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Laser-plasma-based THz Radiation Sources and Their Applications

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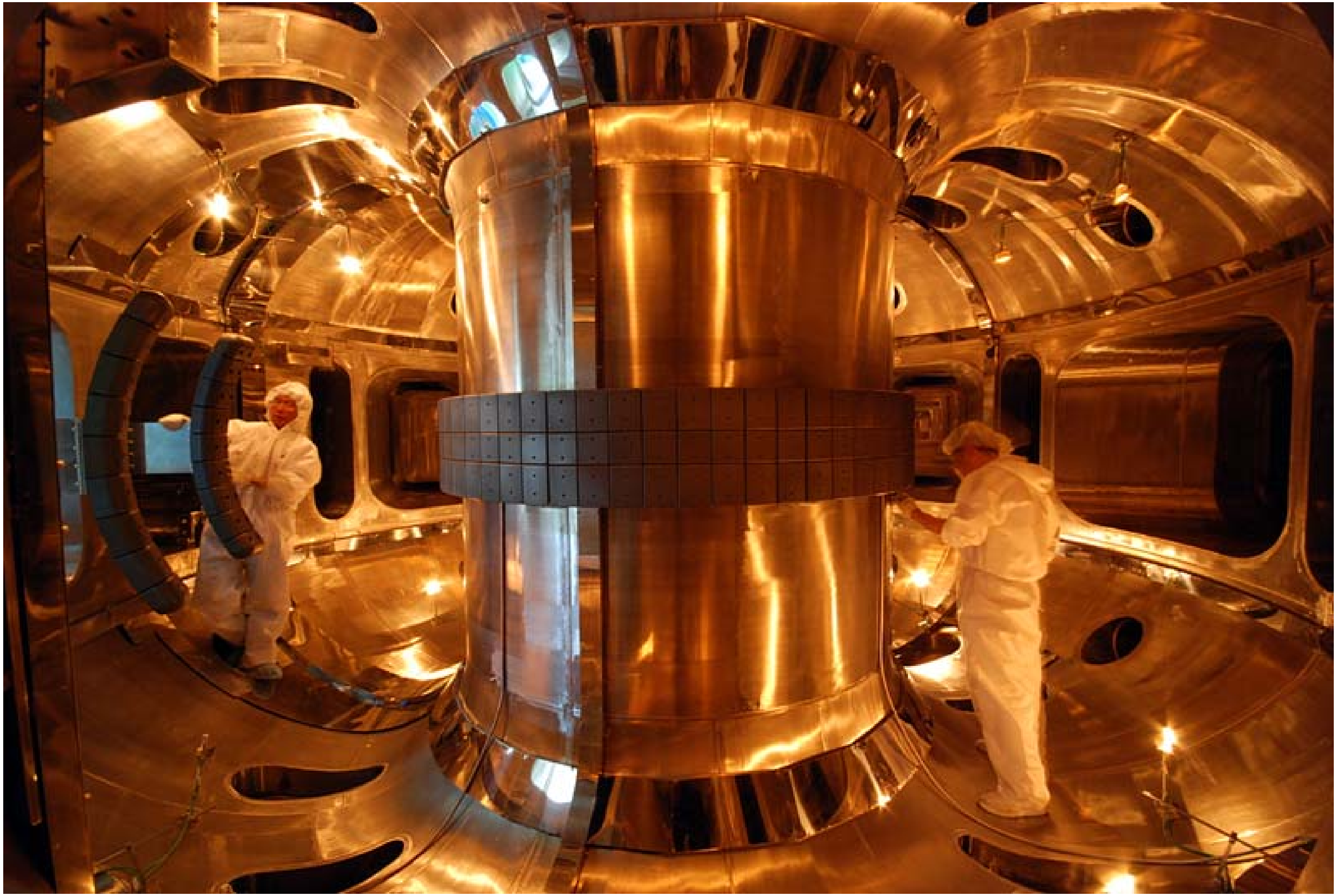
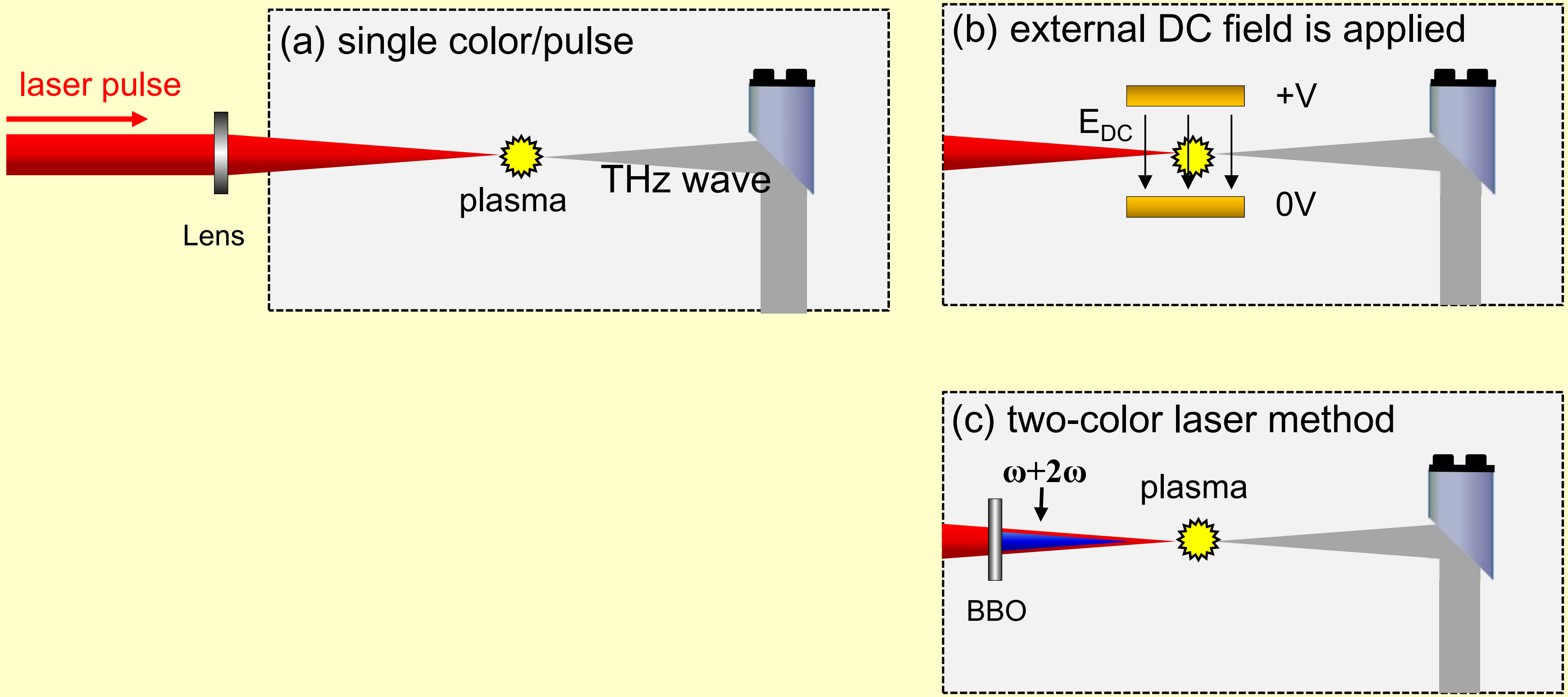


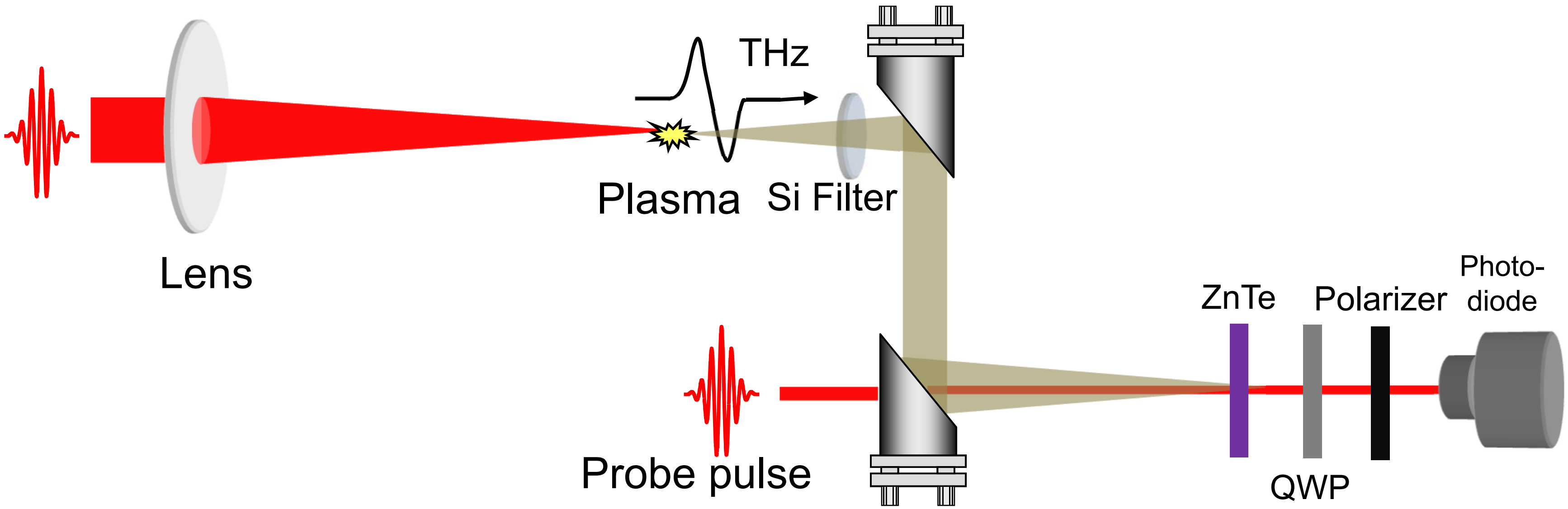
Laser-plasma-based THz Generation Methods

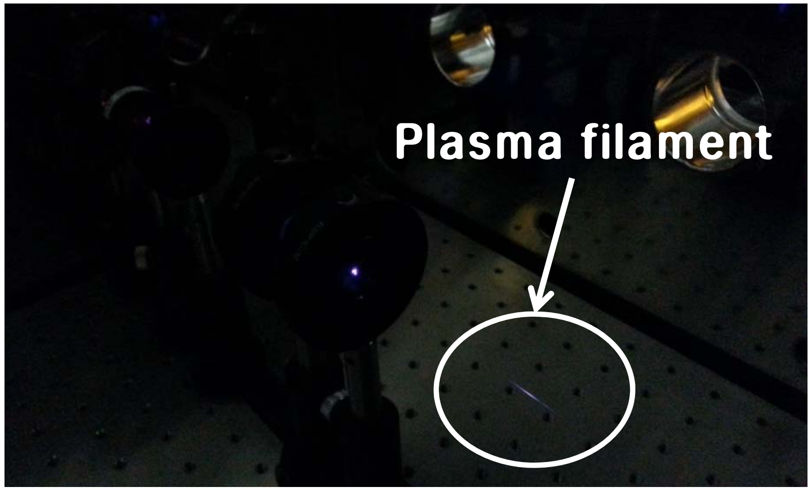


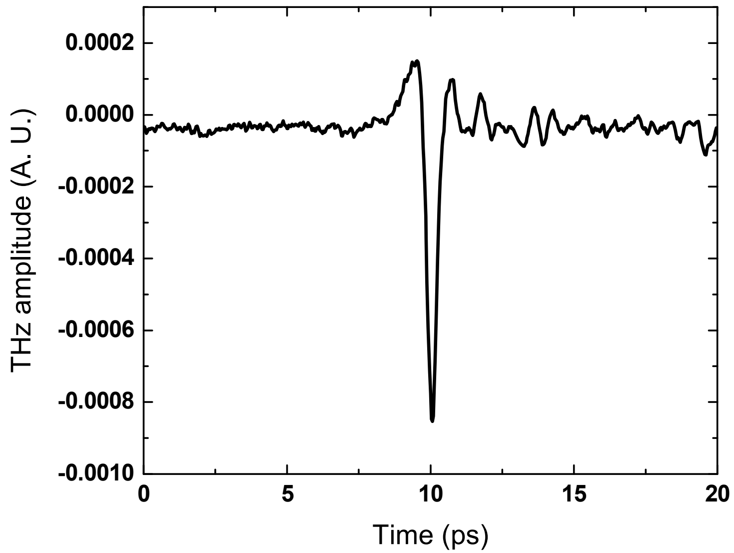
High-power (> 1 MW) broadband THz pulses can be produced by laser-plasma interactions

20 TW/35 fs Ti:sapphire Laser System at GIST

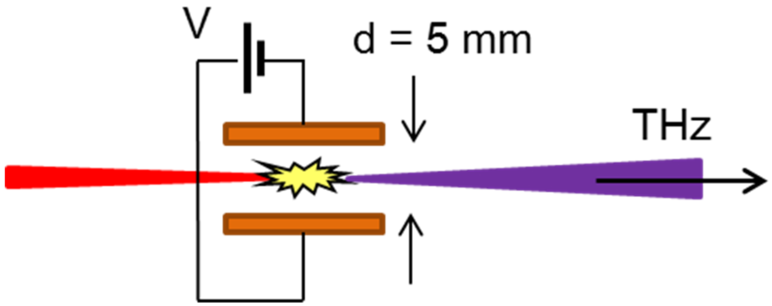
THz Generation by Laser and Plasma

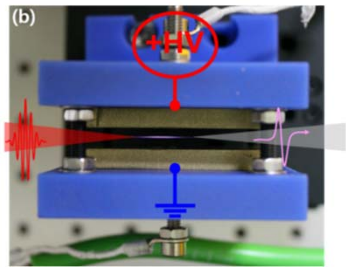


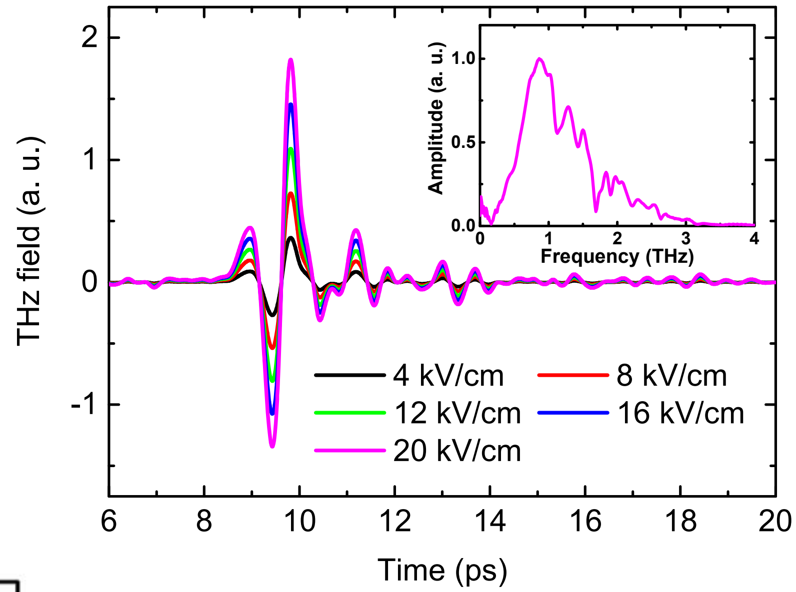


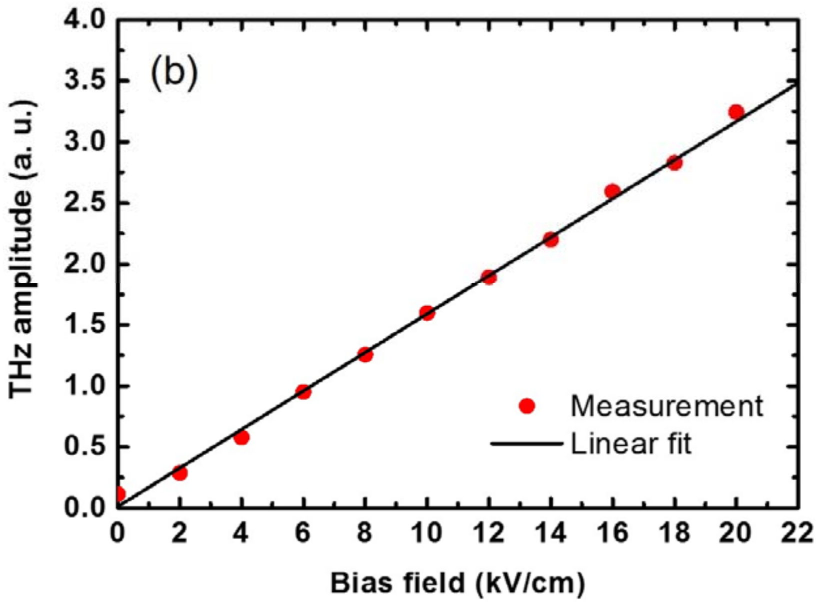


Enhanced THz Generation by DC Field







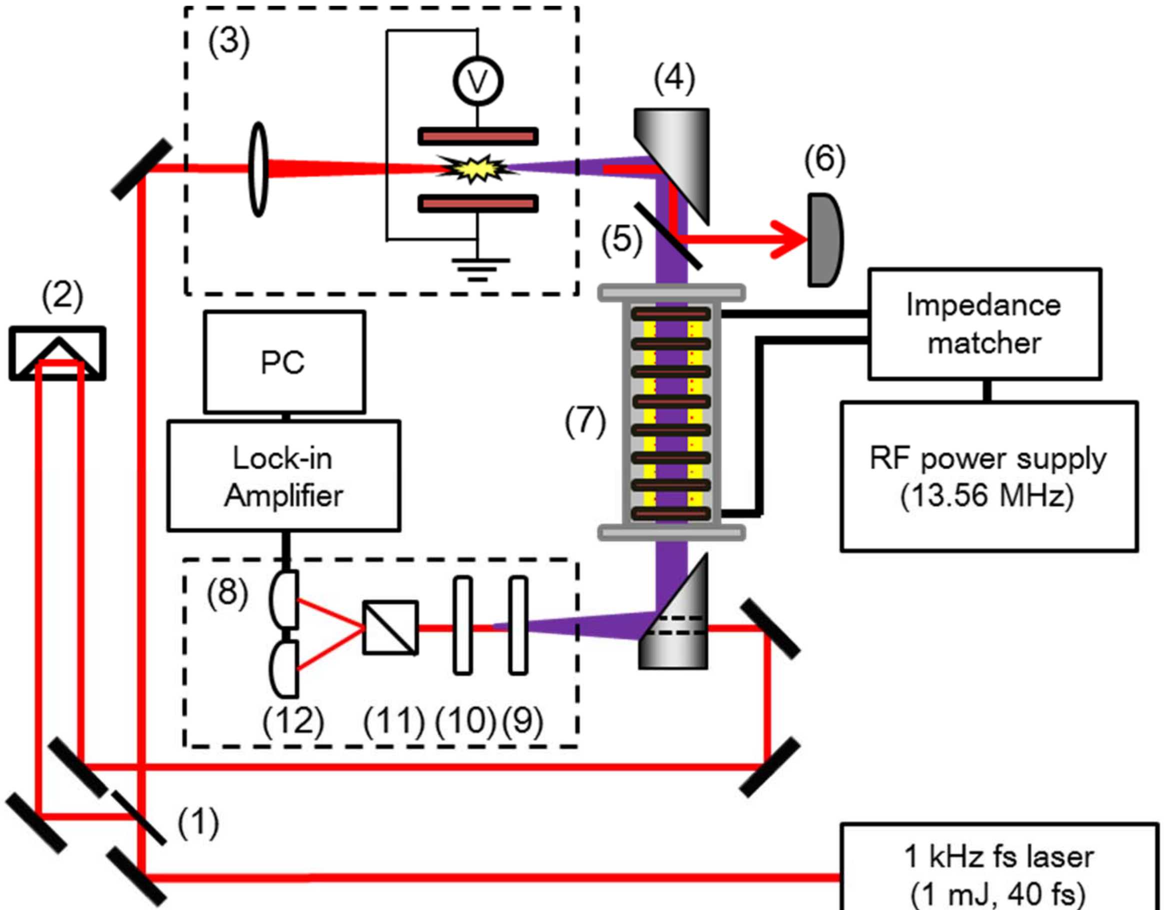


$$E_{THz} = E_{ext}\left[\cos\left(\omega_p t\right) - 1\right]\exp\left(-\nu_c^2 t^2\right)$$

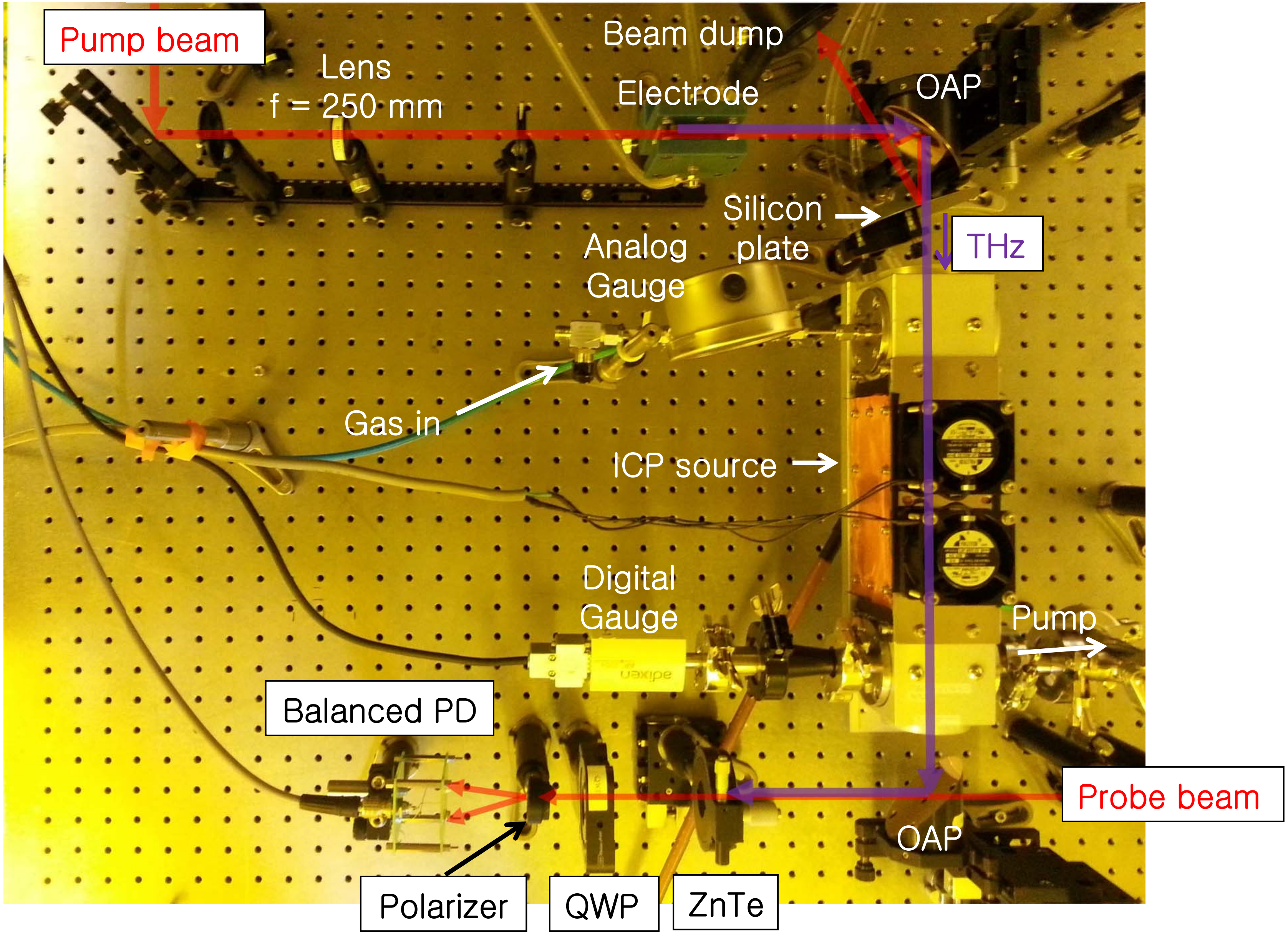
E_{ext} **: external DC electric field**

ν_c **: e-neutral collision frequency**

Schematic for the Experiment

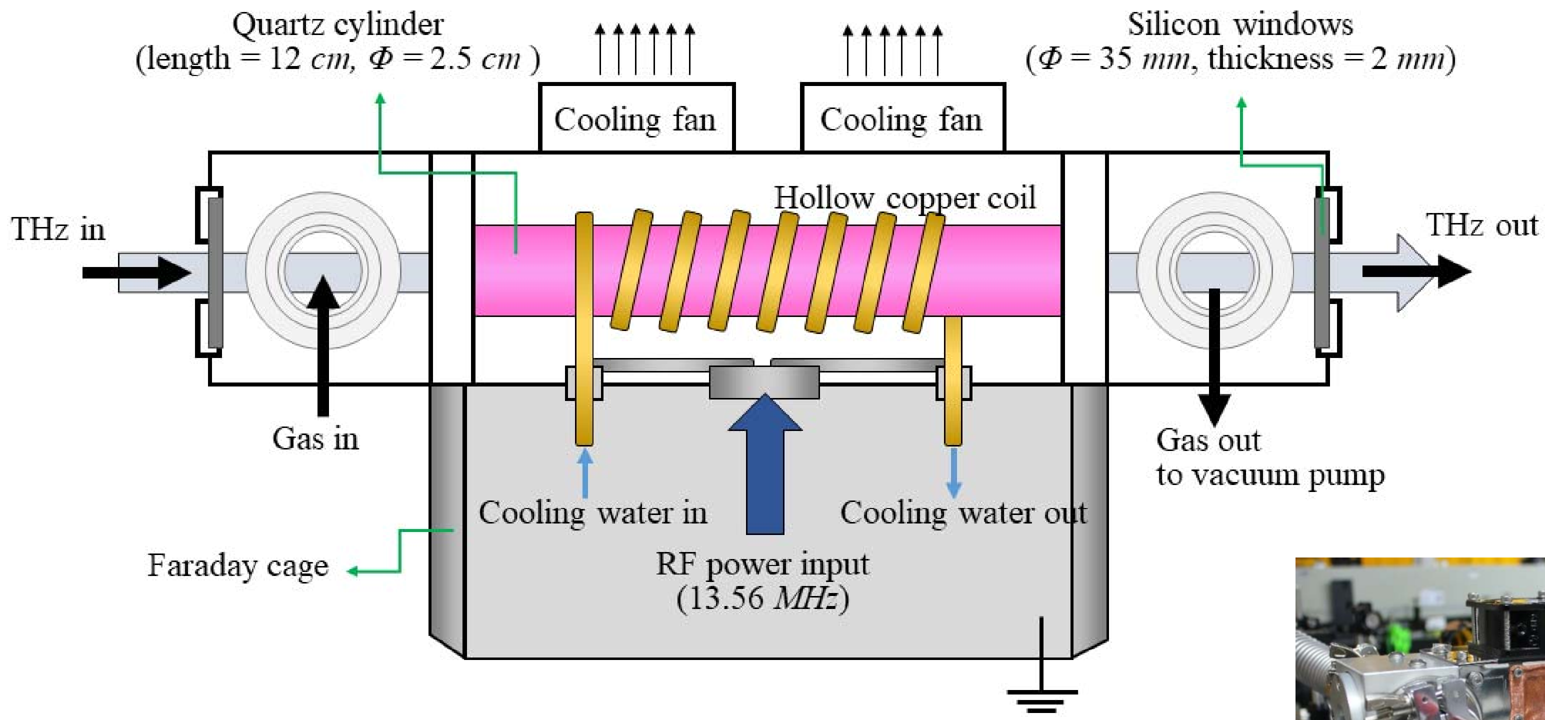


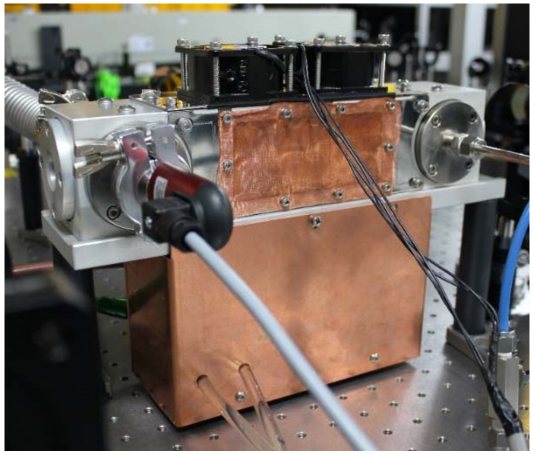
(1) Beam splitter (R= 8 %, T = 92 %)
(2) Delay line
(3) THz generator
(4) OAP
(5) Silicon plate (laser beam cutting)
(6) Beam dump
(7) Inductively-coupled plasma source
(8) THz detector (EO sampling)
(9) ZnTe crystal
(10) Quarter-wave plate
(11) Wollaston prism (polarizer)
(12) Balanced photo-detector



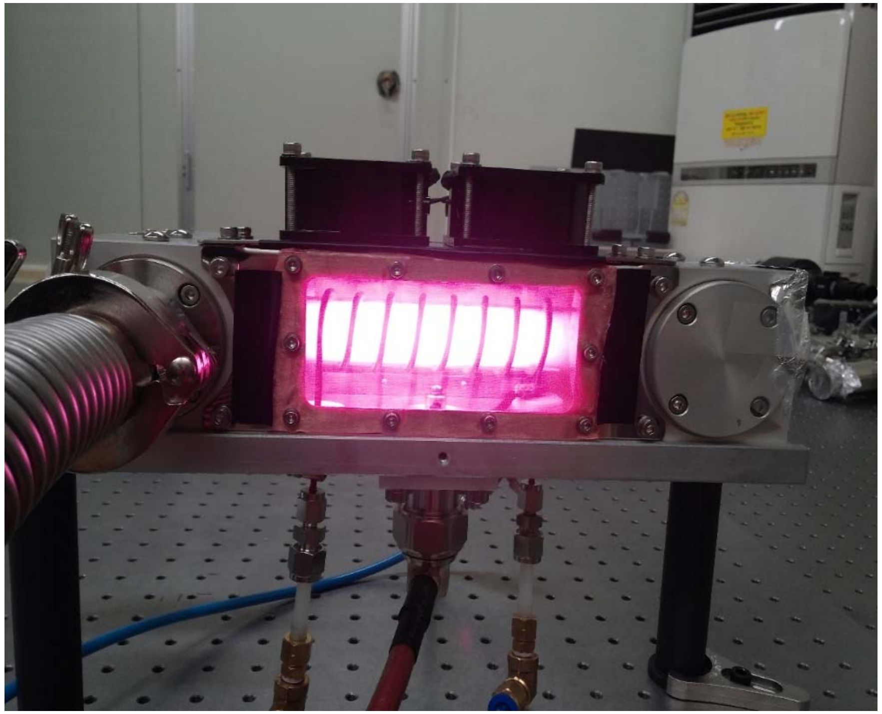
Pump beam
Lens
f = 250 mm
Beam dump
Electrode
OAP
Silicon plate
THz
Analog Gauge
Gas in
ICP source
Digital Gauge
Pump
adixen
Balanced PD
Probe beam
OAP
Polarizer
QWP
ZnTe

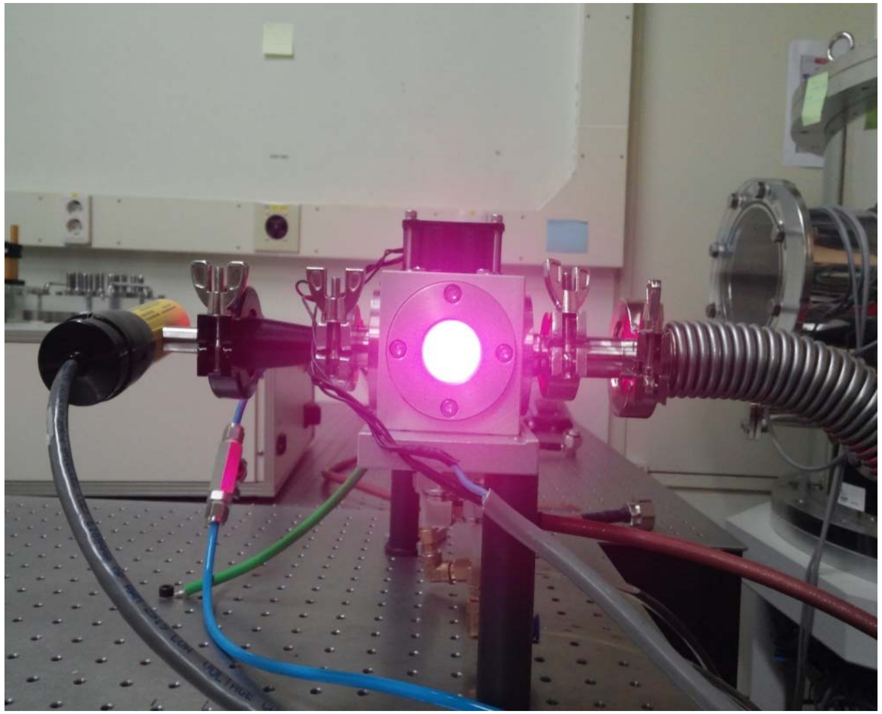
plasma source: Inductively-coupled plasma (ICP) source



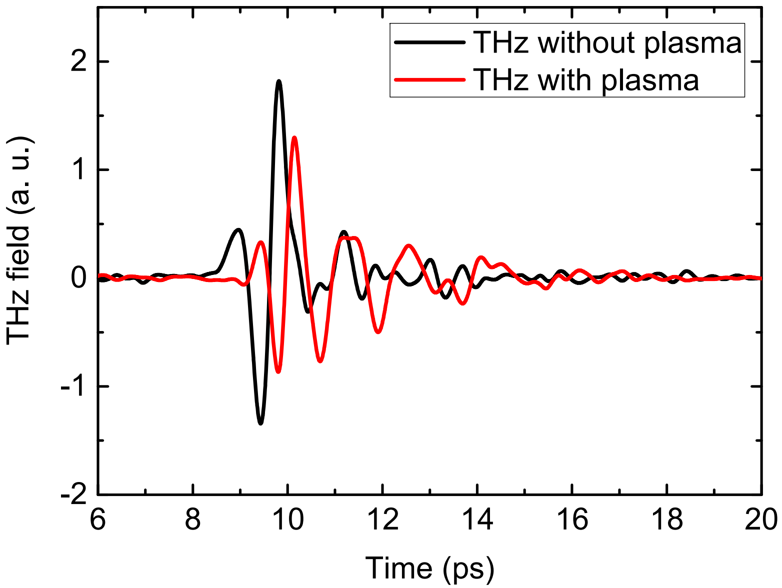


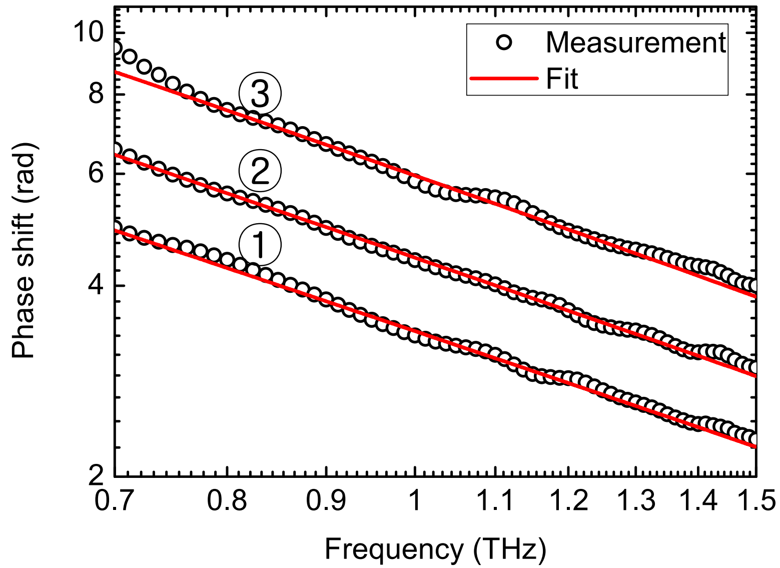
Ar Plasma





THz Wave with and without Plasma





910 mTorr Ar with 500 W RF power

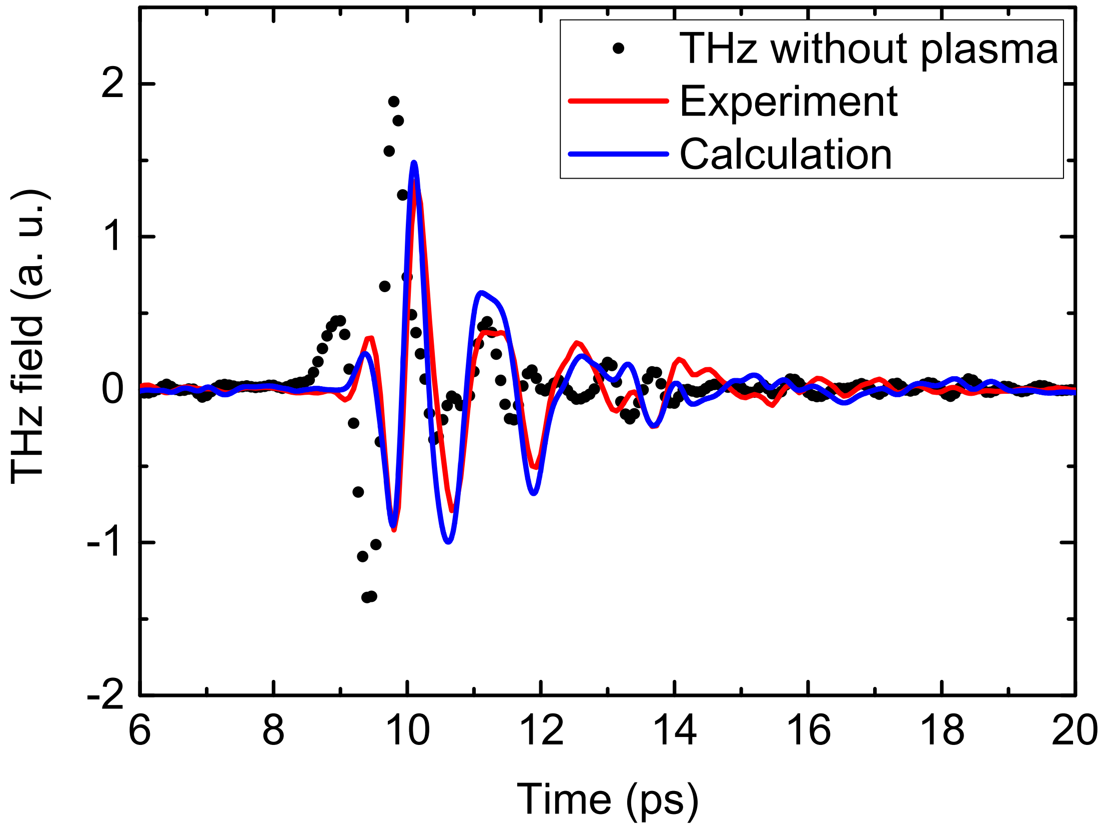
① 910 mTorr, 400 W
② 910 mTorr, 500 W
③ 1,040 mTorr, 500 W

→ $$\frac{\tilde{E}_p(\omega)}{\tilde{E}_r(\omega)} = \exp(i\Delta\Phi)\exp(-\alpha L)$$

$\tilde{E}_p(\omega)$ and $\tilde{E}_r(\omega)$: Fourier transformed spectra of the THz field with and without the plasma

→ Phase shift : $\Delta\Phi \approx \frac{L}{2c}\frac{\omega_p^2}{\omega}, \quad \omega_p^2 = \frac{n_e e^2}{m_e \varepsilon_0}, \quad L = 10\ cm.$

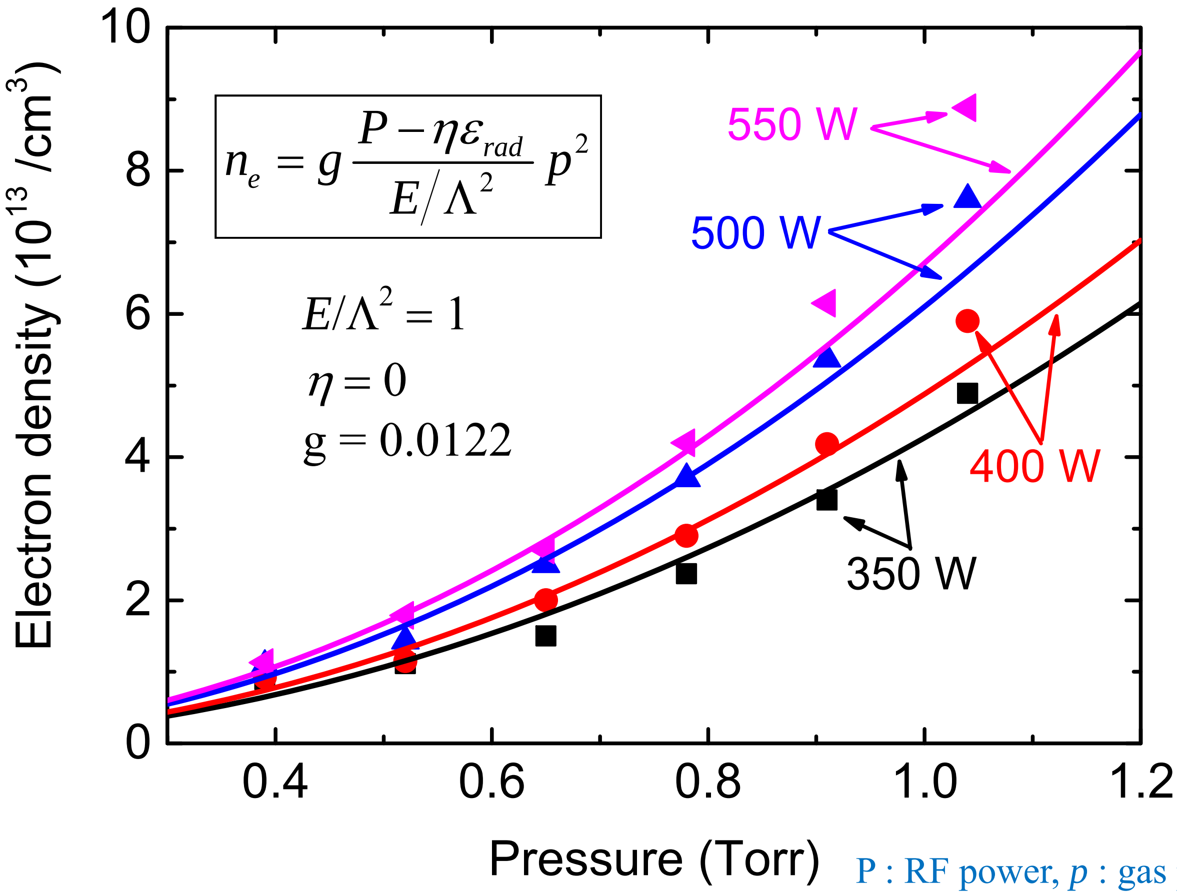
Experiment vs. Calculation



$n_e = 5.3\times10^{13}\ cm^{-3}$

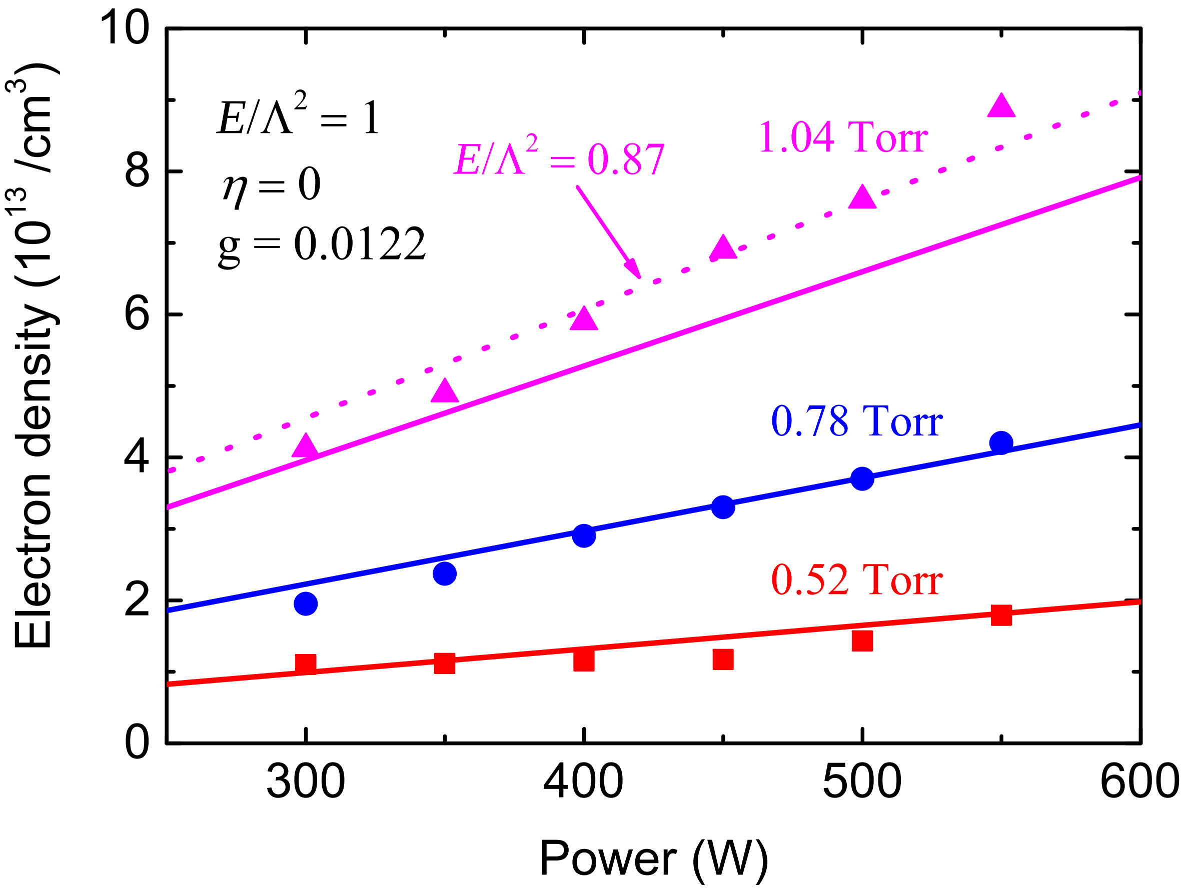
- Experimental condition : pressure=910mTorr (Ar), RF power=500 W
- Plasma length : 10 cm

Plasma Density vs. Pressure



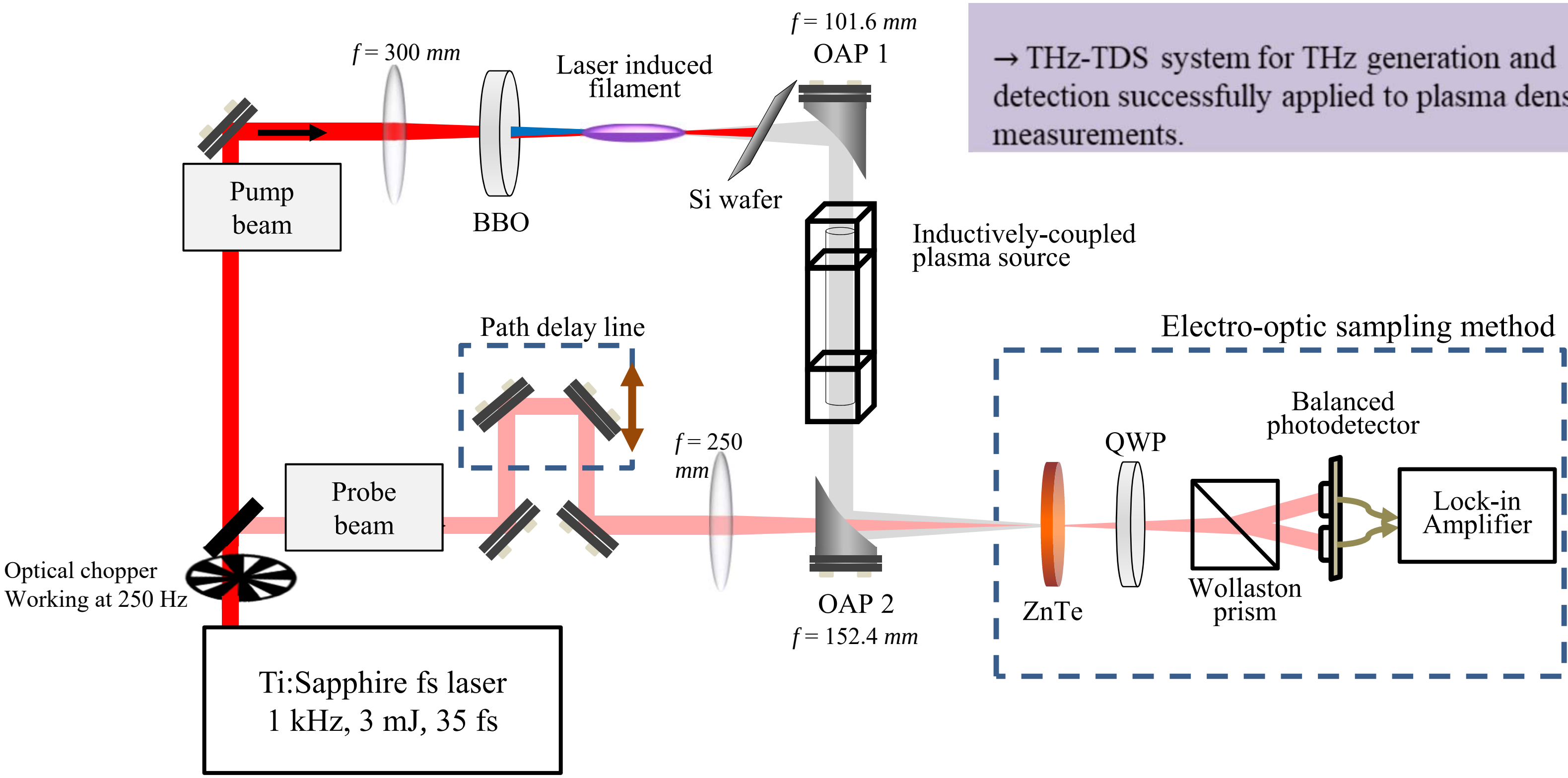
P : RF power, p : gas pressure
E : electric field
Λ : inverse of the density gradient (uniformity)
$\eta\varepsilon_{rad}$: energy loss by the radiation
g : constant depending on the geometrical configuration

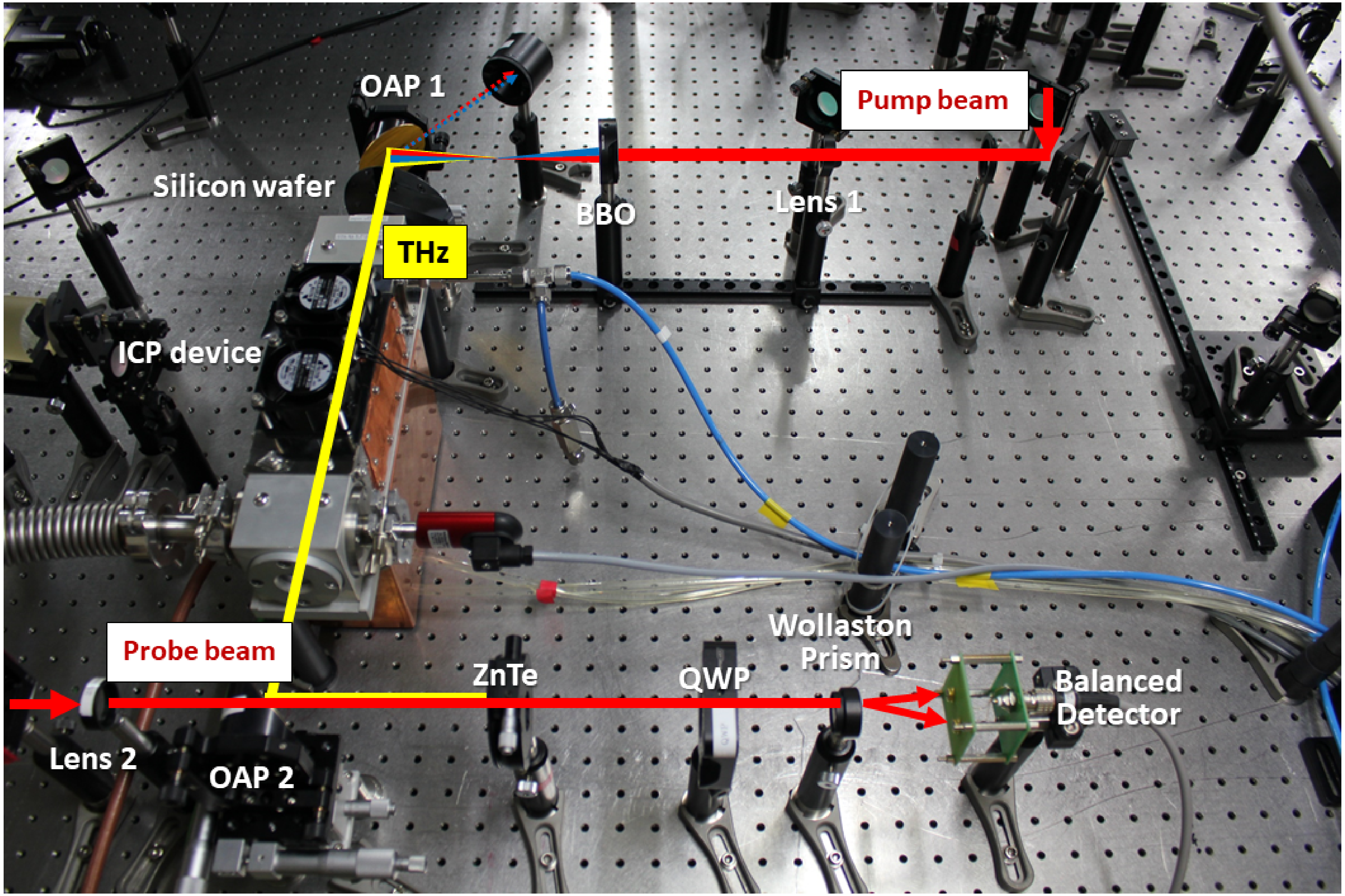
Plasma Density vs. RF Power



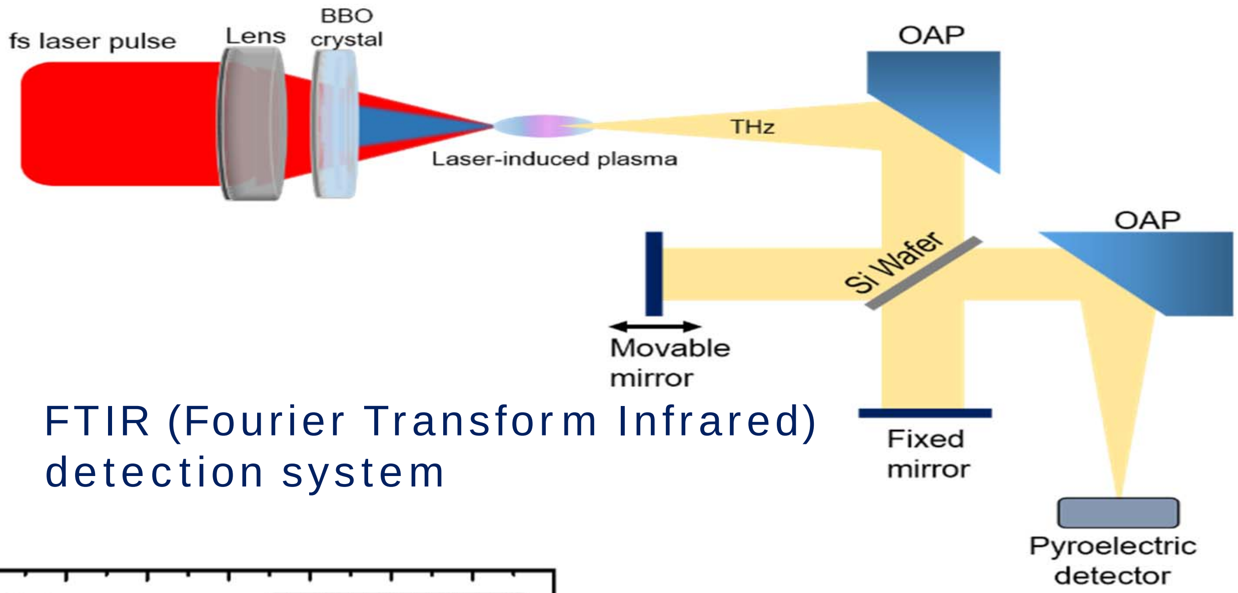
Two-color-based THz-TDS

→ THz-TDS system for THz generation and detection successfully applied to plasma density measurements.

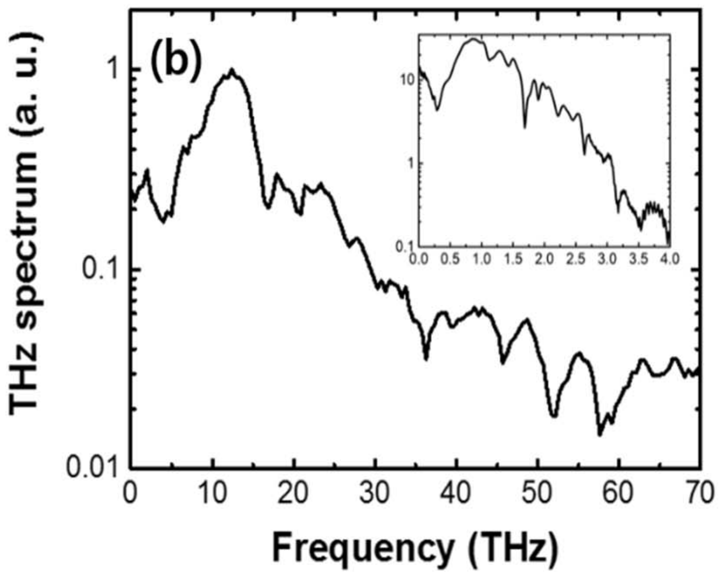



OAP 1
Pump beam
Silicon wafer
BBO
Lens 1
THz
ICP device
Probe beam
Wollaston
Prism
ZnTe
QWP
Balanced
Detector
Lens 2
OAP 2

Two-color Method : broader bandwidth

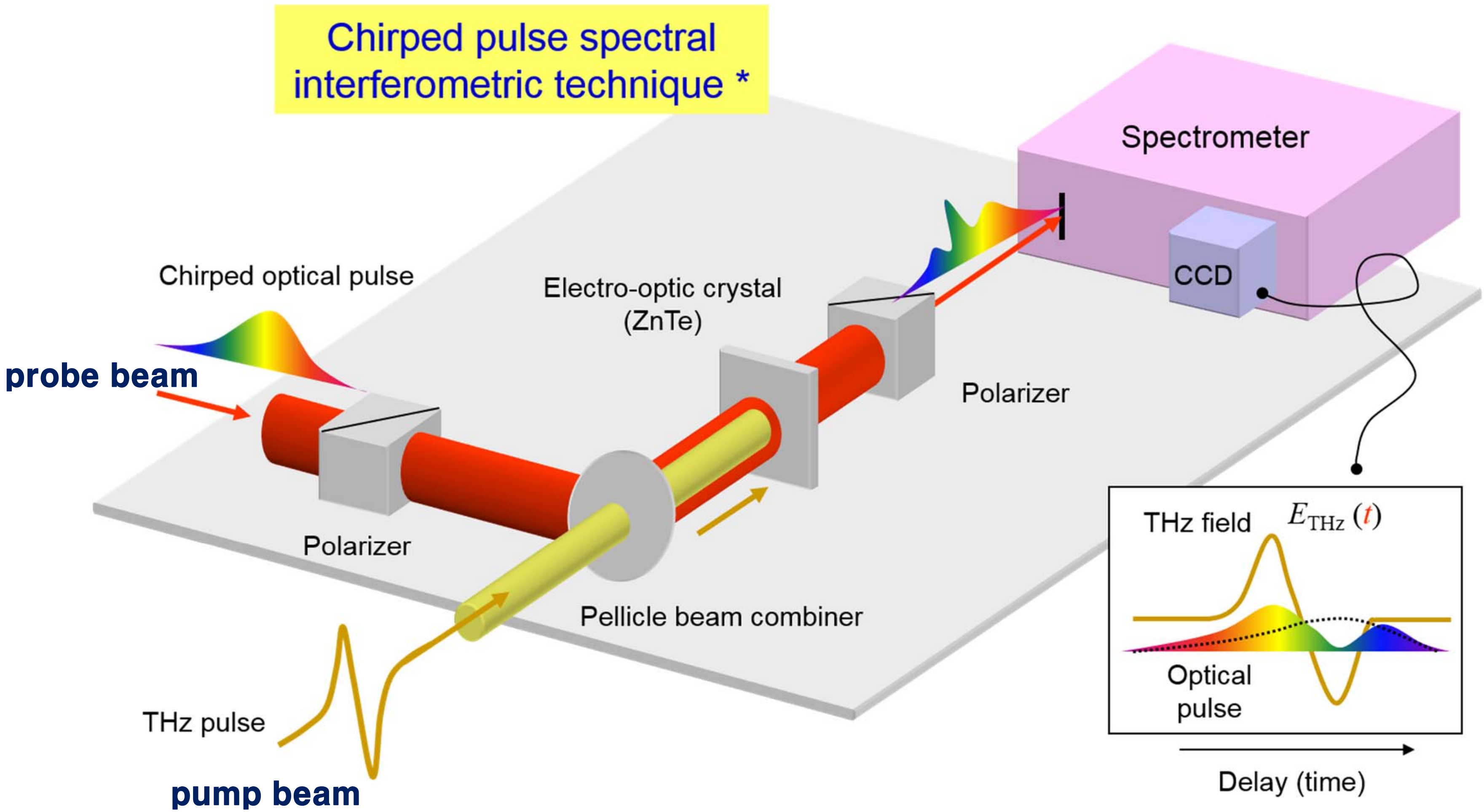


FTIR (Fourier Transform Infrared) detection system



Broader bandwidth THz pulse can cover higher densities

Single-shot Method



Conclusions

- Strong laser-plasma interactions can generate broadband THz pulses
- Laser-plasma-based THz methods can be used for high-density ($10^{13} < n_e < 10^{17}$ cm^{-3}) plasma diagnostics
- Sing-shot method based on the spectral interferometry is also possible

Thank you