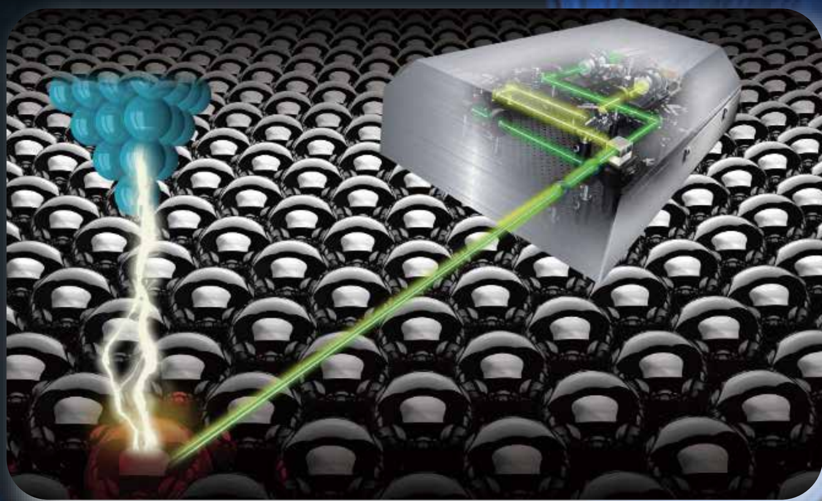
UNISOKU
TII Group

NEW

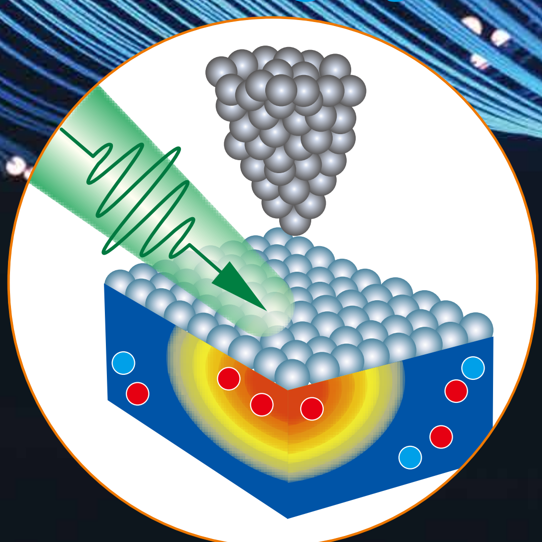
Time-resolved scanning tunneling microscopy system



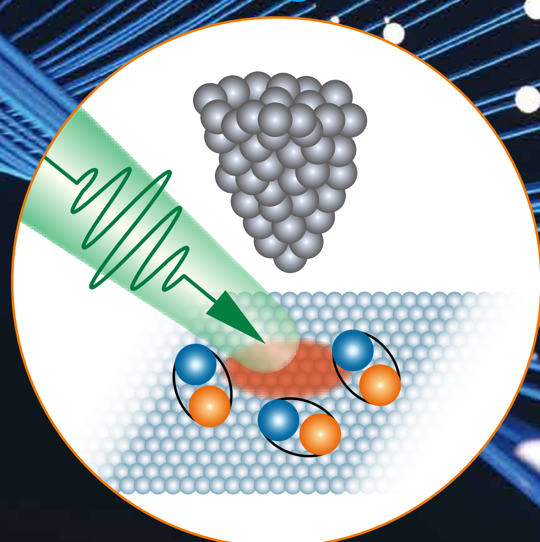
Our compact and modular optical system realizes easy time-resolved STM measurements

Ultrafast dynamics measurement of photoexcited phenomena at the nanoscale

Carrier & Charge dynamics



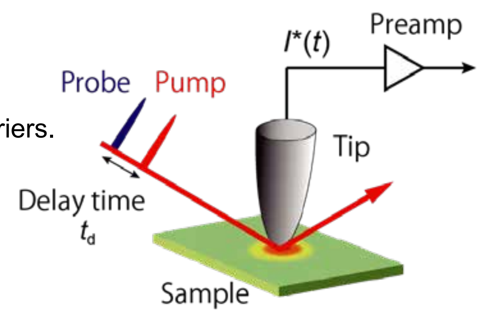
Exciton dynamics



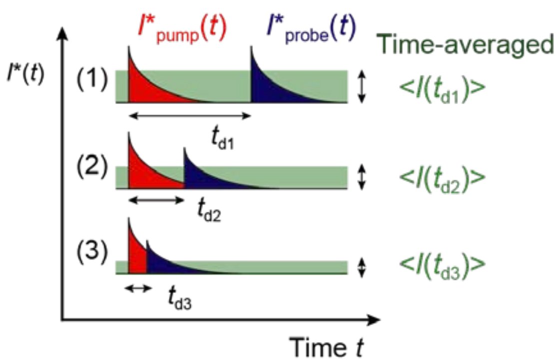
This system is a commercialized optical pump-probe STM developed by Shigekawa and Takeuchi Laboratory at University of Tsukuba.

Principle of time-resolved STM

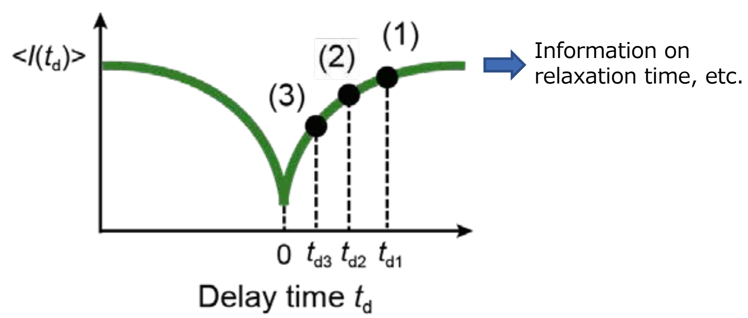
We irradiate the pump light and probe light onto the sample, and measure a tunneling current between the sample and the probe (right figure). When the delay time is short (long), the number of carriers excited by the probe light becomes small (large) because the excited states are occupied (not occupied) by photoinduced carriers. As a result, the tunneling current will be small (large). (left figure below). By measuring the delay time dependence of the tunnel current, we can obtain the information on carrier dynamics such as relaxation time (right figure below). Furthermore, by changing the probe position, the carrier dynamics can be measured with nanoscale spatial resolution.



Relation between transient tunneling current induced by pump and probe light and time-averaged tunneling current



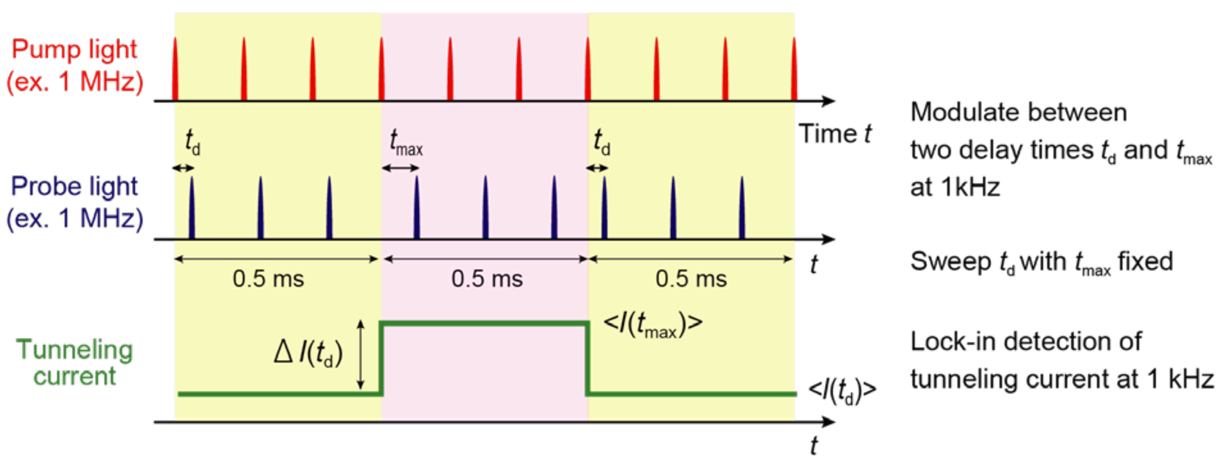
Delay time dependence of time-averaged tunneling current



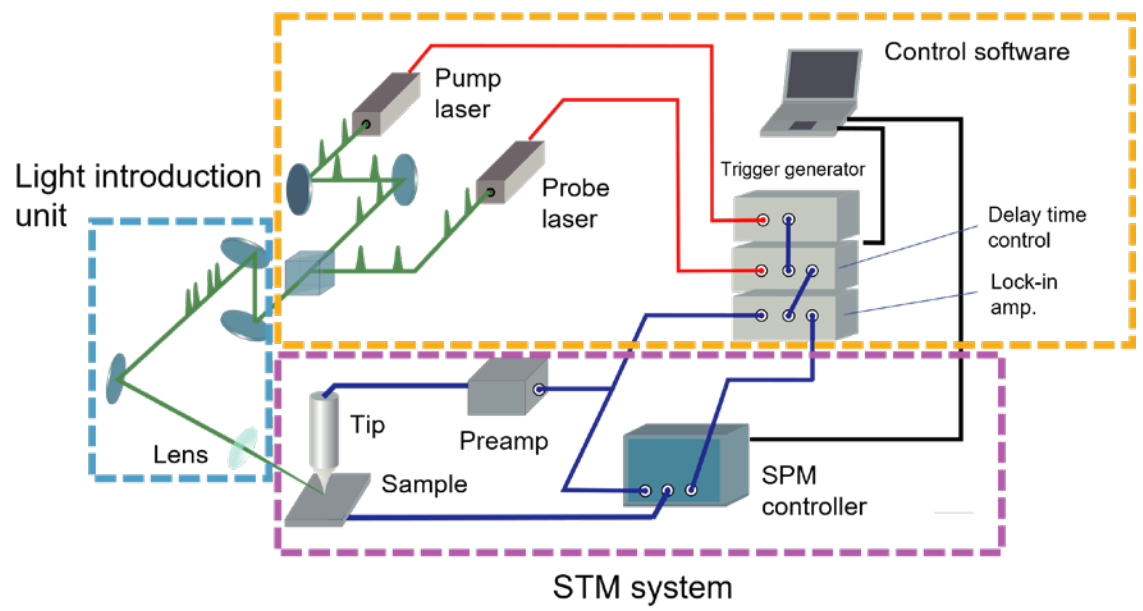
Unique delay time modulation technique

To suppress the thermal expansion effect of the probe due to the light irradiation and to detect minute time-resolved tunneling current signals with high accuracy, the delay time modulation technique in which the delay time is varied in a square wave manner is effective (patented).

The system is equipped with the delay time modulation system suitable for time-resolved STM measurements and a lock-in amplifier for detecting tunnel currents synchronized with the modulation. You can start a time-resolved STM measurement simply by irradiating a sample under the probe with excitation light.



Basic system configuration



Delay-time modulation excitation-light source unit

Integrating into an existing STM system possible!

Features

- The delay-time modulation method by electronic control realizes a compact and easy-to-operate optical system.
- Lasers can be selected according to the application.

Excitation-light source unit (outer case is removed in the photo)

Basic specifications

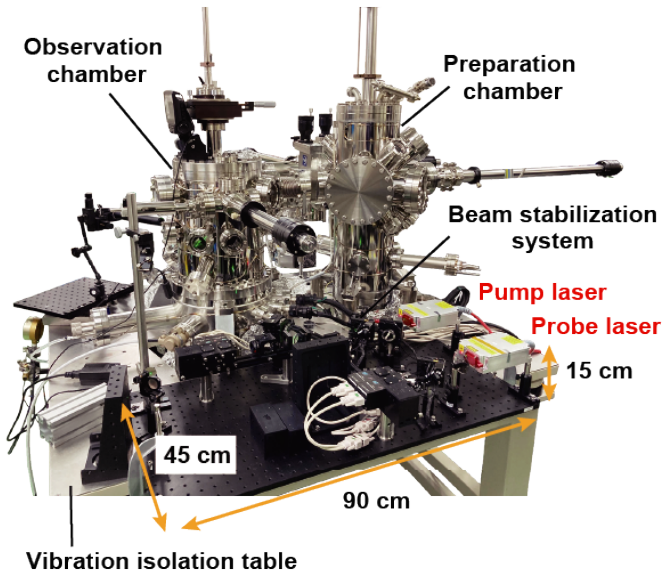
	Picosecond system	Nanosecond system
Average power (one laser unit)	>25 mW@1 MHz (532 nm)	12-35 mW@10 MHz
Pulse intensity	>25 nJ (532 nm)	1.2 ~ 3.5 nJ
Center wavelength*	Select from 532, 775 nm	Select from 405, 450, 488, 520, 640, 785, 820 nm
Pulse width	45±15 ps	Min: 6±1 ns, Max: 39±3 ns
Jitter	25 ps	25 ps
Laser repetition frequency	532 nm: 1 kHz -1 MHz 775 nm: 20-80 MHz	Max. 10 MHz
Temporal resolution**	~70 ps	~9 ns

*Available wavelengths are subject to change.
**These values are theoretically calculated from the system configuration and are subject to change depending on the sample to be measured.

Low temperature ultrahigh vacuum time-resolved STM system

USM1400-OPP

The detail is reported in Sci. Rep. **13,** 818 (2023).



Features

Compact excitation-light source unit

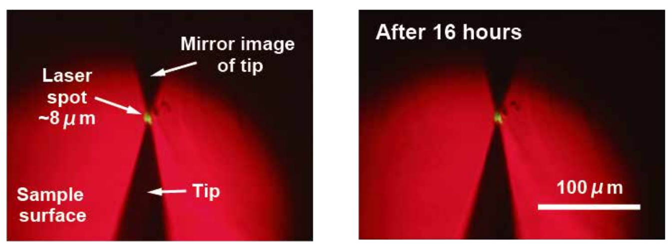
- Temporal resolution ~70 ps
- Easy operation & maintenance
- Stable laser illumination on sample surface
- Wavelengths selectable from 532, 775, 1064, 1550 nm
- Selection of nanosecond lasers also available

Nanoscale carrier dynamics measurement

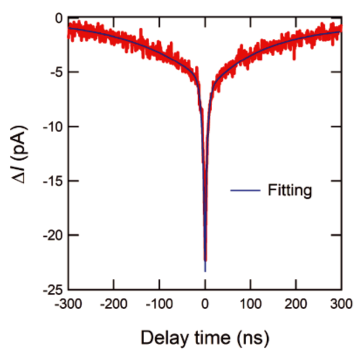
- Spatial resolution ~ 1 nm
- Long-term time-resolved measurement (~1 day)

Stable laser spot position on sample surface

➡ **Suitable for long-term measurements**



Time-resolved tunneling current



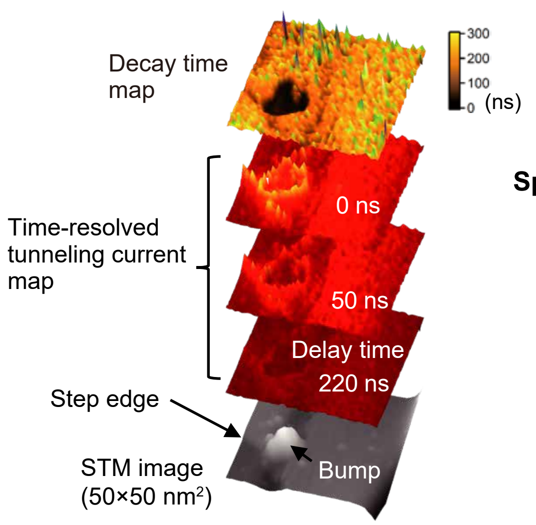
➡ **Relaxation time of photoexcited carriers**

GaAs(110) surface
T = 78 K

Relaxation time
Fast: 4.5±0.2 ns
Slow: 121.3±8.3 ns

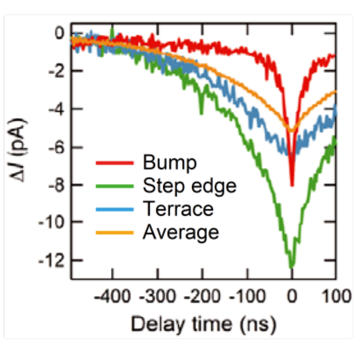
Nanoscale imaging of relaxation time of photoexcited carriers

GaAs(110) surface, *T* = 6 K



The influence of nanoscale structures on carrier dynamics can be imaged!

Spatially dependent time-resolved tunneling current



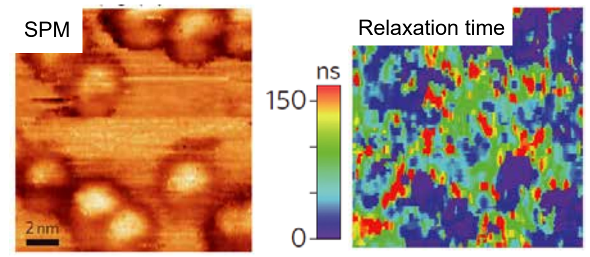
Stable long-term measurement
- 50×50 grid points in 50×50 nm²
- 30 sec/point ~21 hours in total

Spatial resolution ~1 nm

Applications of time-resolved STM

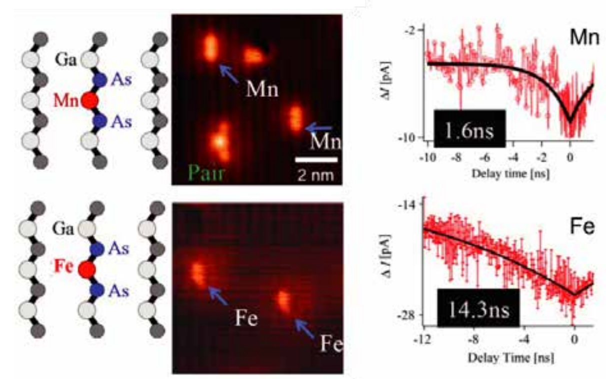
- **Semiconductor materials, heterostructures**
  ex. transition metal dichalcogenides(TMDCs)
  - Carrier recombination
  - Charge dynamics of dopants
- **Photocatalytic materials (ex. TiO_2)**
  - Impurity effect on photoinduced carrier dynamics
  - Polaron dynamics
- **Solar cell materials**
  - Influence of nanostructures and interfaces on the performance

Nanoscale carrier dynamics



Terada *et al*., Nat. Photon. **4**, 869 (2010).

Atomically-resolved carrier dynamics

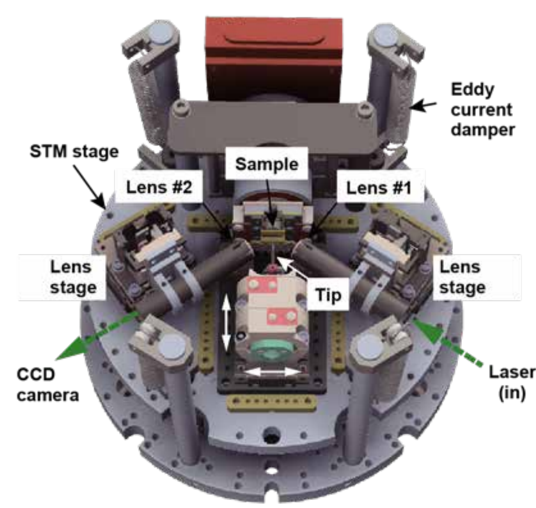


Yoshida *et al*., Appl. Phys. Express **6**, 032401 (2013).

Basic specifications of time-resolved STM (USM1400)

Vacuum level	UHV
Measurement temperature	Room temperature, 78 K 6-100 K
Liq. He holding time	40 h/12 L
STM scan range	1.7 um
Tip coarse motion distance (vertical to sample)	±2.5 mm
Tip stage travel distance (parallel to sample)	±3 mm
Lens stage travel distance	X, Y: ±3 mm Z: ±2 mm
Light incident angle	55° normal to sample surface
Lens	Aspheric lens (NA: 0.3)

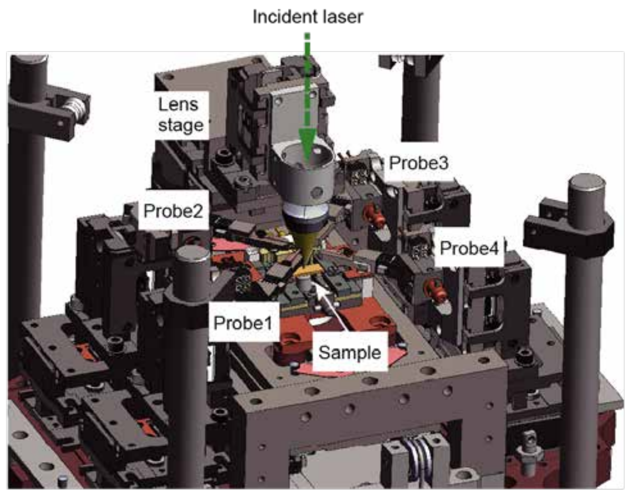
Top view of STM stage



Specifications of the light source unit are described on page 2.

Ultrahigh vacuum time-resolved multiprobe microscopy system

USM1400-4P-OPP



Features

■ Compact excitation-light source unit

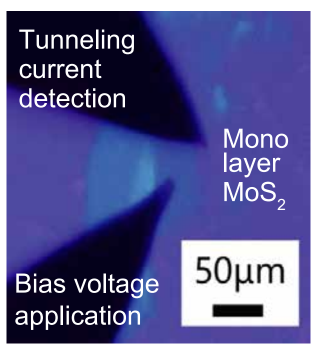
- Temporal resolution ~70 ps
- Easy operation & maintenance
- Stable laser illumination on sample surface
- Wavelengths selectable from 532, 775, 1064, 1550 nm
- Selection of nanosecond lasers also available

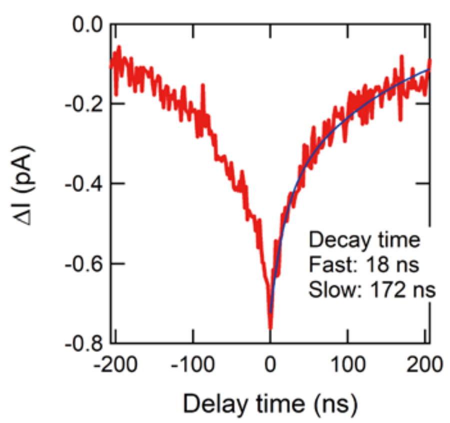
■ Carrier dynamics measurement of a sample on insulating substrate

- Sample and tip observation using long-focus microscope
- Independent control of four probes
- Gate voltage application available

■ Carrier dynamics measurement of a small sample on insulating substrate

Ex. Monolayer MoS_2 on SiO_2 substrate





Demo measurement currently available

Measurement conditions

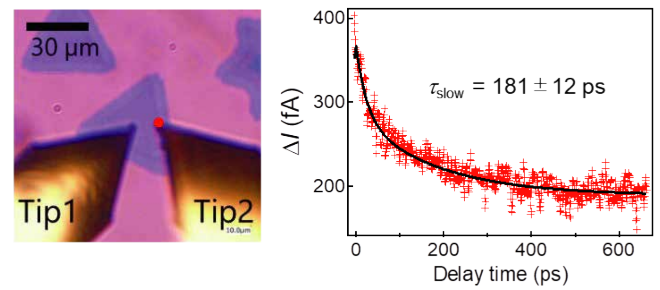
Vacuum level	UHV
Measurement temperature	Room temperature, 78 K
Laser wavelength	532 nm
Temporal resolution	~ 70 ps
Sample gate voltage	Max. ±150 V

Please feel free to contact us (info@unisoku.co.jp) about the detail.

UNISOKU WEB URL

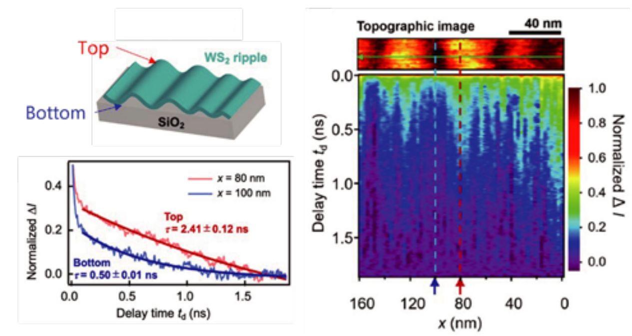
Applications of time-resolved multiprobe microscopy

■ Carrier dynamics of monolayer TMDC heterostructure

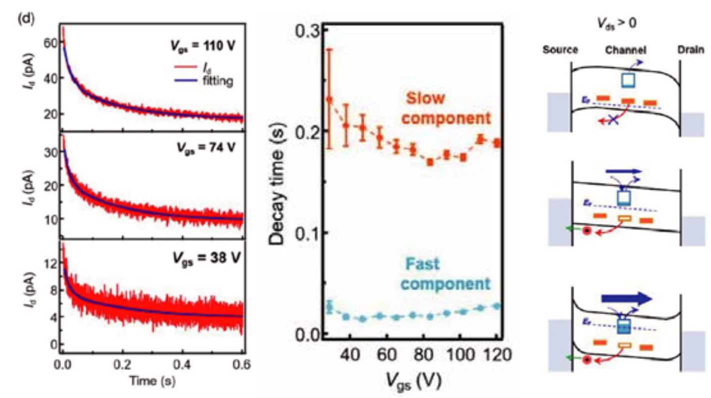


Mogi *et al*., Appl. Phys. Express **12**, 045002 (2019).

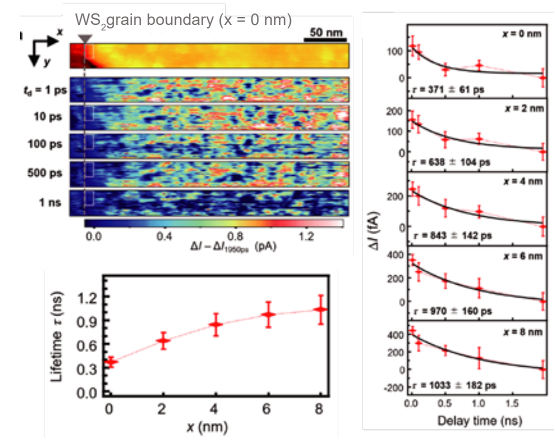
■ Exciton dynamics of monolayer TMDC nanostructures



■ Trap level dynamics of monolayer TMDC



Mogi *et al*., Jpn. J. Appl. Phys. **61**, SL1011 (2022).

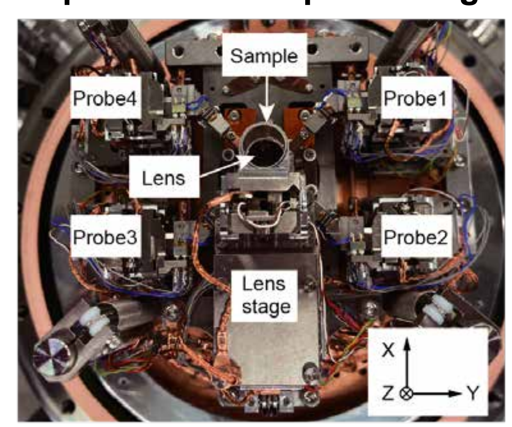


Mogi *et al*., npj 2D Mater. Appl. **6**, 72 (2022).

Basic specifications of time-resolved multiprobe microscopy

Vacuum level	UHV
Measurement temperature	Room temperature (Low temperature is optional)
Number of probes	4
STM scan range	2 um×2 um
Sample stage travel distance	X, Y: ±2 mm
Probe stage travel distance	X. Z: ±2 mm, Y: ±4 mm,
Lens stage travel distance	X: -12 mm ~ +1.5 mm Y: ±2 mm Z: ±2 mm
Light incident angle	Normal to the sample surface
Lens	Aspheric lens (NA: 0.3)

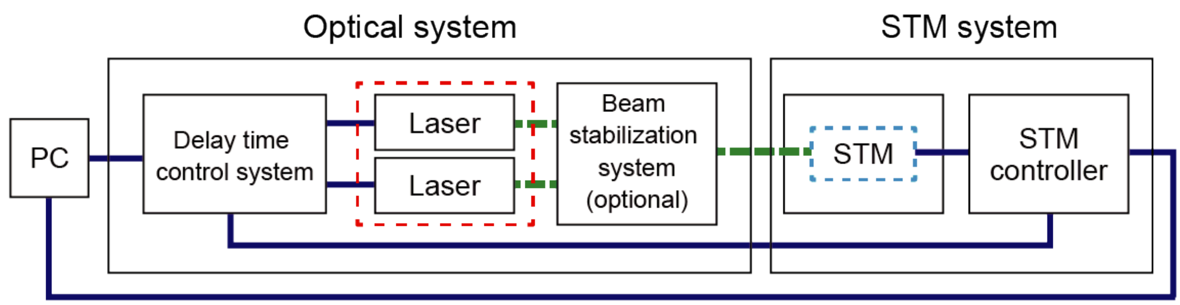
Top view of multiprobe stage



Specifications of the light source unit are described on page 2.

Various combination of STM and laser systems

Various laser and STM system combinations are available depending on the application.
Please feel free to contact us.



Laser

*Available wavelengths are subject to change.

	Picosecond system	Nanosecond system
Pulse width	35 ps	6 - 39 ns
Wavelength*	532, 775 nm	405, 450, 488, 520, 640, 785, 820 nm
Repetition frequency	532 nm: 0.05-1 MHz 775 nm: 20-80 MHz	MAX. 10 MHz

STM

	STM (single probe)	Multiprobe
System model	USM1200 (ultra-low He consumption) USM1400 (standard) USM1800 (cryogen free)	Room temperature USM1400 (UHV or in the air) Low temperature USM1400

Please feel free to contact us
if you are considering incorporating the optical system into your existing STM.

USM1200

USM1400

USM1800

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