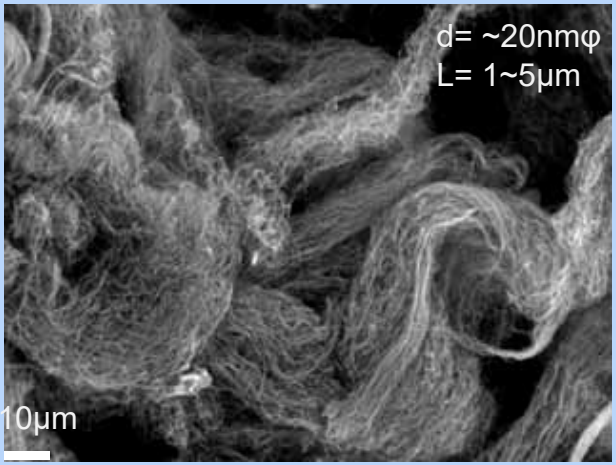
Tribological Property and Biocompatibility of Titanium Plate Coated with Carbon Nanotubes

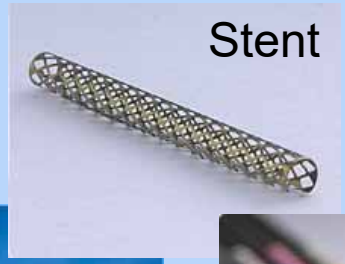
Carbon nanotube



- Superior self-lubrication
- High yield stress
- High Young's modulus
- High electrical & thermal conductivity

Naturally uniform as bundles due to van der Waals forces

Titanium



Boeing 787 Dreamliner

- High strength
- Good corrosion resistance
- Good biocompatibility
- Low density

Poor Tribology property contacted with other materials and Ti

Objectives

1. **Investigate tribological property and wear behavior of pure Ti plate coated with CNTs under dry sliding condition.**

① Network-structured MWCNTs coating on Ti plate.

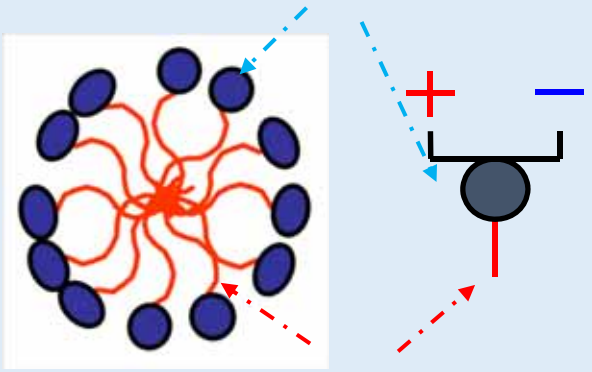
② Analysis on interface between CNTs and Ti substrate.

③ Effect of annealing temperature on tribological behavior of CNTs coating films.

2. **Investigate the biocompatibility of pure Ti plate coated with CNTs.**

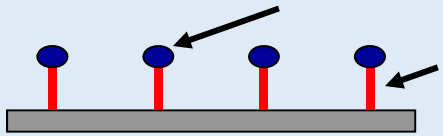
CNTs bundle disassemble in zwitterionic surfactant solution

"Heads"; hydrophilic



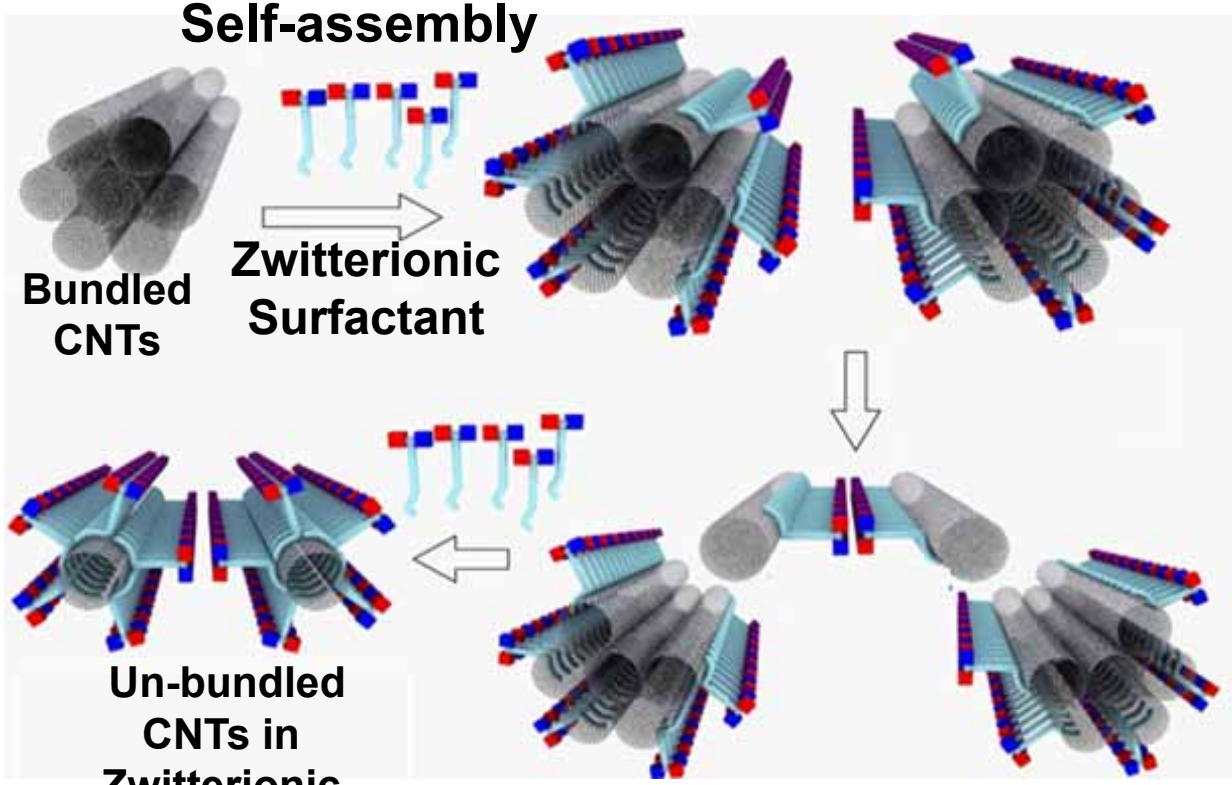
"Tails"; hydrophobic

Headgroup

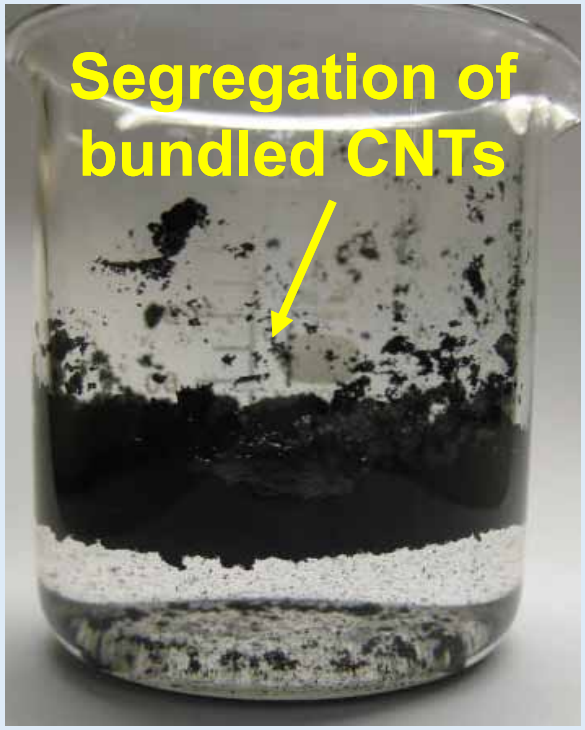


Tail

CNT



CNT dispersions



CNTs distributed in water after ultrasonic vibration

CNTs distributed in water with surfactants

Preparation of specimen

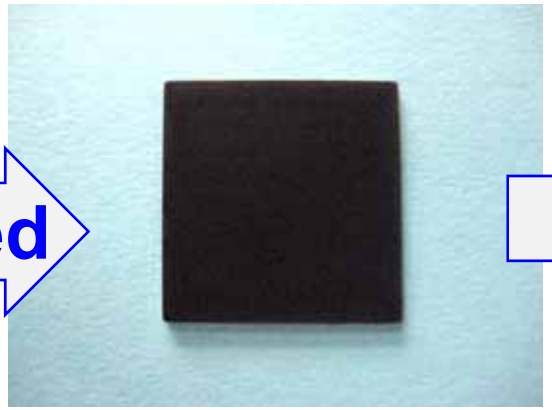
Pure Ti plate

Dipped

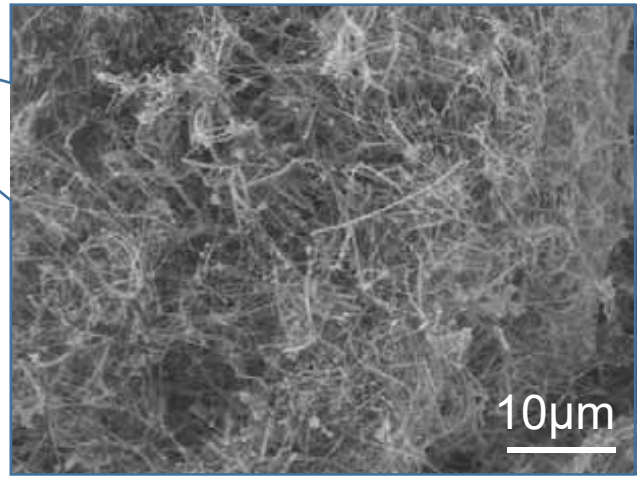
Surfactant solution with un-bundled CNTs

Annealed

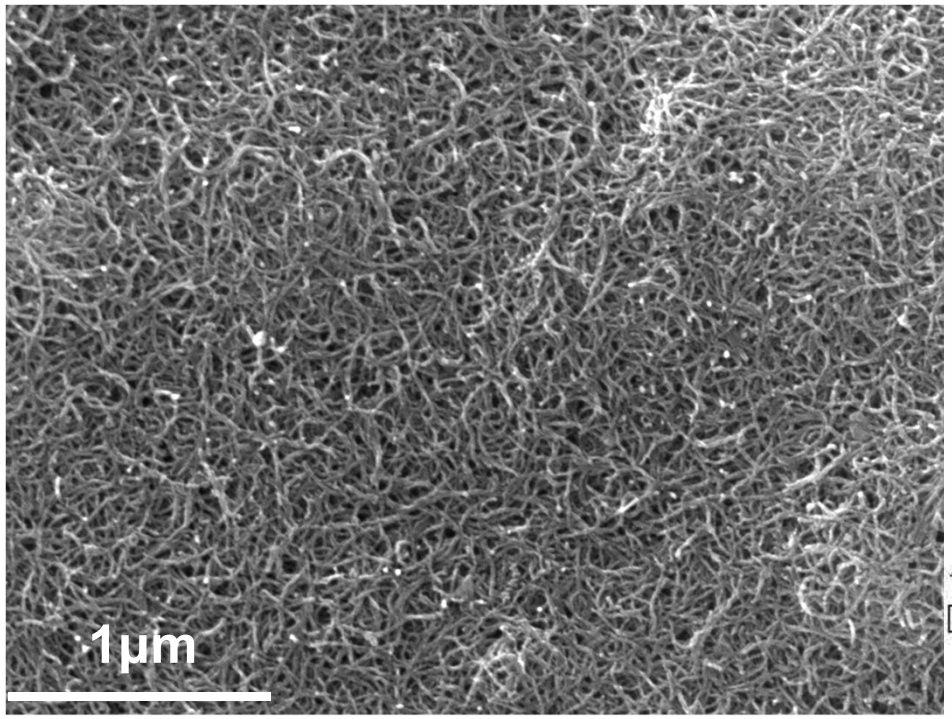
Coated with un-bundled CNTs

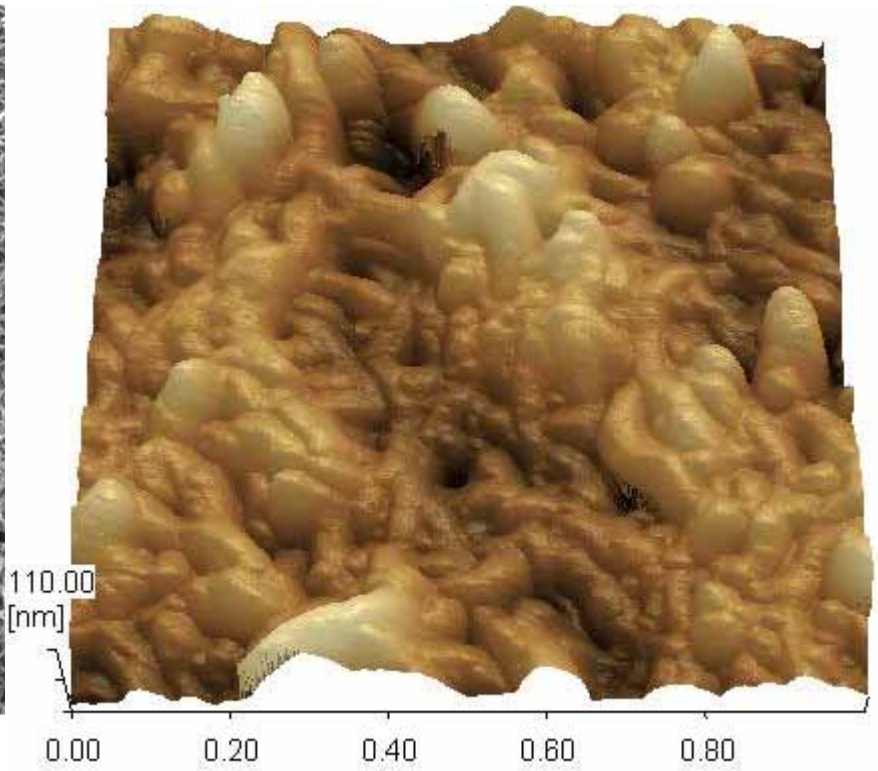


- **Ball-on-disk wear test**
- **XRD & SEM-EDS analysis**



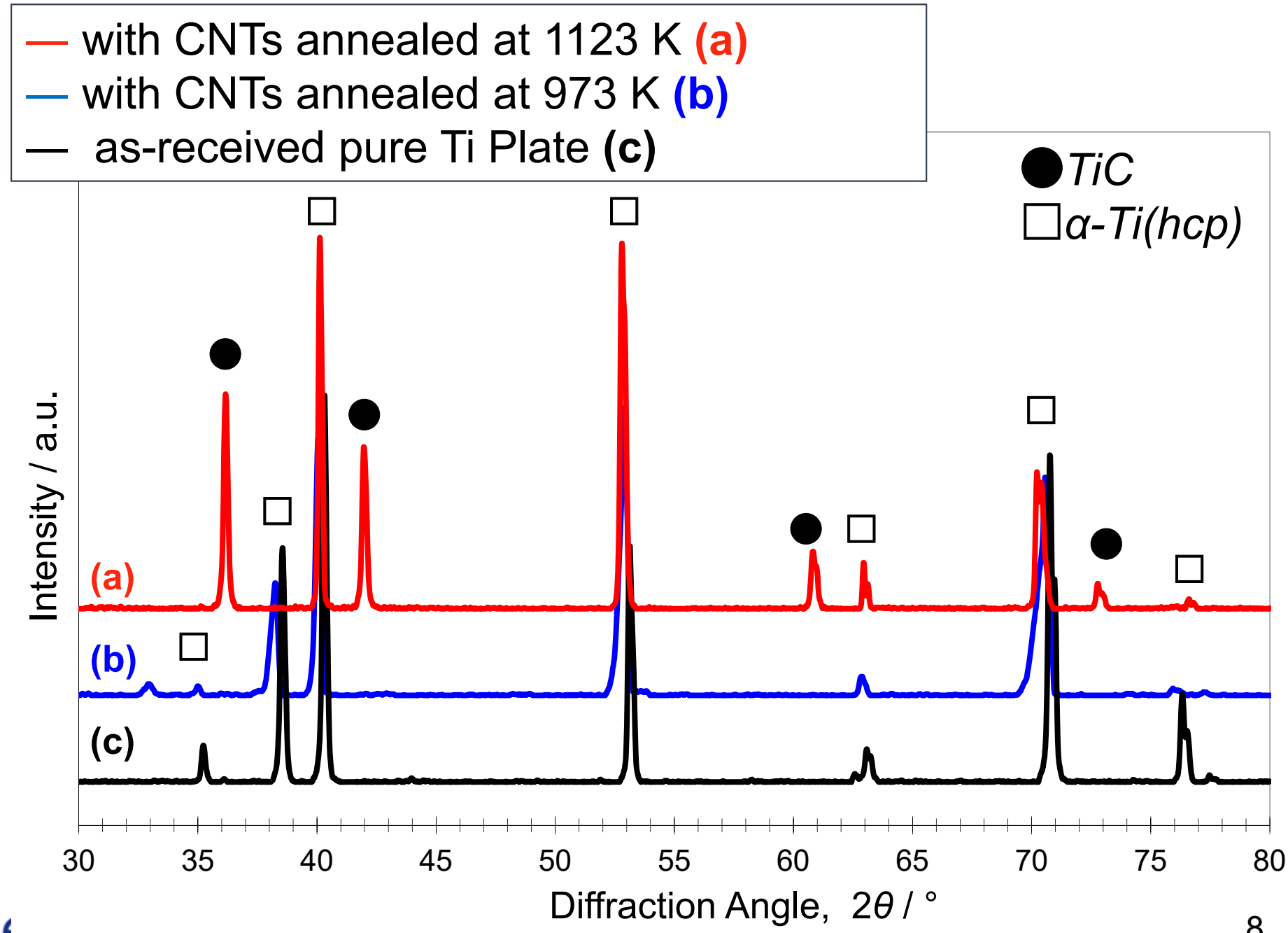
SEM and AFM observation



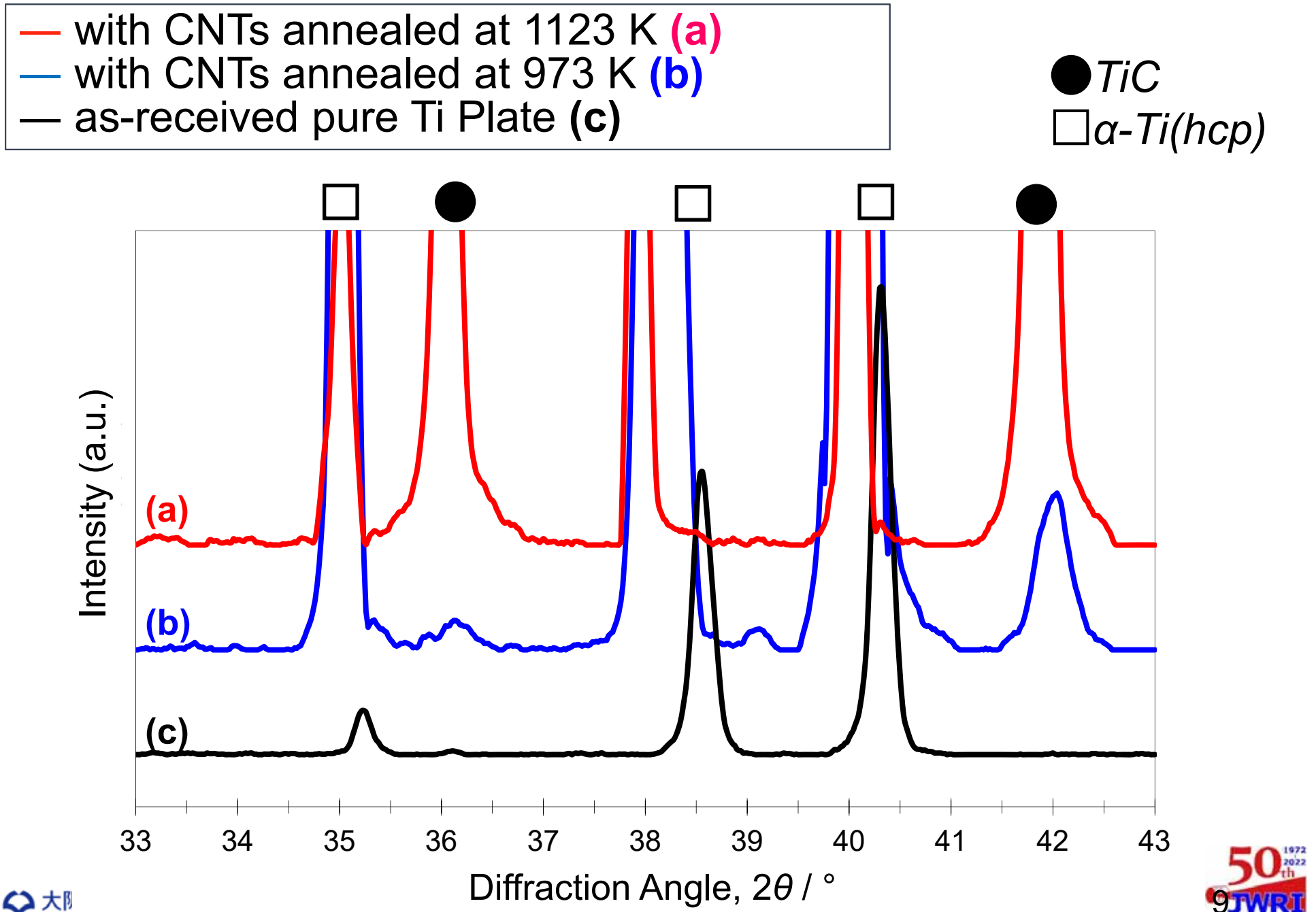


Observed by SEM & AFM on CNTs coated on pure Ti plate annealed at 1123 K

XRD result

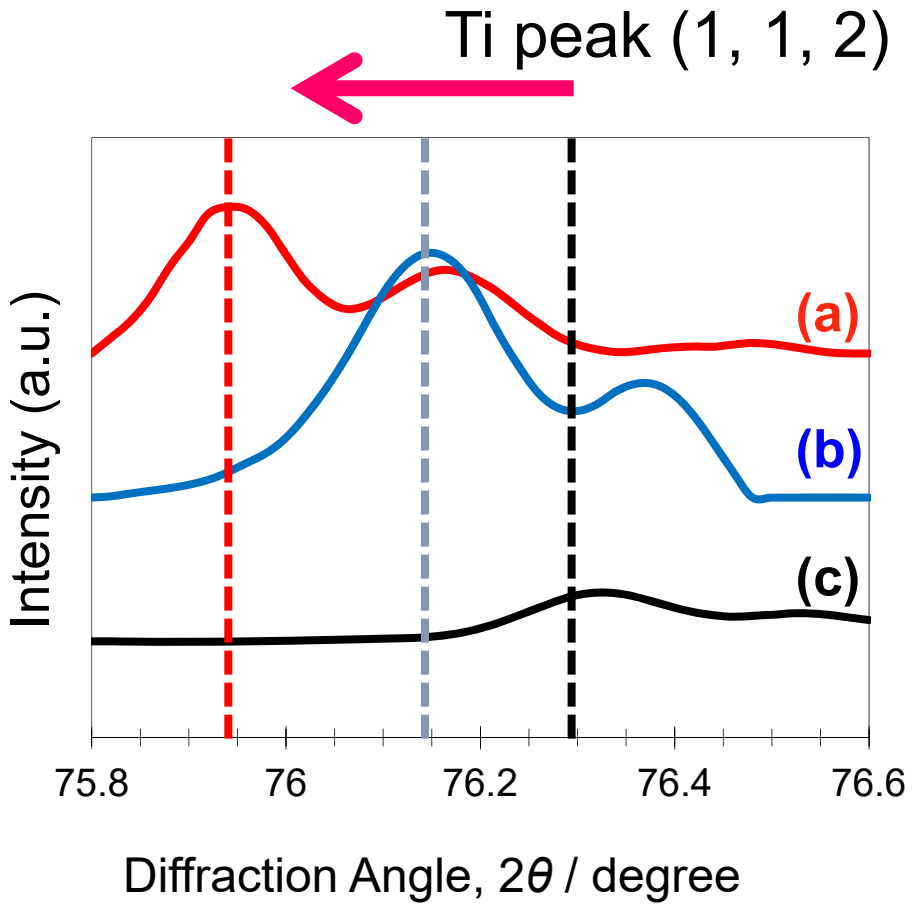

with CNTs annealed at 1123 K (a)
with CNTs annealed at 973 K (b)
as-received pure Ti Plate (c)
TiC
α-Ti(hcp)
Intensity / a.u.
(a)
(b)
(c)
30
35
40
45
50
55
60
65
70
75
80
Diffraction Angle, 2θ / °

XRD result


with CNTs annealed at 1123 K (a)
with CNTs annealed at 973 K (b)
as-received pure Ti Plate (c)
TiC
α-Ti(hcp)
Intensity (a.u.)
(a)
(b)
(c)
33
34
35
36
37
38
39
40
41
42
43
Diffraction Angle, 2θ / °

XRD result

— with CNTs annealed at 1123 K **(a)**
— with CNTs annealed at 973 K **(b)**
— as-received pure Ti Plate **(c)**

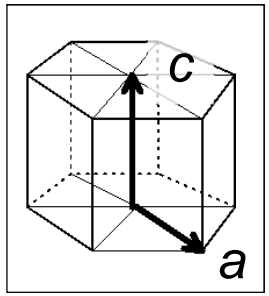


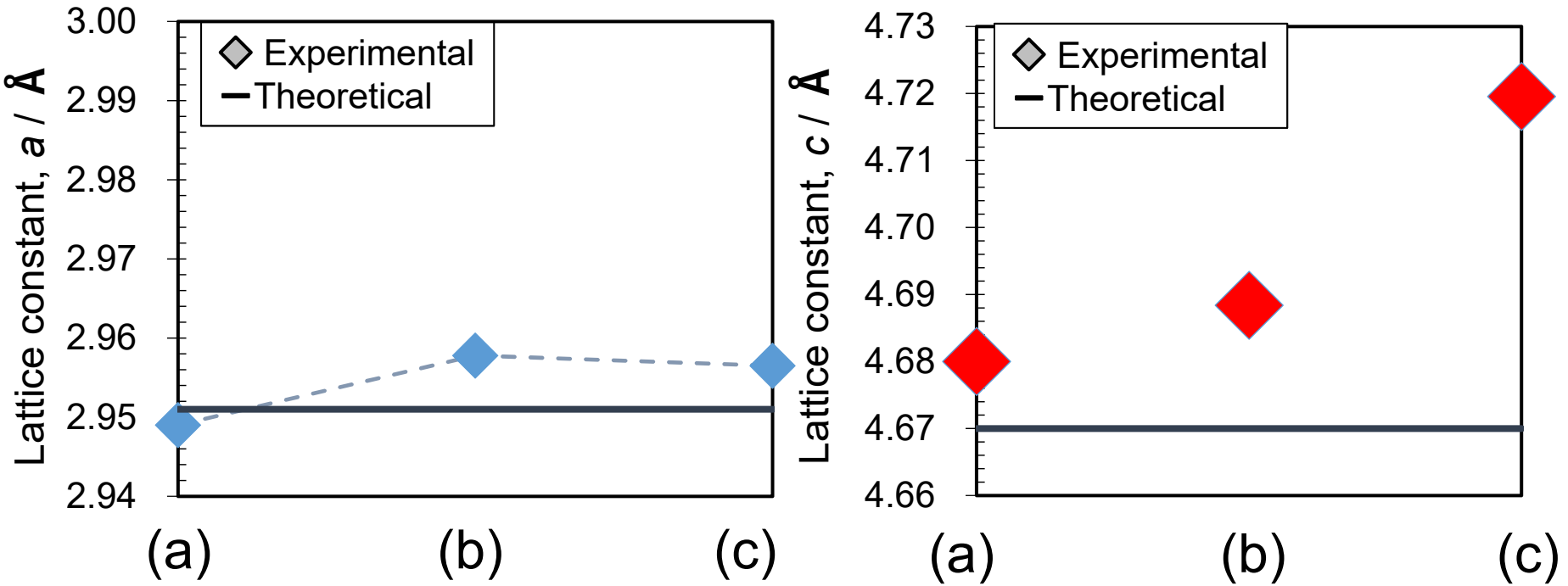
$$d = \frac{1}{\sqrt{\frac{4\left(h^2 + k^2 + hk\right)}{3a^2} + \frac{l^2}{c^2}}}$$

h, *k*, *l*: Miller indices
***a*, *c*: Lattice constant**

XRD result

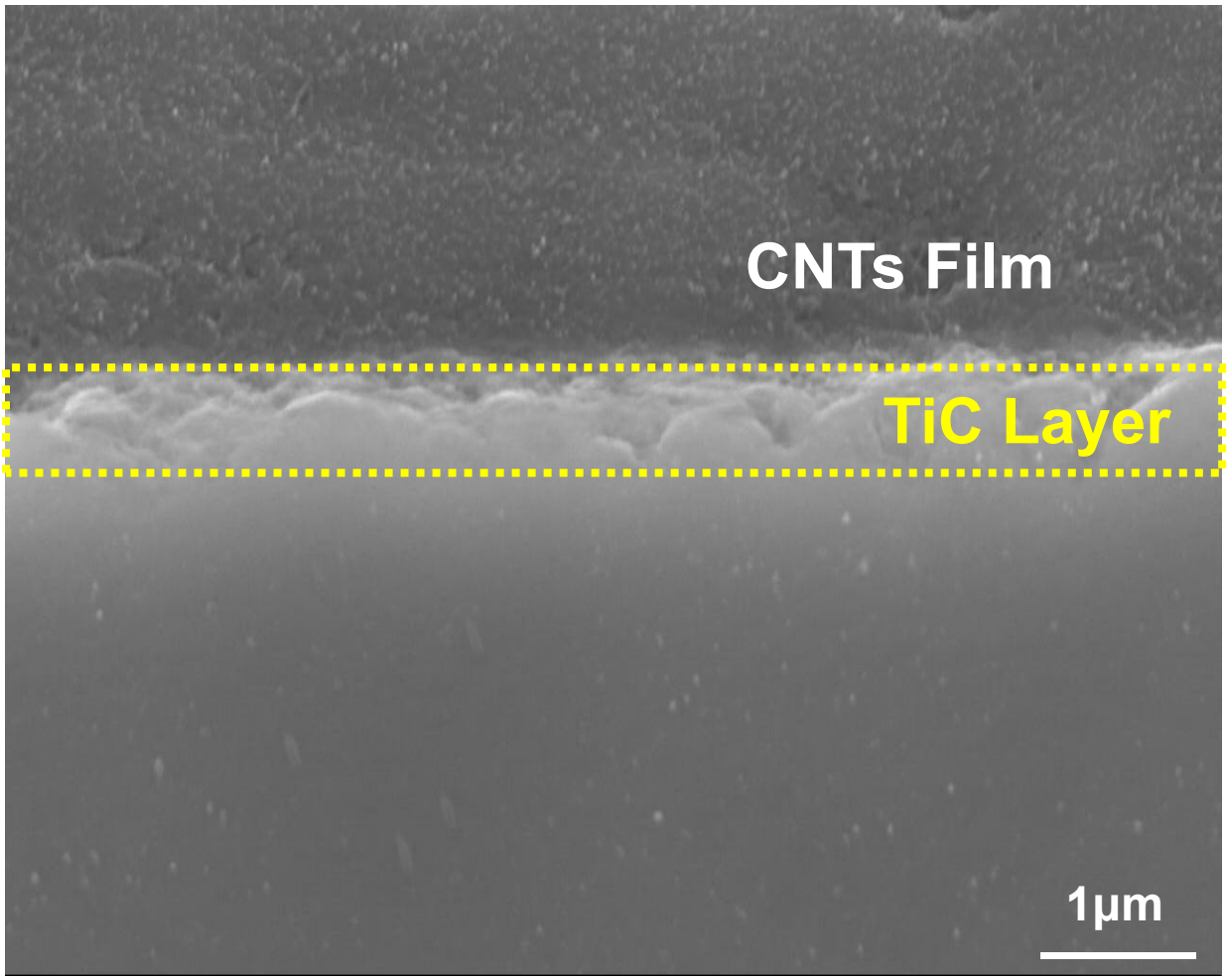
(a) with CNTs annealed at 1123 K
(b) with CNTs annealed at 973 K
(c) as-received pure Ti Plate





Relationship between lattice constant

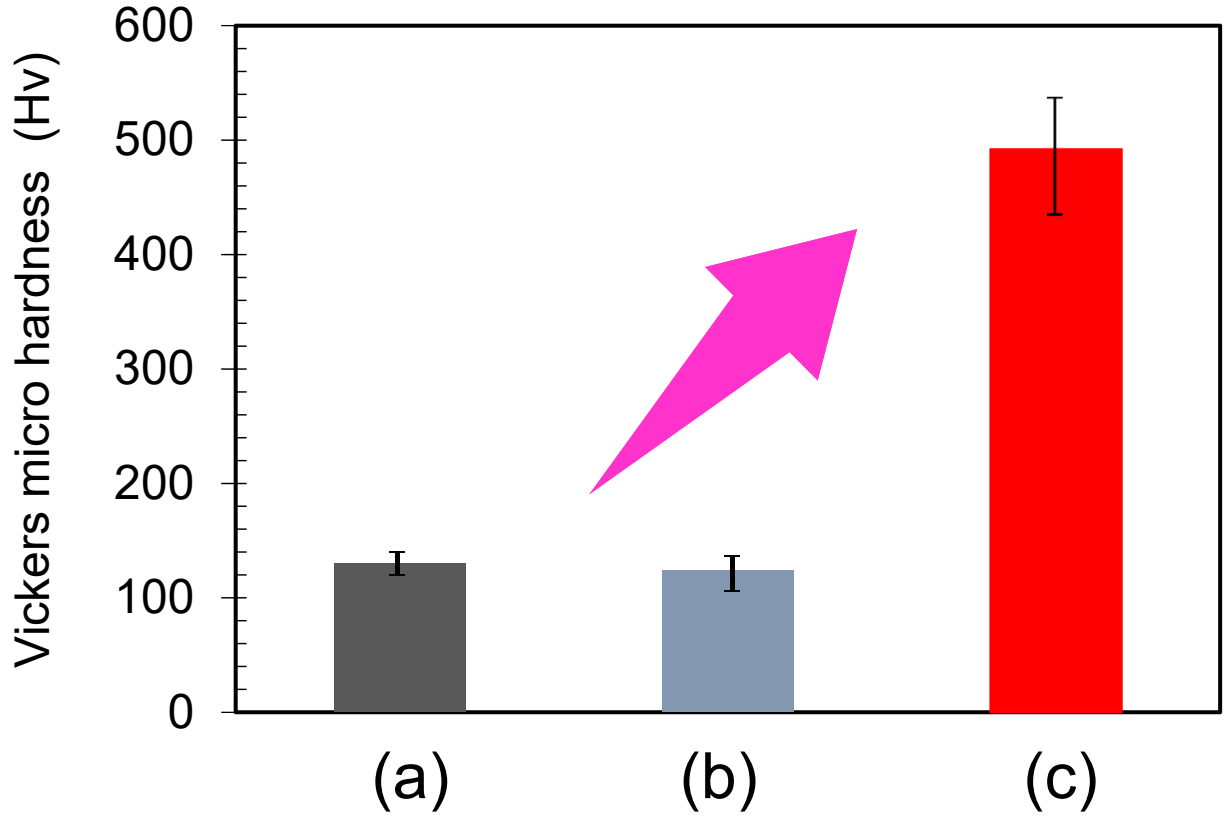
SEM-EDS analysis result

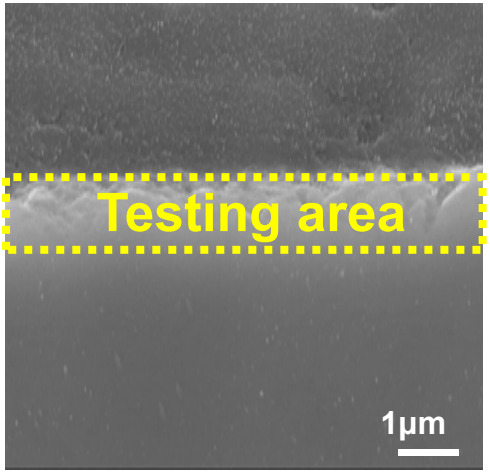


Cross-section of pure Ti plate coated with CNTs annealed at 1123 K

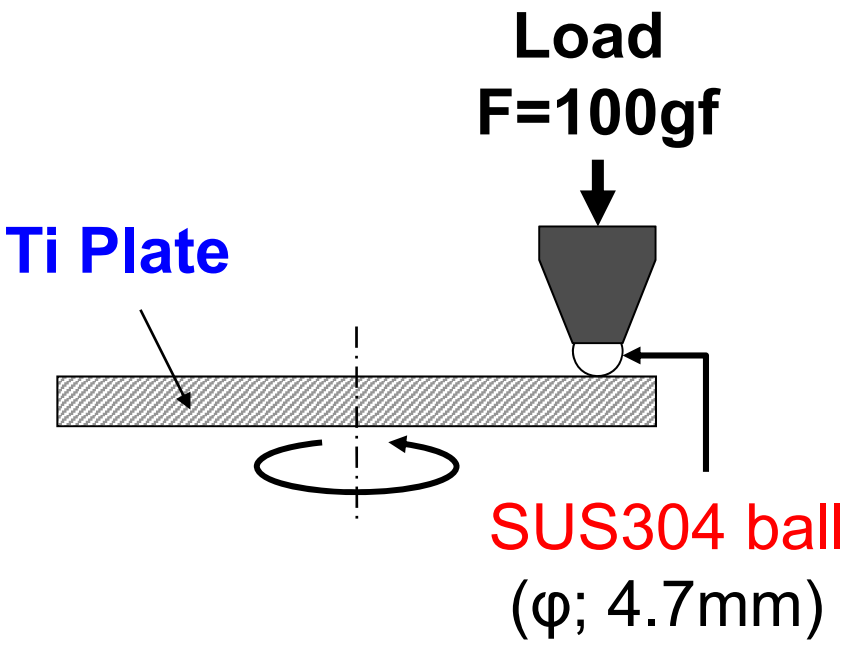
Hardness result

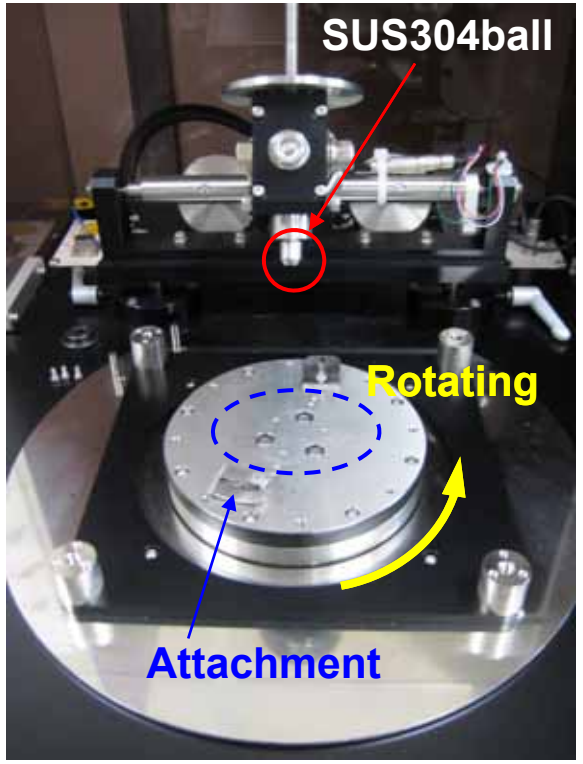
(a) with CNTs annealed at 1123 K
(b) with CNTs annealed at 973 K
(c) as-received pure Ti Plate





Ball-on-disk wear test

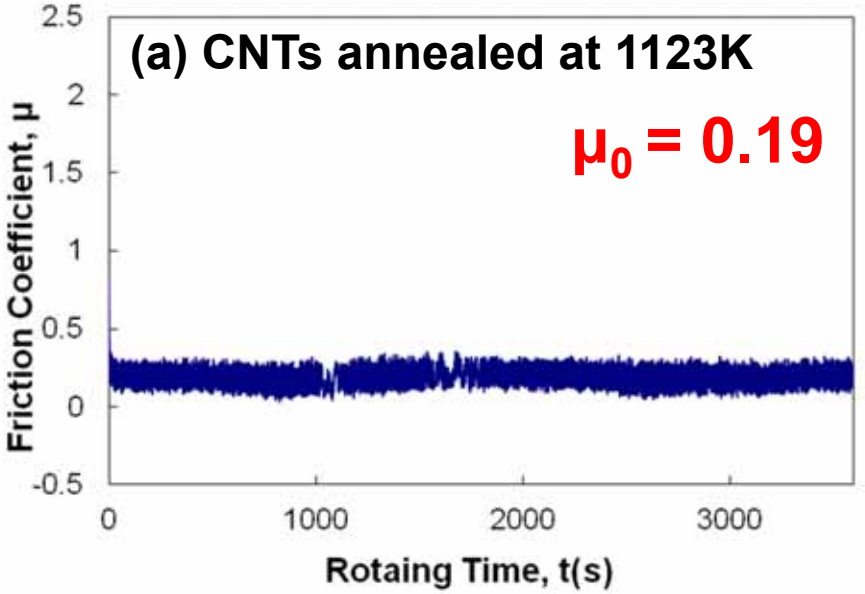


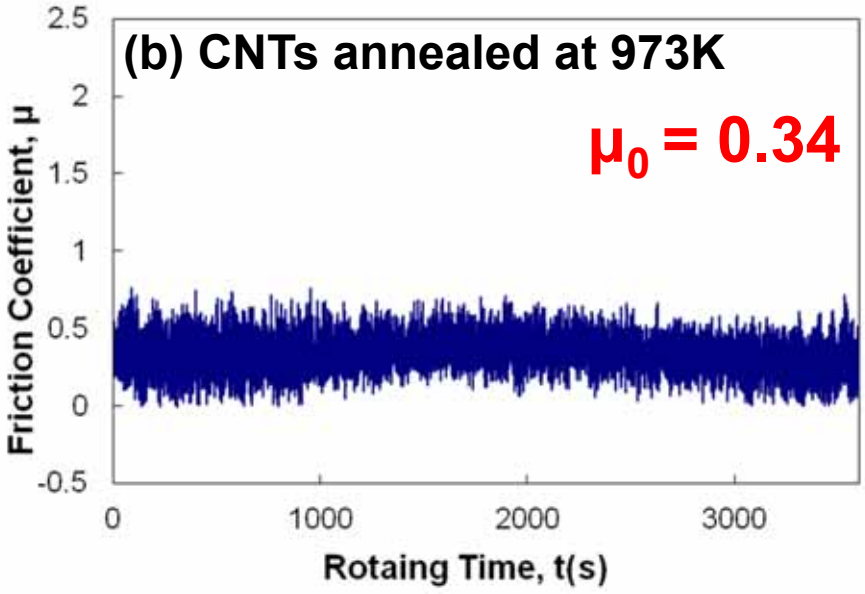


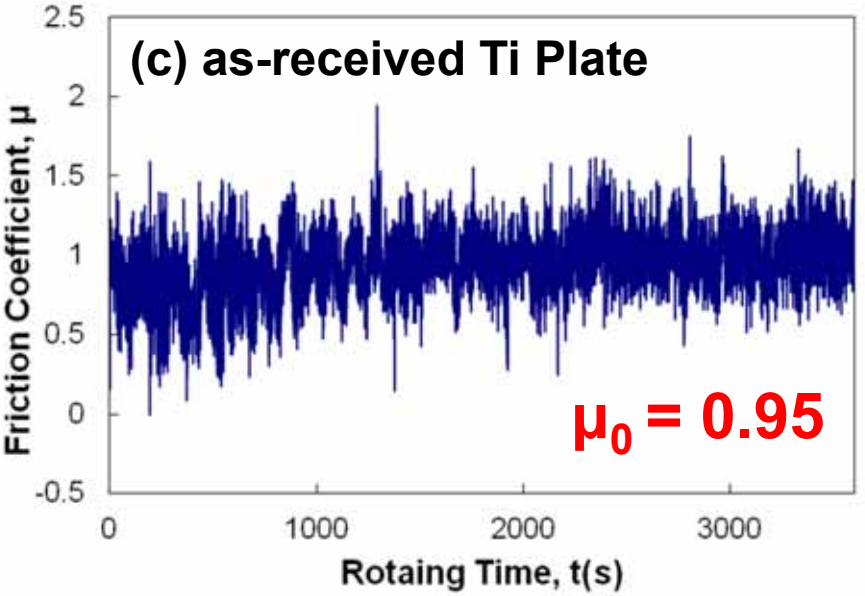
Total sliding distance, L =113m (←31.4 mm/s×3600s)

Test condition: Room Temperature,
No lubricant (Dry condition)

Ball-on-disk wear test results







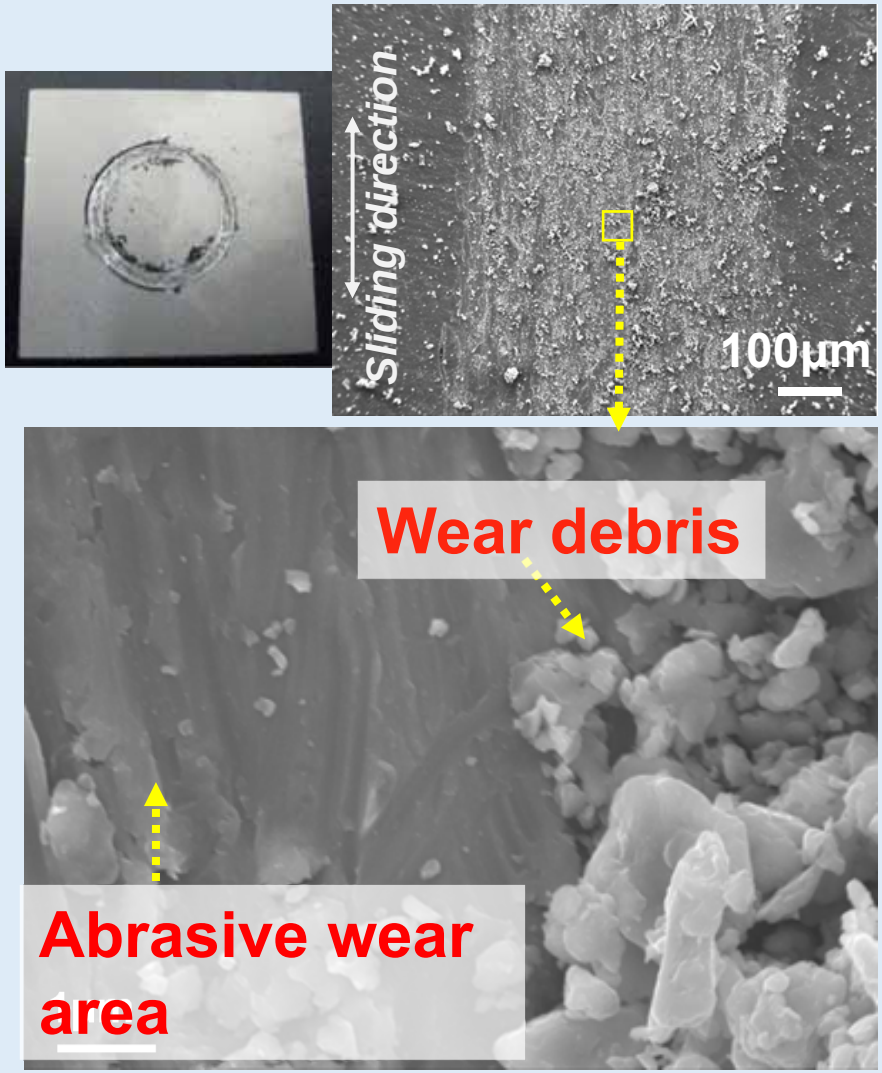
Conditions

- Counterpart Material ; SUS304 Ball
- Load ; 100gf
- Rotating Speed ; 31.4mm/s

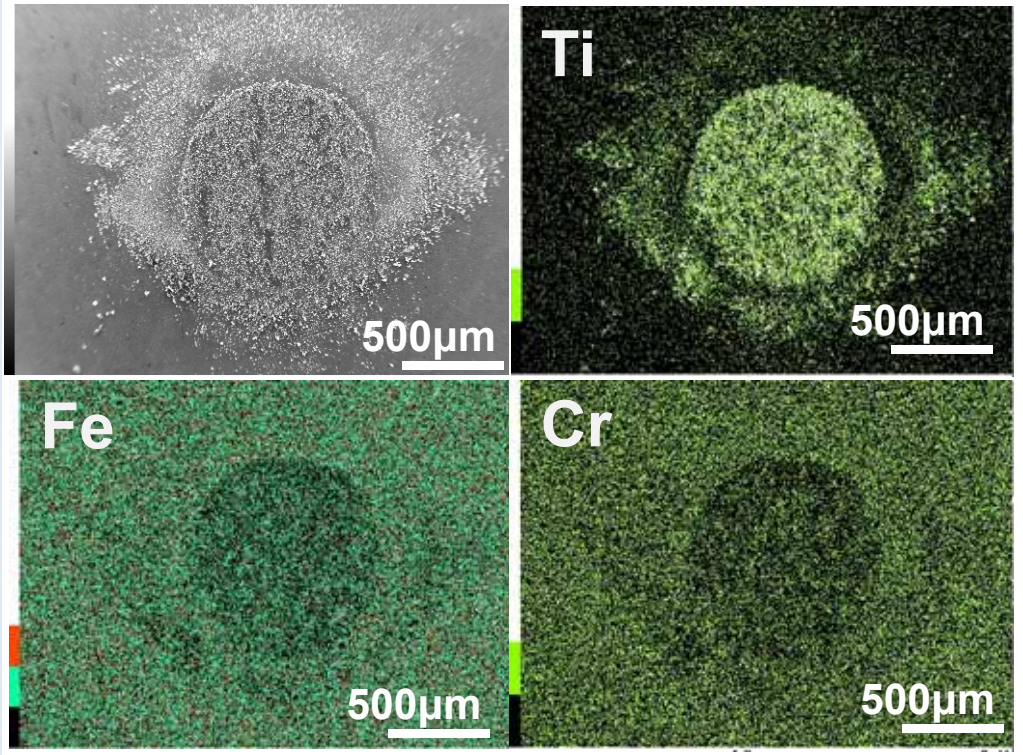
Ball-on-disk wear test results

Wear track of Ti plate as received (with NO film) and SUS 304 ball

Pure Ti Plate



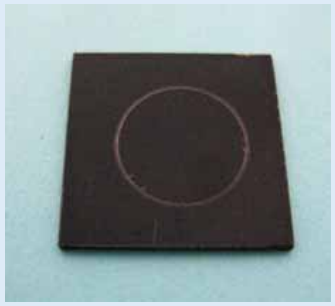
Counterparts material (SUS 304 ball)

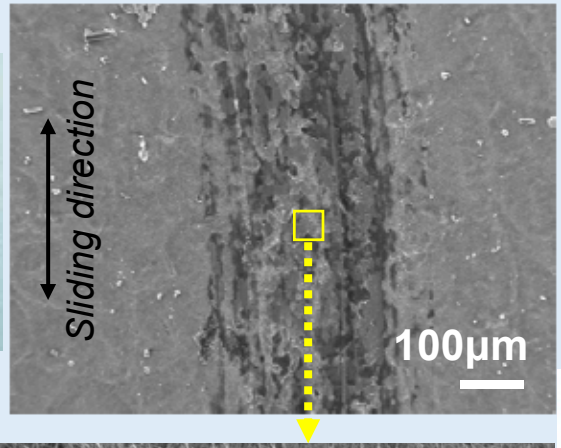


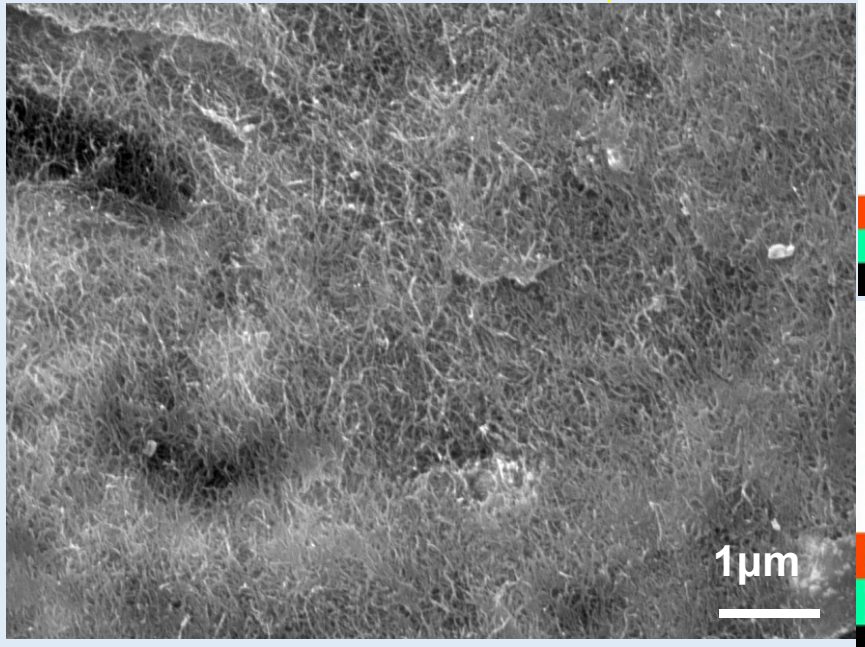
Ball-on-disk wear test results

Wear track of Ti plate coated with CNTs annealed at 1123K and SUS 304 ball

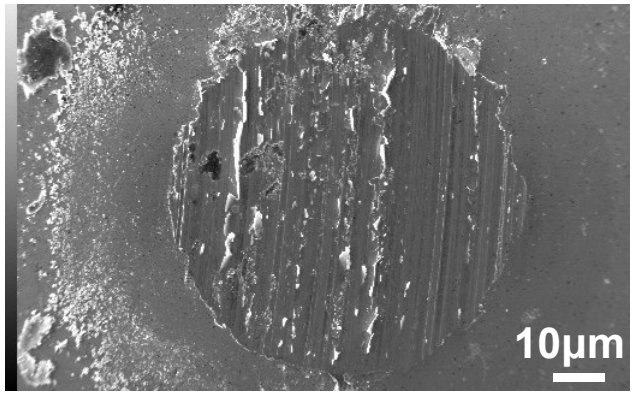
Ti Plate coated with CNTs

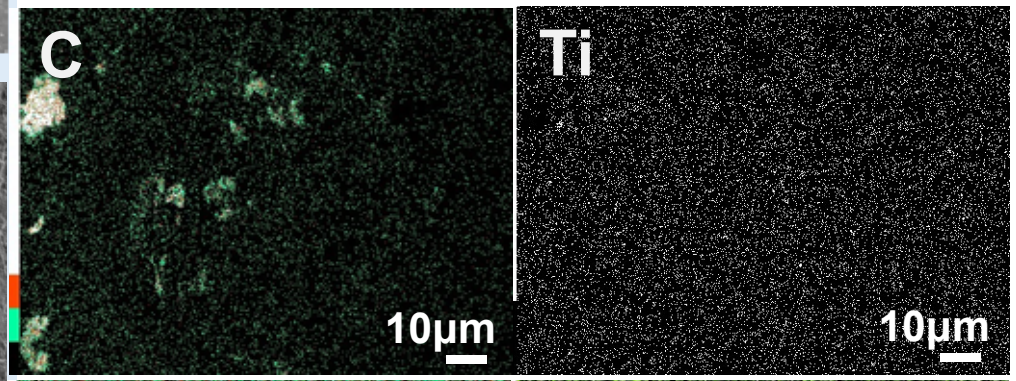


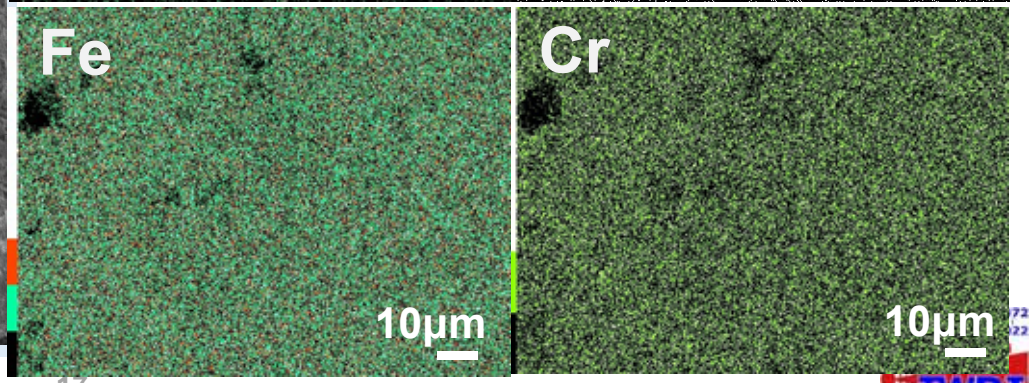




Counterparts material (SUS 304 ball)







Object #2

Investigate the biocompatibility of pure Ti plate coated with CNTs

Surface modification of Titanium surface by CNTs

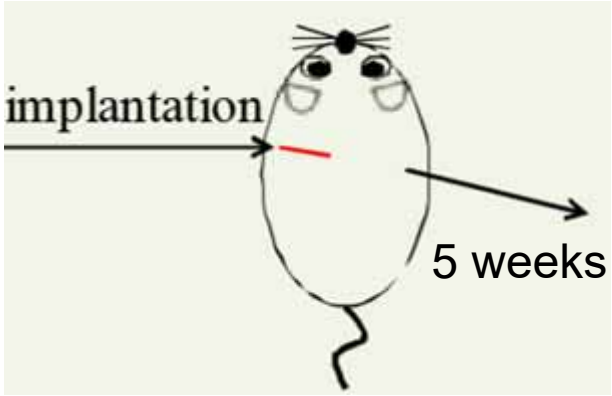
Facilitating tissue engineering

CNTs hold as a tissue engineering substrate ?

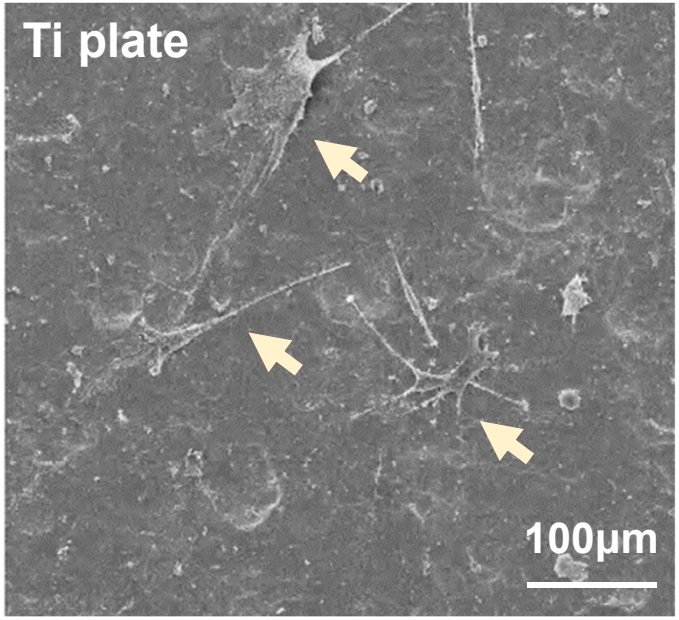
Examined

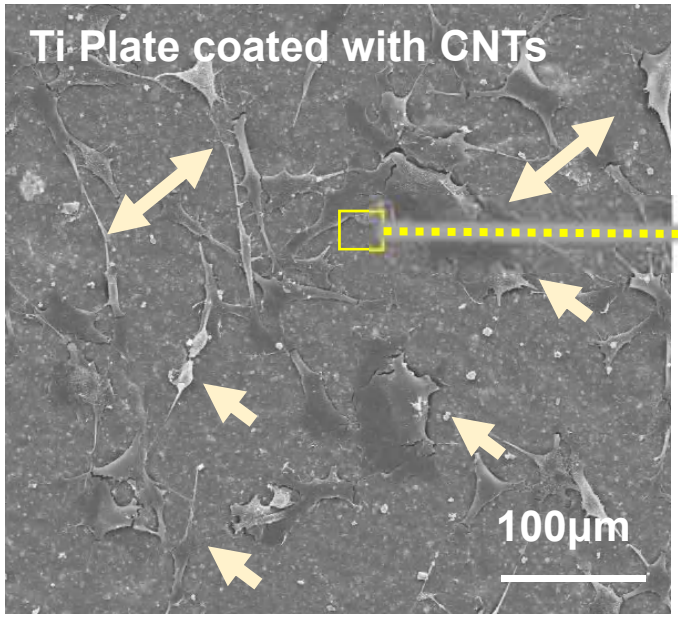
① Cell adhesion after 72 h

② Biocompatibility of rat



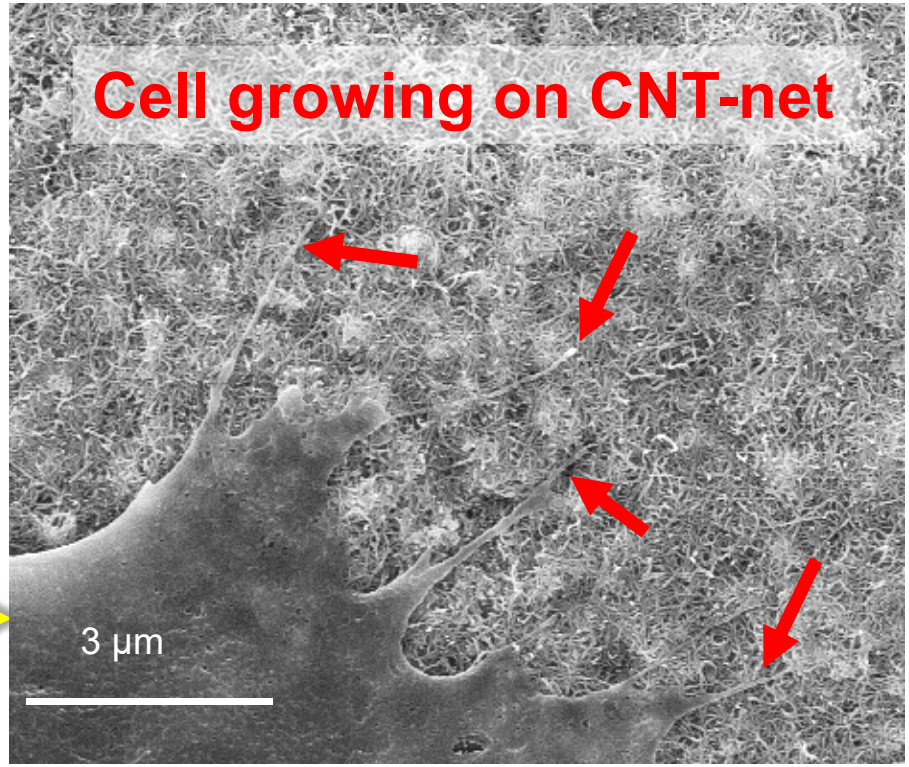
Tissue engineering - Cell adhesion test result





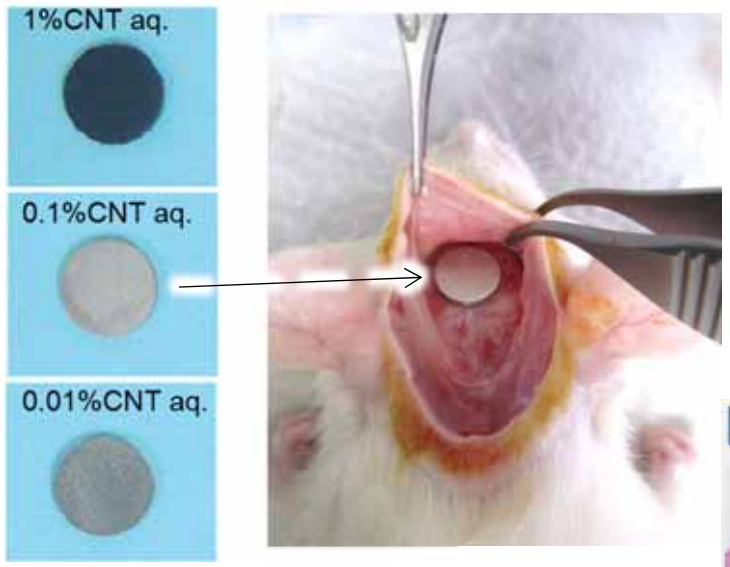
Cell attachment and spreading out

Ti plate coated with CNTs > Ti plate

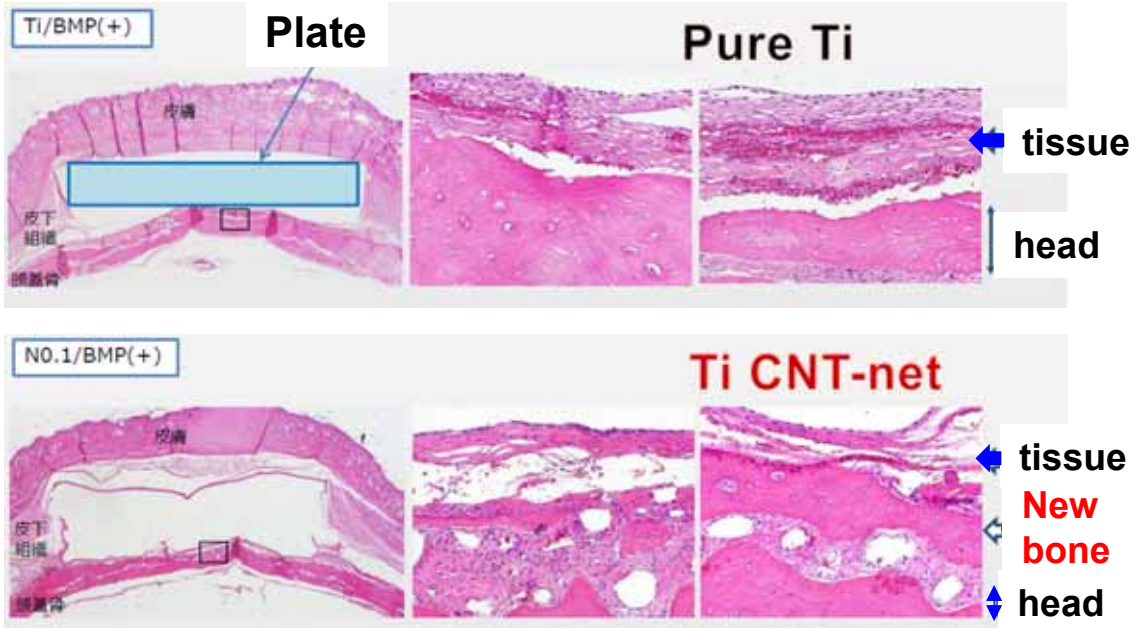


Well-demonstrated **CNTs** in the tissue engineering

Evaluate the biocompatibility of CNT-net nano morphologies



- Observations at 5 weeks after implantation into rat
- Inflammatory cell infiltration was rarely observed
  - ➡ **good biocompatibility**
- **Promoting new bone formation by CNT-net**



Conclusions

1. CNTs were successfully coated on Ti plate annealed at 973 K and 1123 K.

2. Formation of network-structured CNT films was effective to reduce the friction coefficient of Ti plate due to their excellent self-lubricant effect.

3. Annealing at 1123 K caused TiC formation at interface between CNTs and Ti substrate, and then excellent metallurgical bonding was obtained. As a result, CNT films were obviously remained at wear track even after dry sliding when SUS304 stainless ball was used as a counterpart material.

4. CNT-net nano modification provided the acceleration of new bone formation to the Ti plate surface.