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6C-3-2

Development of Electron Projection Lithography using Wafer-Size nc-Si Surface Electron Emitter

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Background and Purpose

Massively parallel EBL system is attractive for advanced lithography

⇒ ***Key issue:*** *development of emitter which meets the requirements.*

We have developed nanocrystalline Si (nc-Si) **ballistic cold cathode:**
Appl. Surf. Sci. 146, 371 (1999)

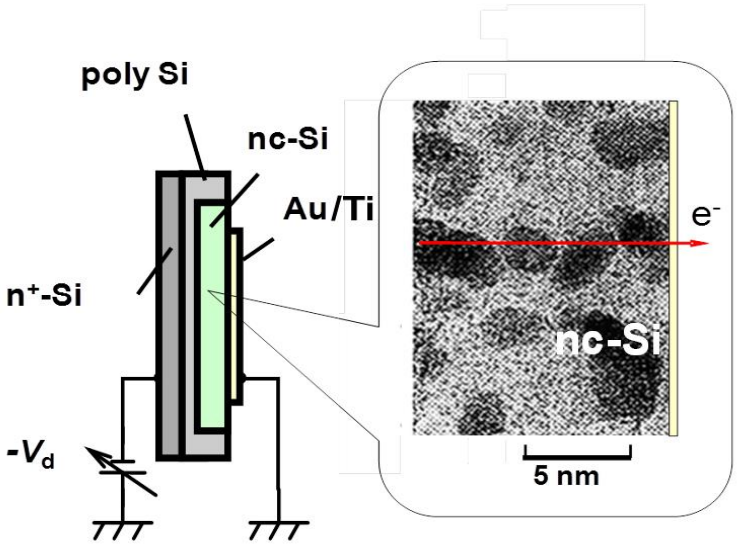
(1) Uniform, Energetic, Directional, and Planar emission.
(2) Capability of high speed switching with a low driving voltage.
(3) Small energy dispersion of emitted electrons.

These features are compatible with Massively Parallel exposure**:**
JVST B 31, 06F703 (2013)

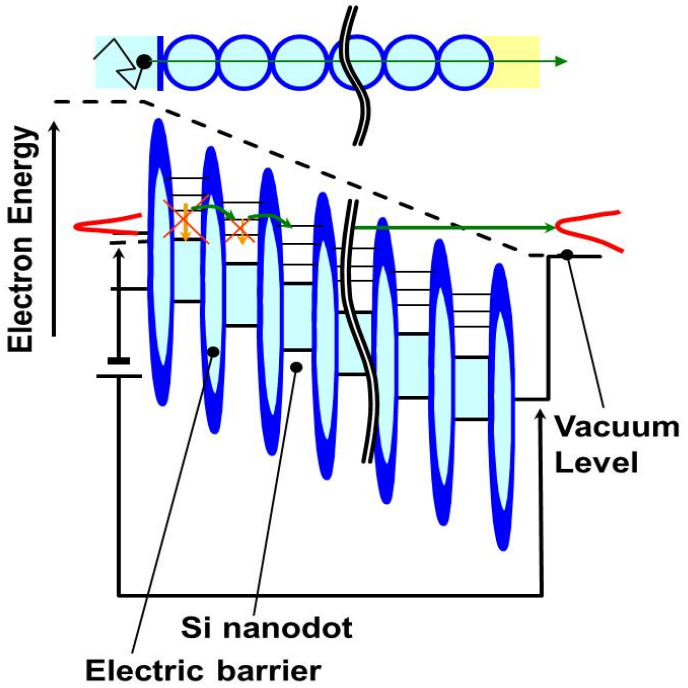
This work

- Fabrication of a 4”-diam nc-Si emitter with patterned emission windows.
- Evaluation of the emission characteristics including the uniformity.
- Application to 1:1 electron projection lithography.

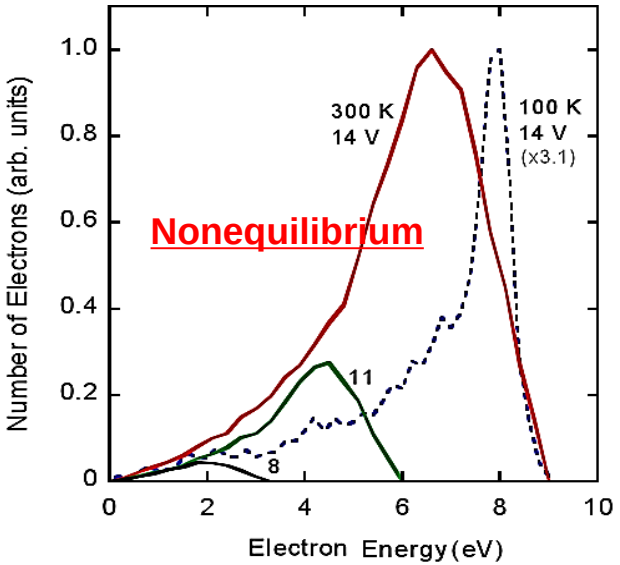
nc-Si surface electron emitter & ballistic emission mechanism



Emitter structure and TEM image of nc-Si dots



Model of ballistic hot electron generation and emission: Appl. Phys. Lett. 98, 062104 (2011)



Output electron energy distribution: Appl. Phys. Lett. 81, 2472 (2002)

When a positive bias voltage is applied to the surface electrode with respect to the substrate, electrons are accelerated by cascade tunneling without suffering serious energy loss.

Features and Possible Applications

	nc-Si emitter	Conventional FED
Energy	**5 ~7 eV**	~ k*T*
Angle	**Directional**	**Dispersive**
Mode	**Surface**	**Point**
Media	**Vacuum, Air, Solutions**	**only in High vacuum**

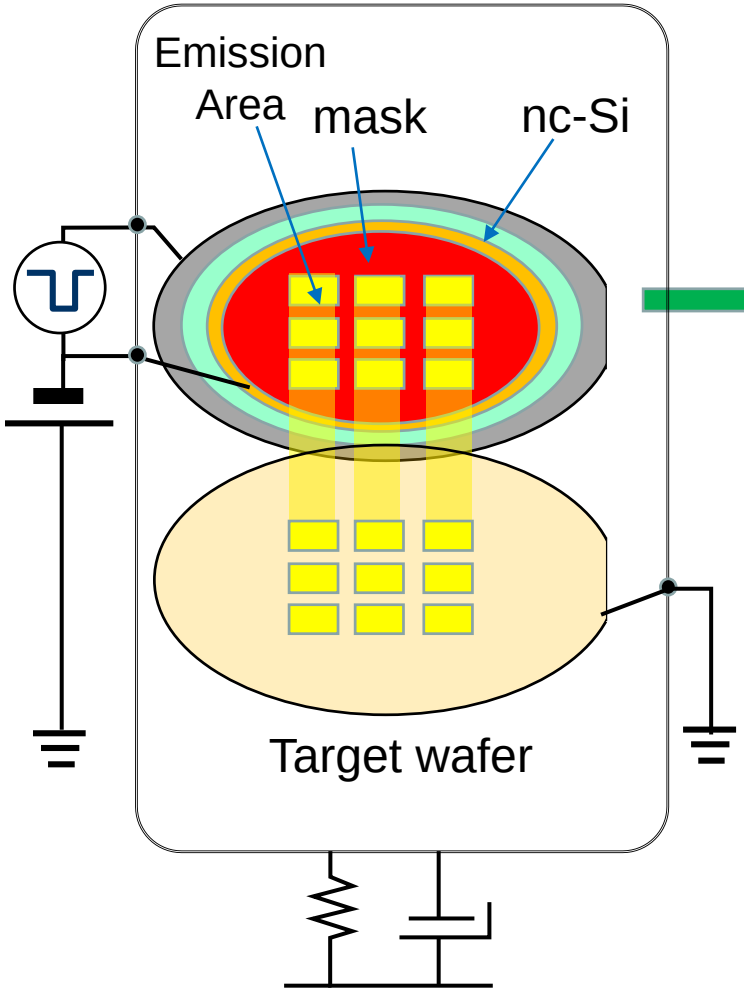
☆ Vacuum : Flat Panel Display (SID, 2004)
Parallel EB Lithography (JVST, 2008)
Night Image Pick-up (JVST, 2008)

☆ Gases : Negative Ion Source (Air) (JVST, 2007)
VUV Emission (Xe) (JVST, 2009)

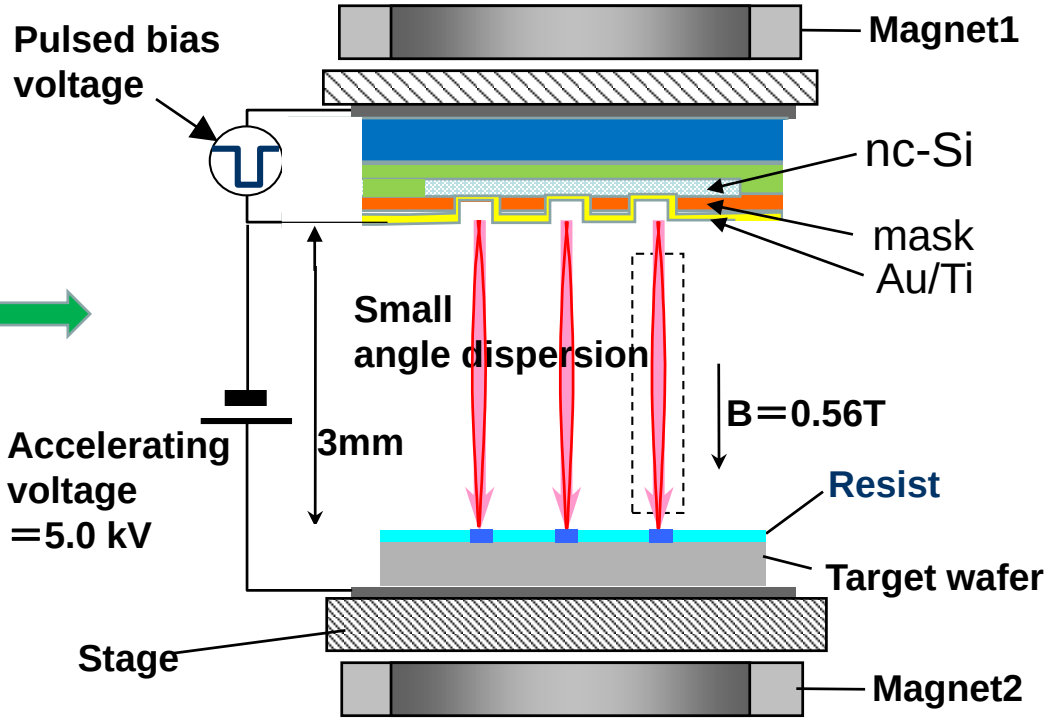
☆ Solutions : H_2 generation and pH control (APL, 2007)
Thin Films (EESL, 2010; APL, 2013)

***Evaluation of the electron emission characteristics in the large area of the emitter**

EB Projection Lithography using Wafer-Size nc-Si Surface Emitter
(Surface Electron Emission Lithography)



The vacuum chamber with anti-vibration mount



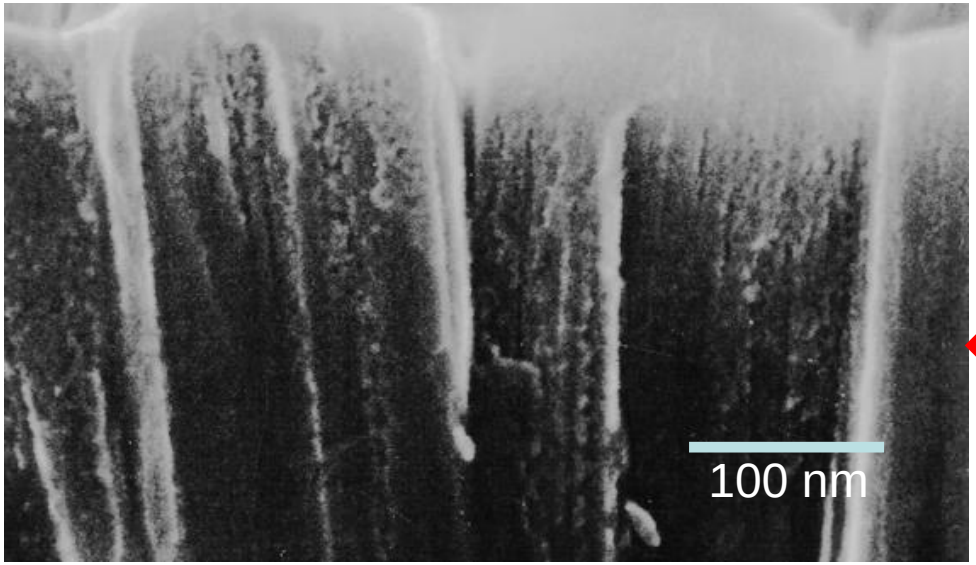
The electron beam through the window of the patterned mask strikes the resist on the target.

⇒ Replica of the pattern

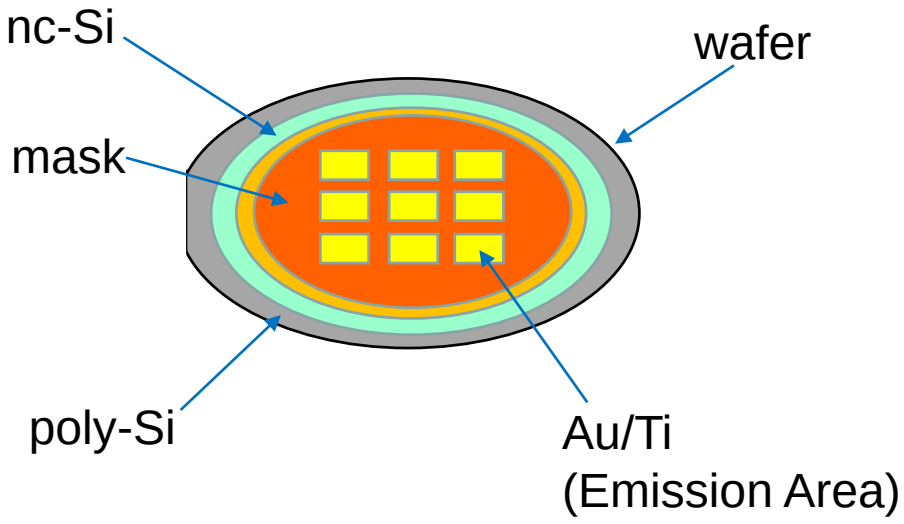
Resolution : $R = r\omega\Delta t = \sigma_v \Delta t = \sigma_v [\sigma_v/(eE/m)] = m\,\sigma_v^2/eE$

σv: deviation of initial electron velocity

Fabrication Process of Wafer-Size nc-Si Surface Electron Emitter

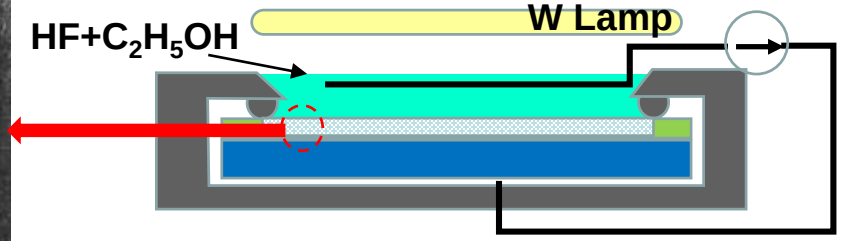


SEM Image of the cross-section of the nanocrystalline Si(nc-Si) Layer



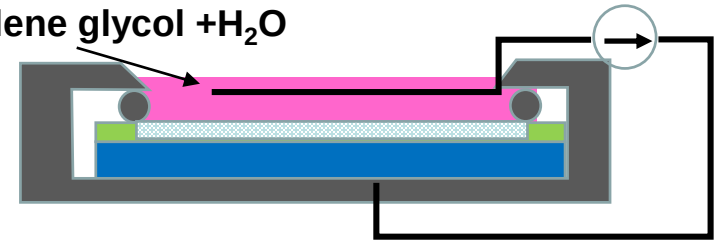
1. Poly-Si layer deposited on n++Si substrate (The surface was polished by CMP)

2. Anodization to form nc-Si layer

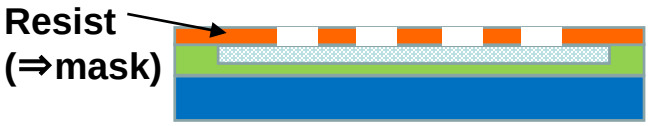


3. Electrochemical Oxidation of nc-Si layer

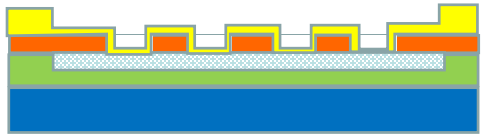
Ethylene glycol +H_2O



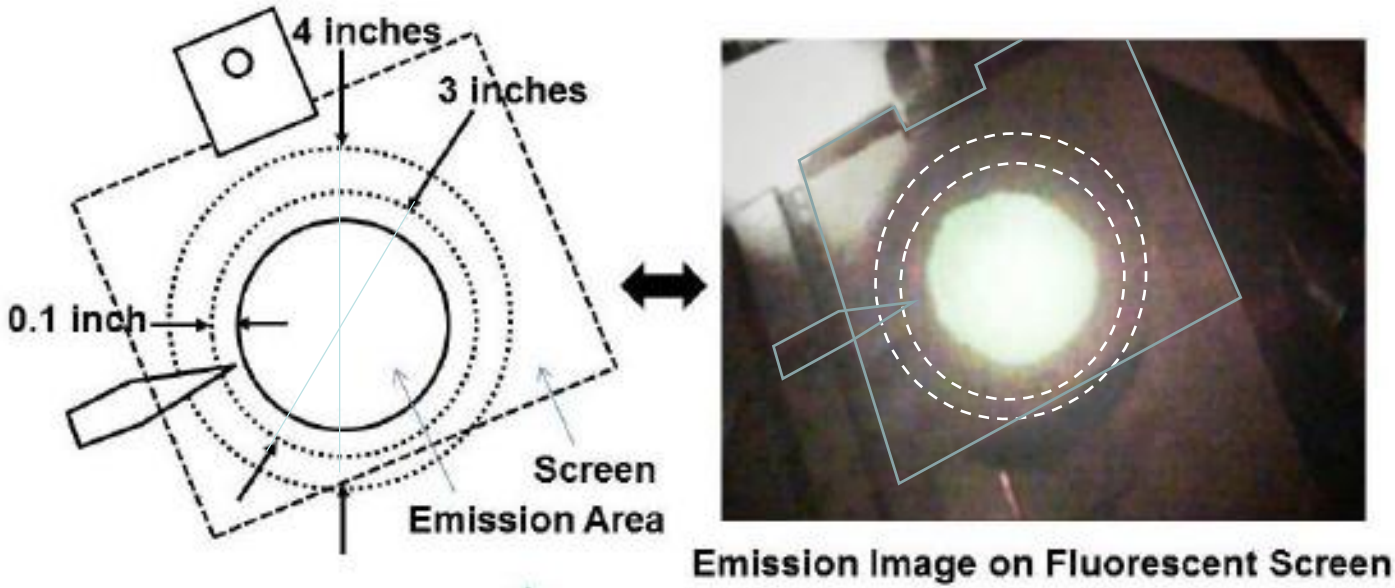
4. Resist coating & patterning (EB direct writing or photolithography)

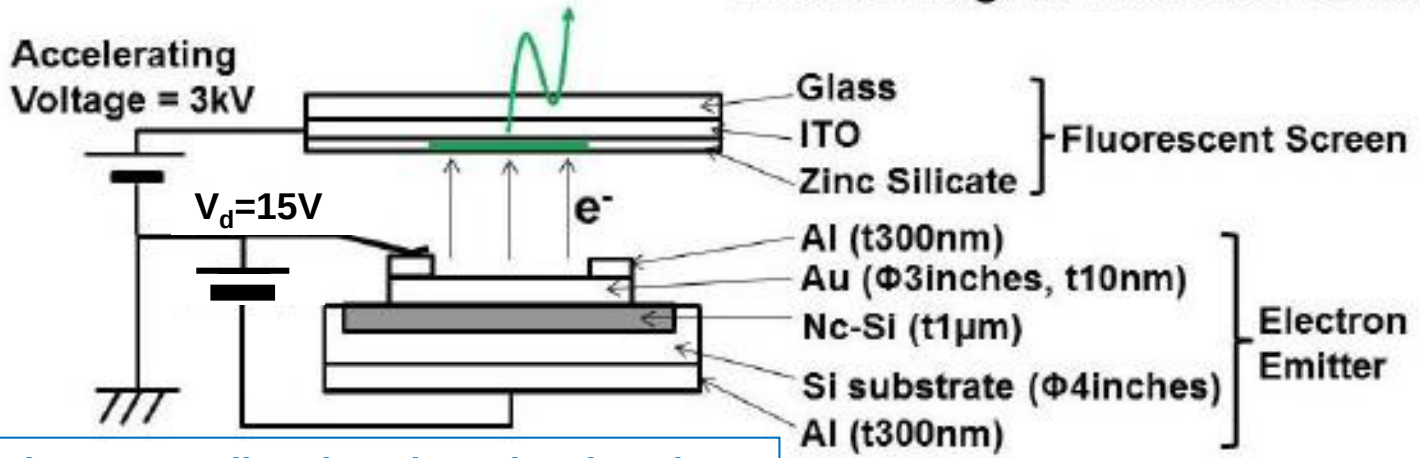


5. Surface Electrode deposition with RF sputter



Observed 4”-emission image on fluorescence screen

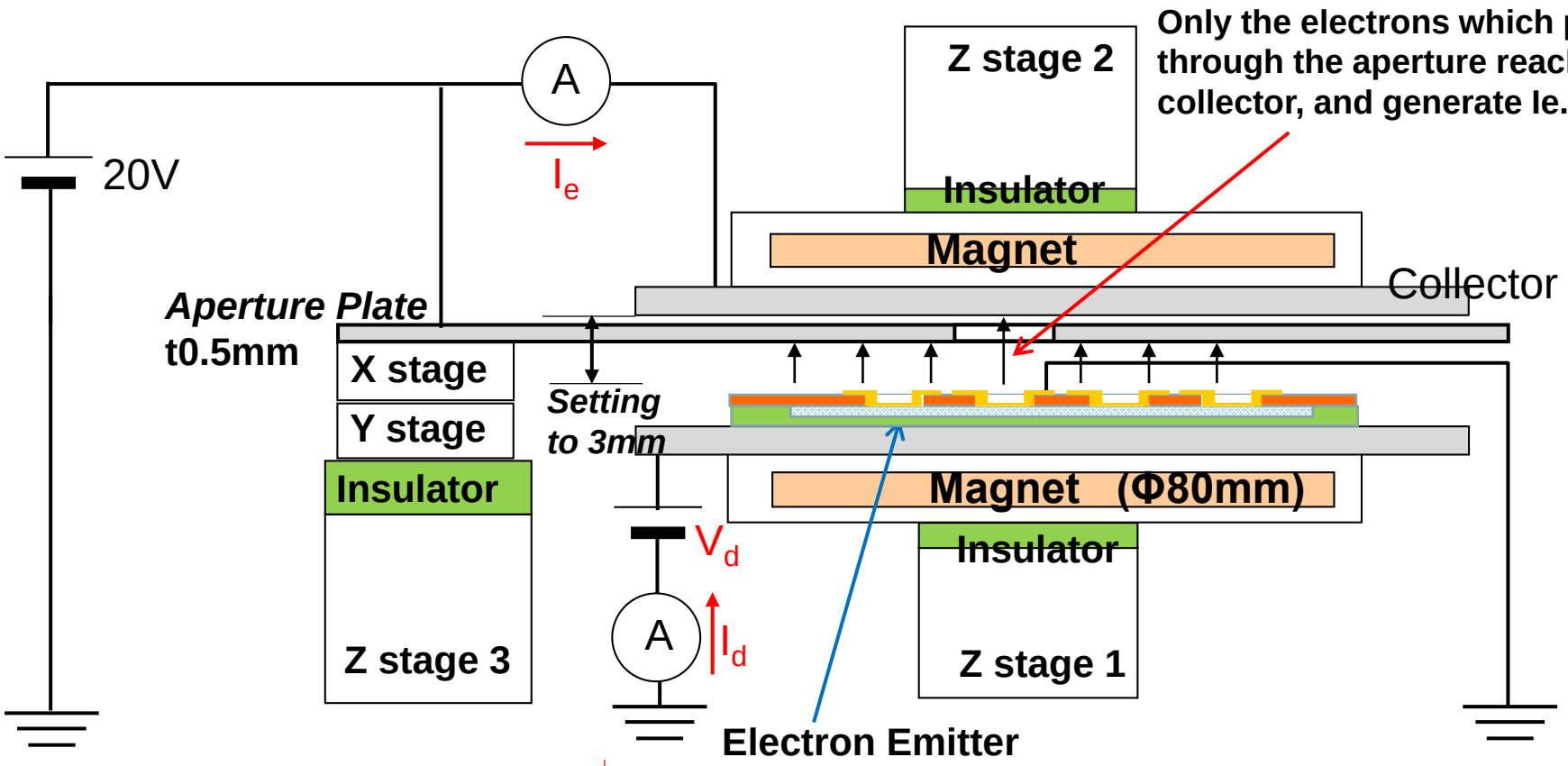




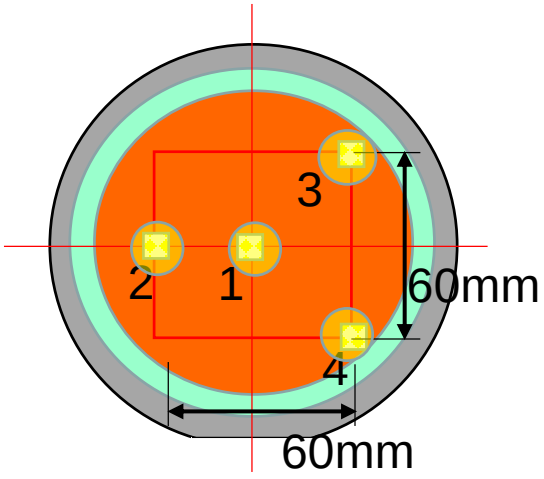
The surrounding ring-shaped pad apply voltage to the surface electrode uniformly.

*The emission current of about 400uA was obtained with Vd of 15V.

Confirmation of the emission uniformity

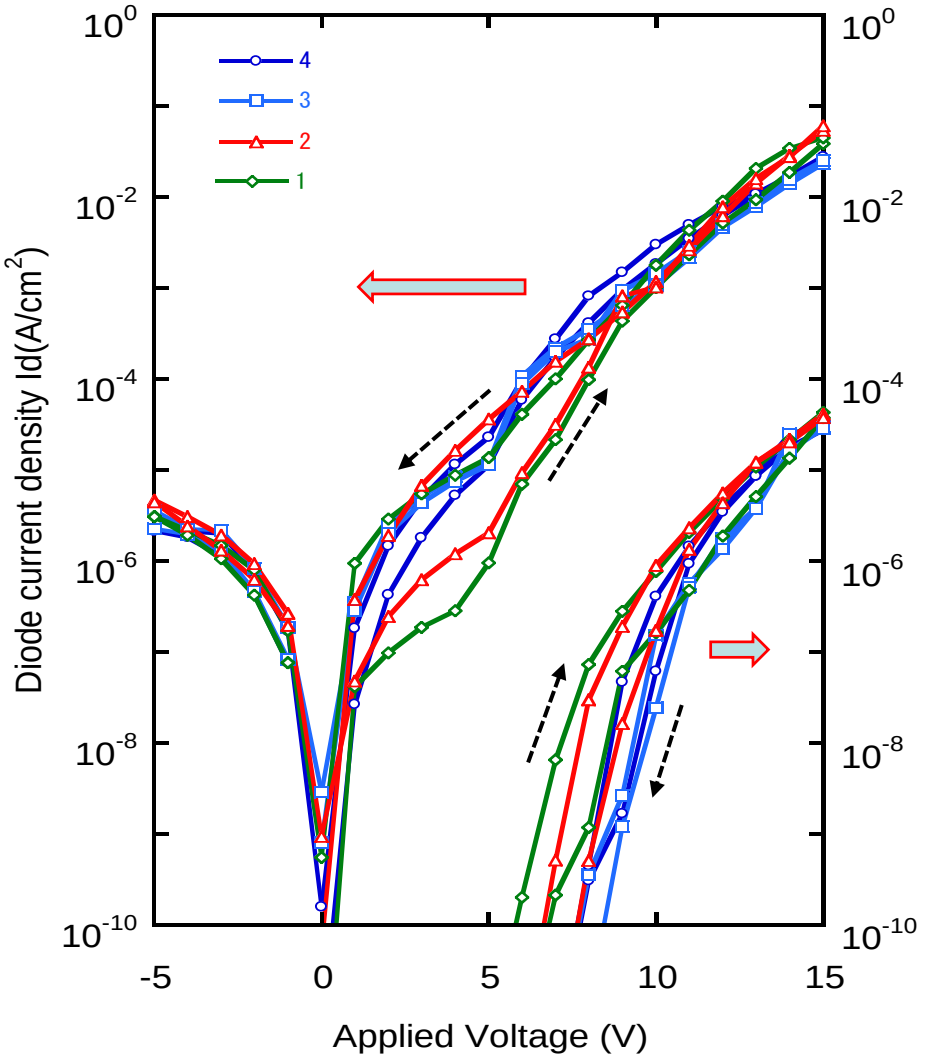


*Measurement of the magnetic field intensity on four position.

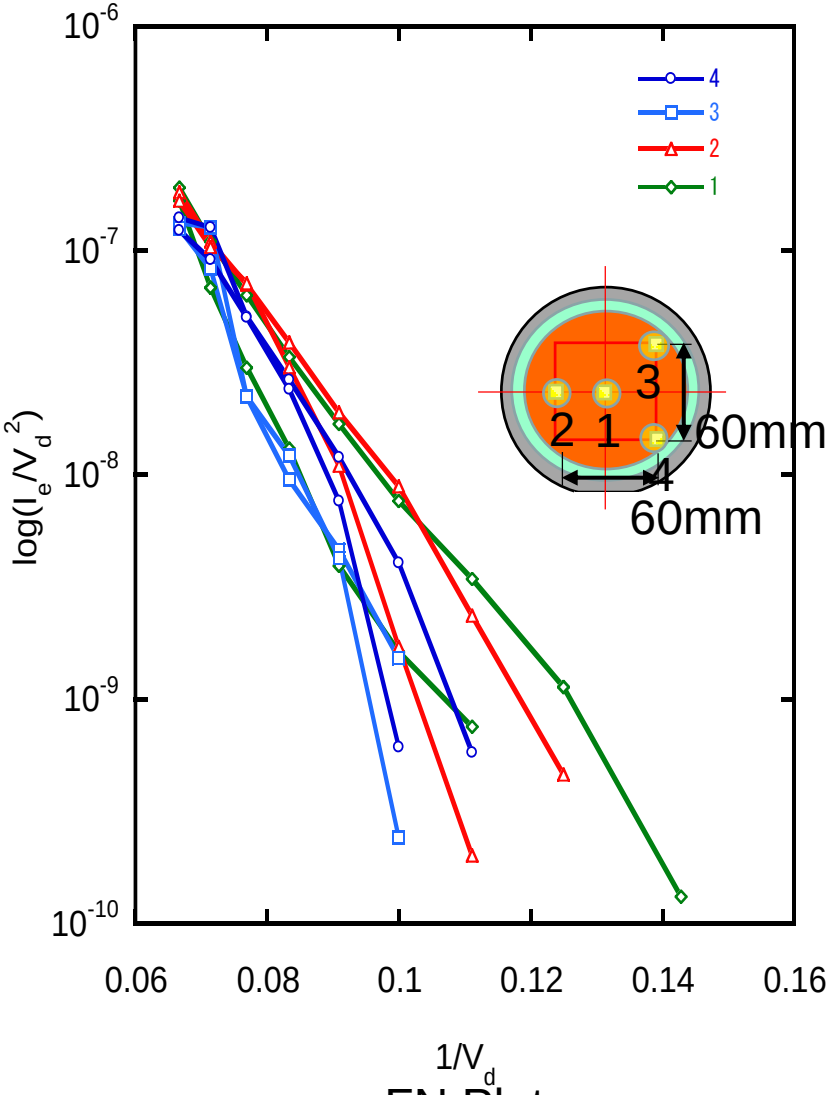


Position	Magnetic Field (T)
1	0.56
2	0.56
3	0.54
4	0.54

Electron Emission Characteristics at 4 points on the emitter:



IV & Emission

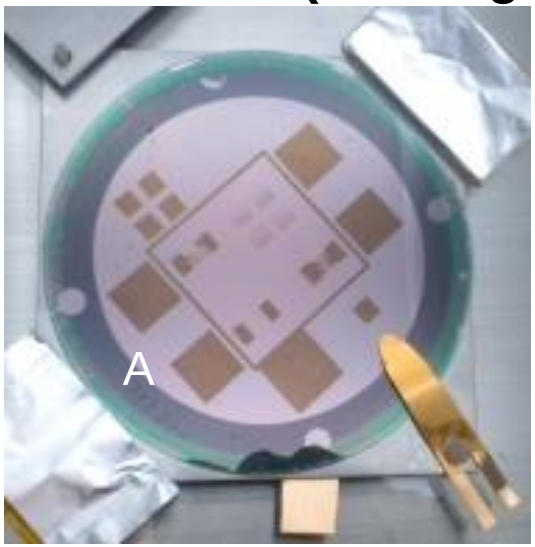


FN Plot

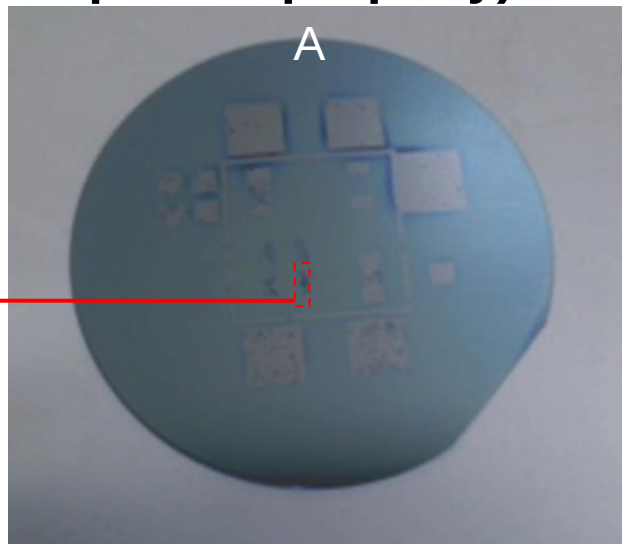
The variation of the amount of emission current among the points under the applied voltage of 15V was about 30%.

FN plot :Linear ⇒ The electron is transported by the FN type tunnel effect inside a nanosilicon layer.

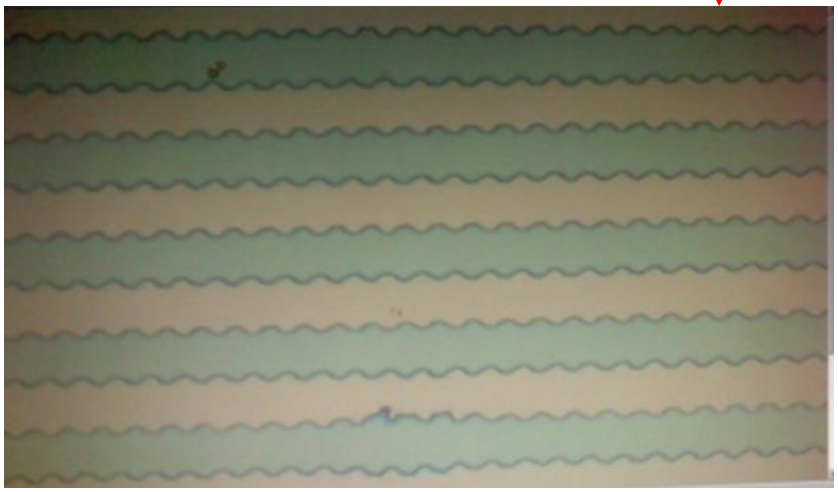
Exposure Results 1: Large pattern (3um～16mm)
(Investigation of exposure property)



Surface Electron emitter



Target Wafer exposed by the emitter

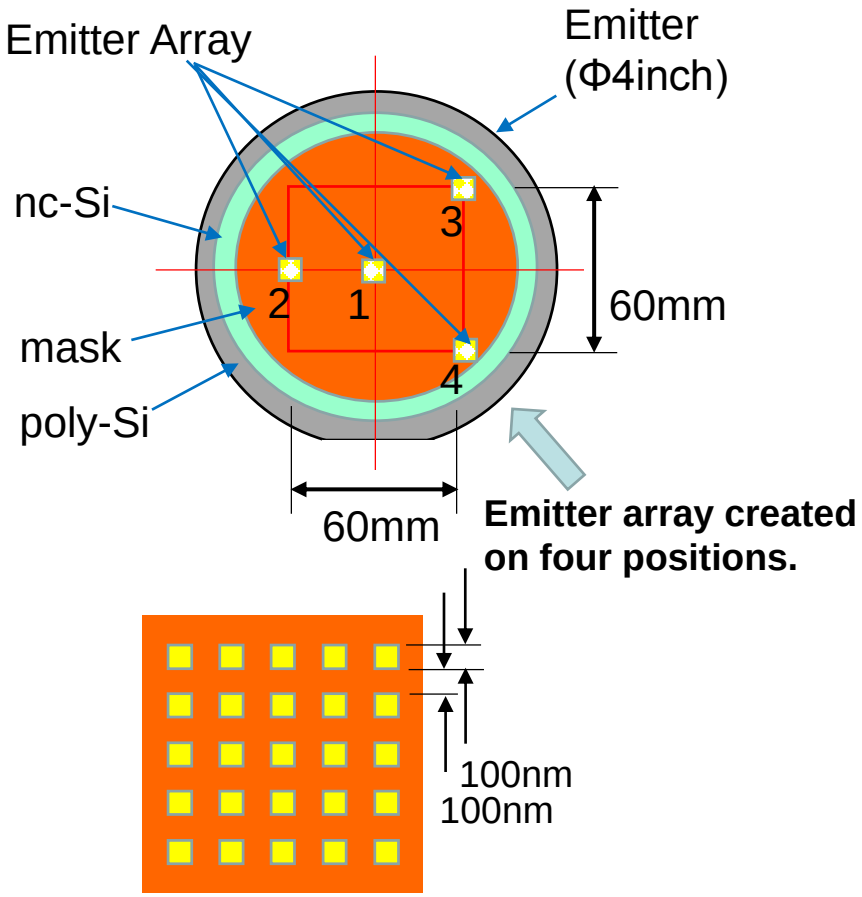


Exposed pattern of the micron order

Line width:10um, Wavelength:5um
ZEP520A :t80nm
Exposure time :0.5s
Estimated Electron dose:
25μC/cm^2
Acc. Voltage:5kV

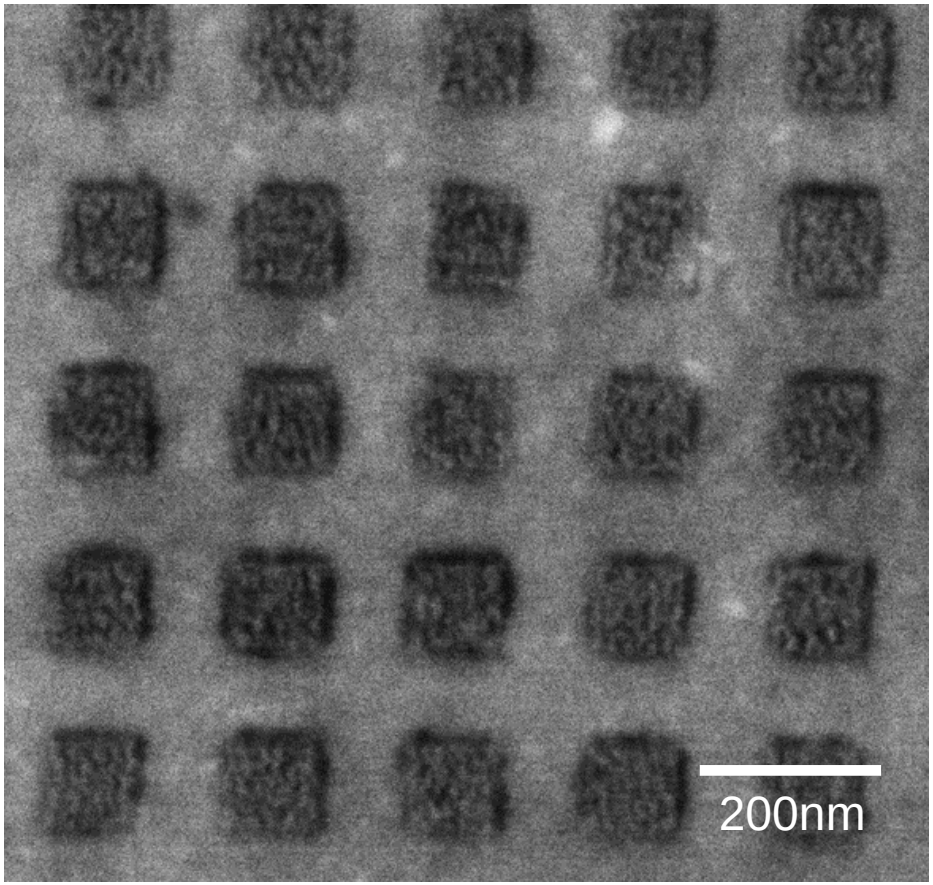
- **Uniform and Low-distortion exposure**
- **This emitter can expose patterns of various sizes on whole wafer simultaneously**

Wafer-size emitter to expose fine pattern over the target wafer (Investigation of exposure property)



Configuration of the emitter array

Each emitter array correspond to the emission area where the emission current was measured previously.

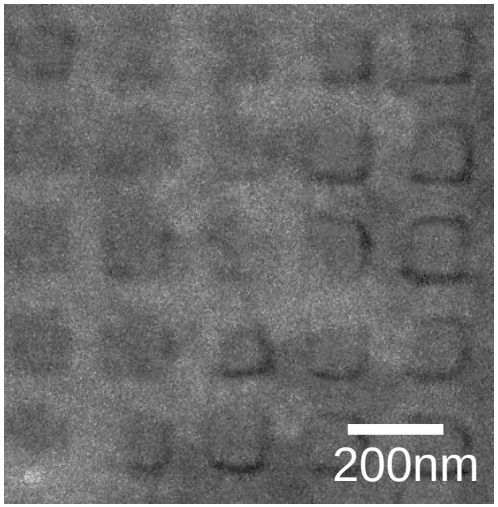


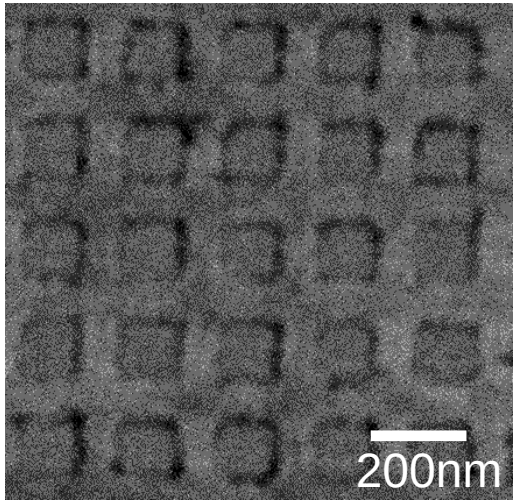
One of 5 × 5 Emitter Array

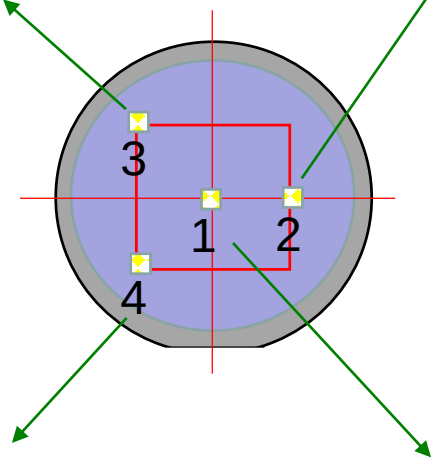
***The microscopic structures of the nc-Si are observed in the rectangular emission region.**

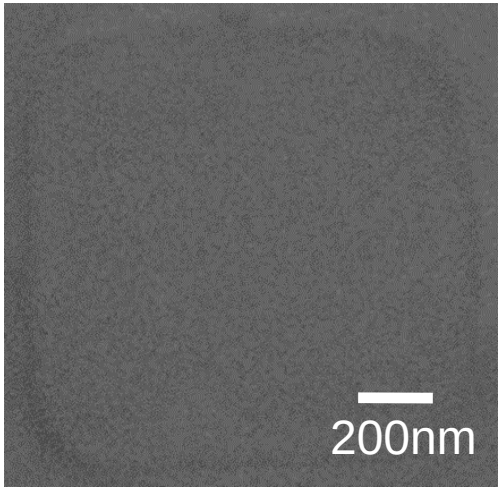
Exposure Results 2: Fine pattern (100nm square dot & space)

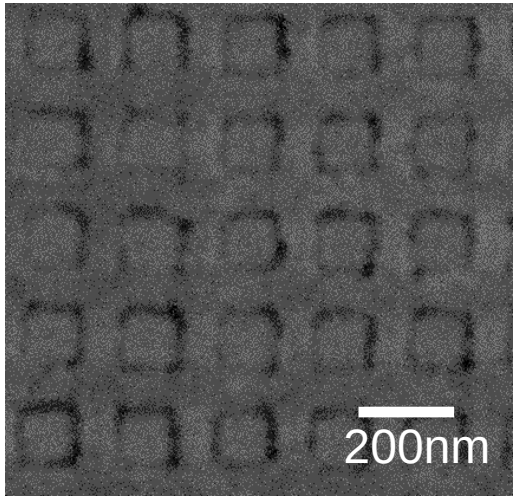
(Investigation of exposure property)











ZEP520A :t80nm
Exposure time :0.5s
Electron dose
(at position
1):25μC/cm^2
Acc. Voltage:5kV

Summary

- Dot & space patterns of 100 nm ~ 1000 μm were exposed in parallel over a large area using 4”-diam nc-Si planar ballistic cold cathode.
- Due to energetic, directional, and uniform emission, this effect is potentially useful for direct one-shot projection of nano-micro patterns on the target.

Future Work

- Device fabrication for improvement in resolution toward 10 nm.
- Development of direct projection EB lithography over a further enlarged surface area.

Acknowledgement

This work is granted by JSPS through First Program initiated by the Council for Science and Technology, and supported by Nanotechnology Platform of MEXT, Japan, at the Center for Integrated Nanotechnology Support, Tohoku University.

Thank you for your attention.