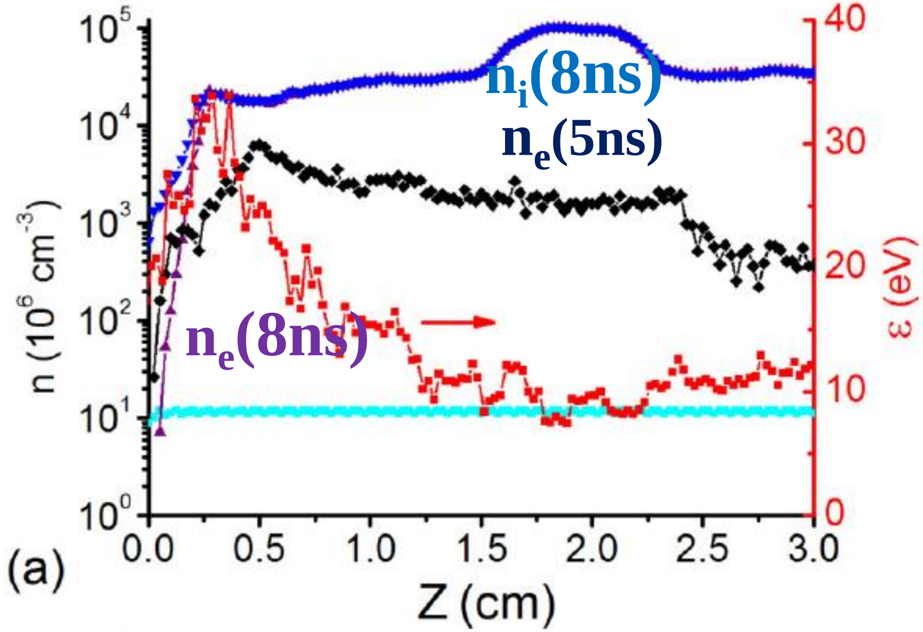
Particle-in-cell simulation



Spatial density and energy

A space-charge microwave sheath near dielectric surface, accelerated by normal components of microwave field, significantly enhancing local electron energy and ionization near dielectric surface.

Detecting discharge at dielectric/air interface



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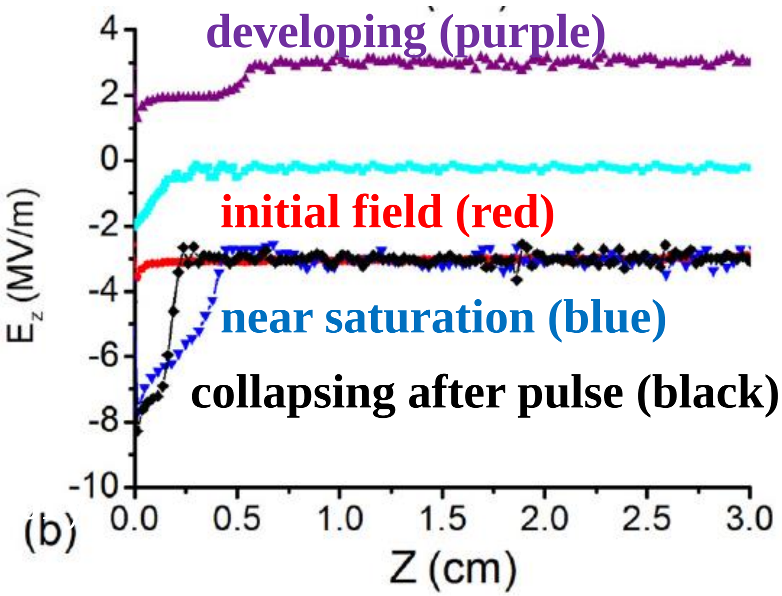

Total Ez-field evolution

The nonlinear positive feedbacks of ionization, higher electron mobility and ultraviolet-driven photoemission due to elevated electron temperature are crucial for achieving the ultrafast discharge.

C. Chang*, J. Verboncoeur, et al., **Phys. Rev. E**, 90, 063107,2014/12/09.

Many Thanks!