Clustering & Global Challenges
April 07-09, 2021
Online international conference

Health
Smart Energy
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Advanced Materials

Uniaxially Oriented Refractory Nickel Aluminum Films Sputtered at High Temperatures

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MOTIVATION

- For the practical applications, plasmonic materials such as tungsten, molybdenum [1] or metal nitrides [2] and metal carbides have been proposed; however, they are not robust against oxidation if they are used at elevated temperature in air. Hence, the practical applications of thermal metallic emitters are limited to the strict vacuum or inert gas ambient conditions.
- Nickel-based superalloys containing Ti, Ta, and W are used in a base material as a turbine blade or a turbine vane of a jet engine or the like in many cases with a surface of a base material coated to inhibit high temperature oxidation and heating [3].
- The intermetallic nickel aluminium alloy (NiAl) is a promising candidate which retains different merits like high-melting point, extreme hardness, as well as low density and high thermal/electrical conductivity. ***Especially, excellent oxidation resistance due to the formation of a protecting alumina layer on the surface leads to be robust against oxidation if nickel aluminum alloy is used at elevated temperature in air [4].***

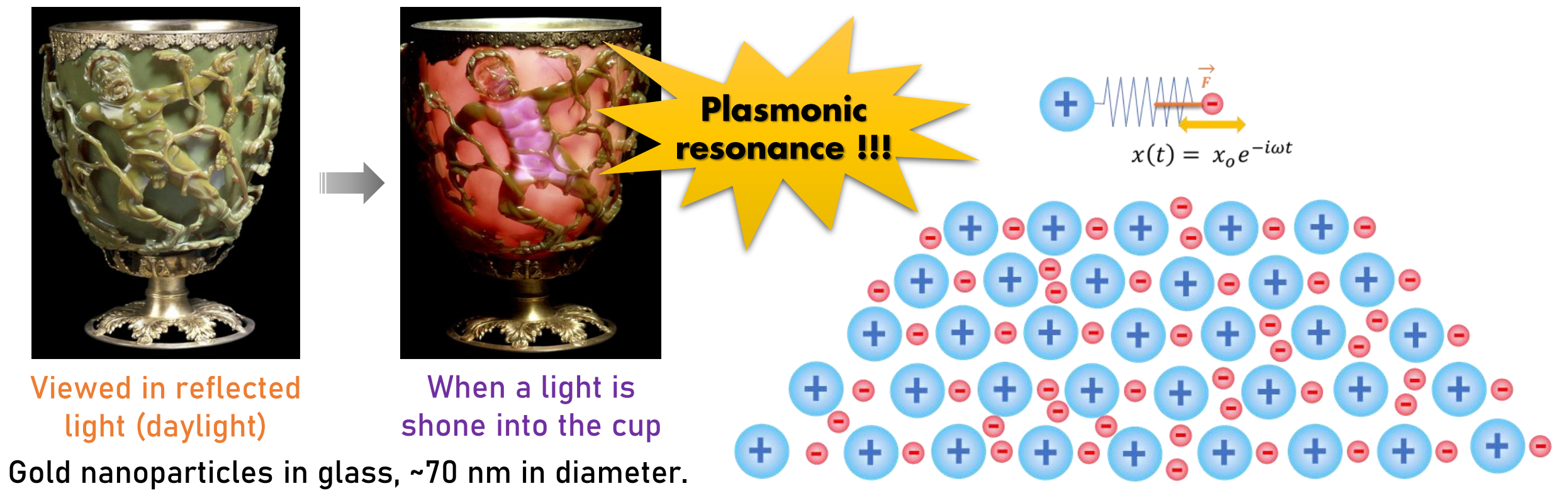
➔ These all make NiAl a material-of-choice for high-temperature practical applications.

INTRODUCTION

PLASMONICS THEORY

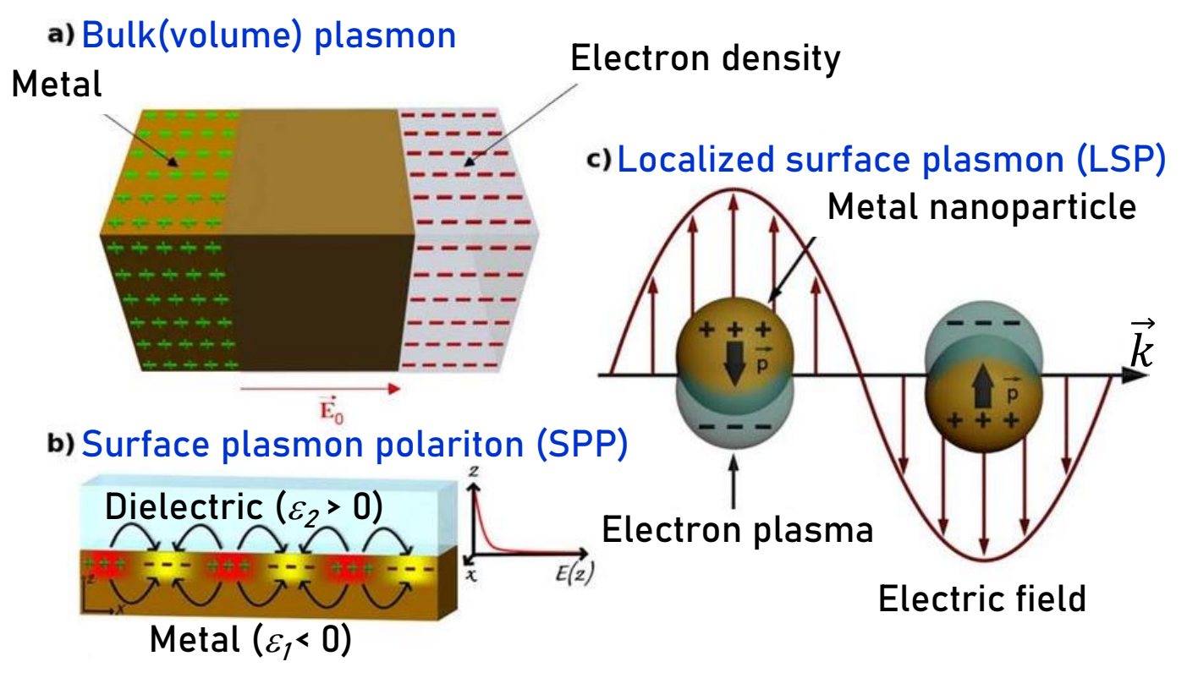
- ☐ **Plasmonics:** generation, detection, control , and use of plasmon as information and energy carriers.
- ☐ **Plasmons:** collective charge oscillations of conduction electrons in metallic materials driven by electromagnetic waves (or electron beams).

The cup illustrates the myth of King Lycurgus

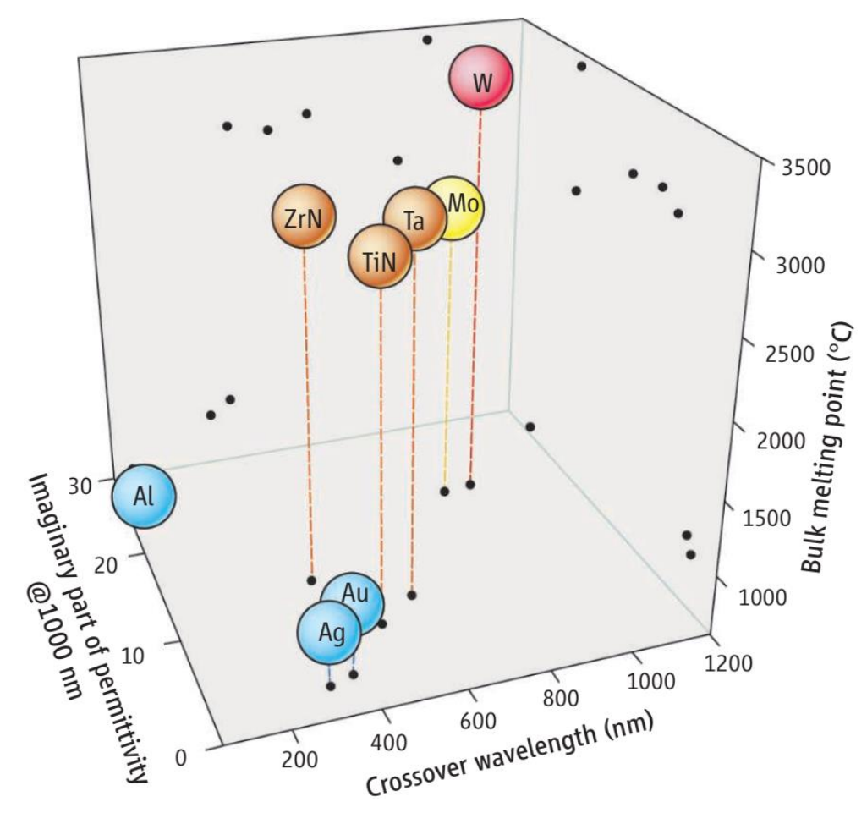


Gold nanoparticles in glass, ~70 nm in diameter.
Color response different to that of gold in bulk.
- Particles resonantly reflect green light.
- Strong absorbance around 500nm and below.

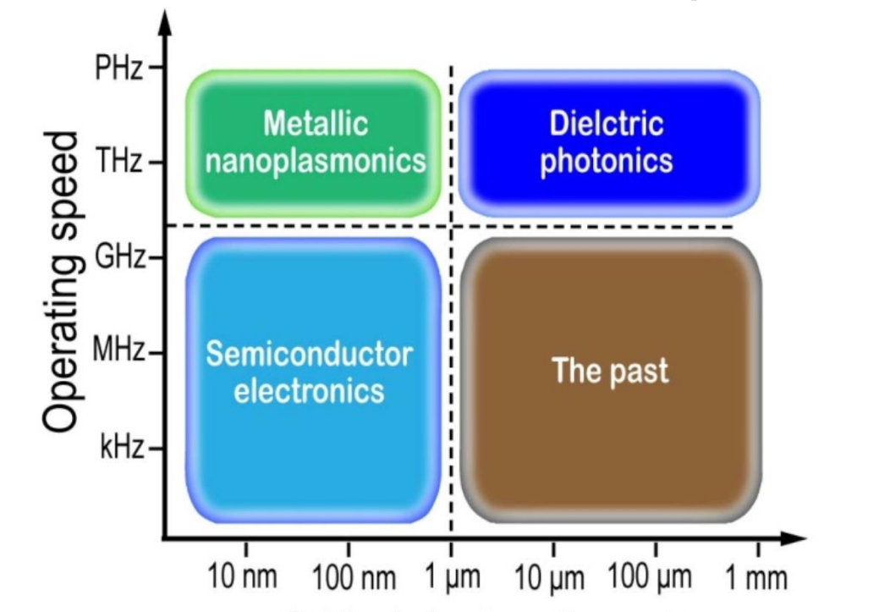
Plasma oscillation in metal



Schematic illustrations of plasmonic modes



Traditional RefractoryPlasmonic Materials [5]



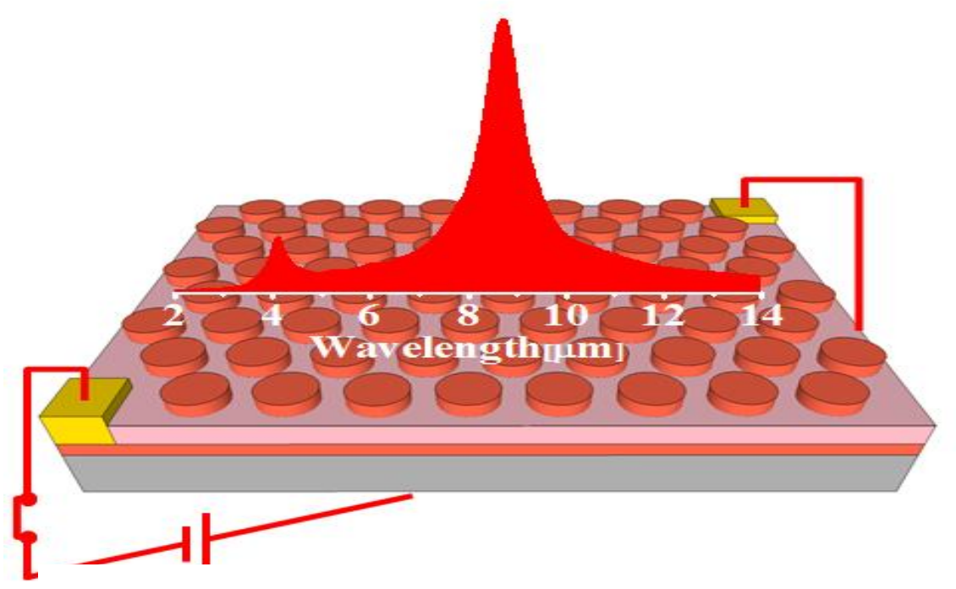
The different domains in terms of operating speed and device size [6]

- ☐ Improved synergy between electronic and photonic devices.
- ☐ Solution to the size – compatibility problem.
  - Plasmonics naturally interfaces with *similar size to electronic components.*
  - Plasmonics naturally interfaces with *similar operating speed to photonic networks.*

THERMAL EMITTER DEVICES

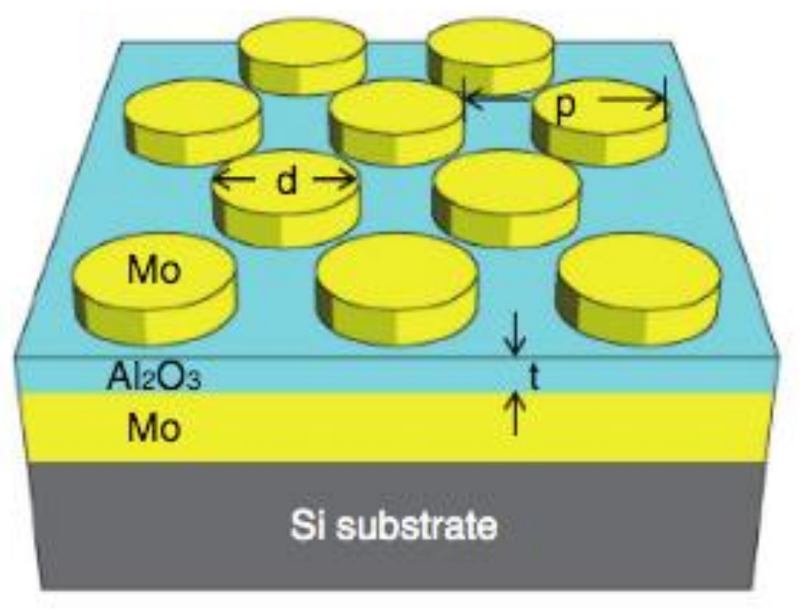
Kirchoff law in thermal radiation:
in thermal equilibrium condition
Emissivity = Absortivity

Narrow band thermal emission

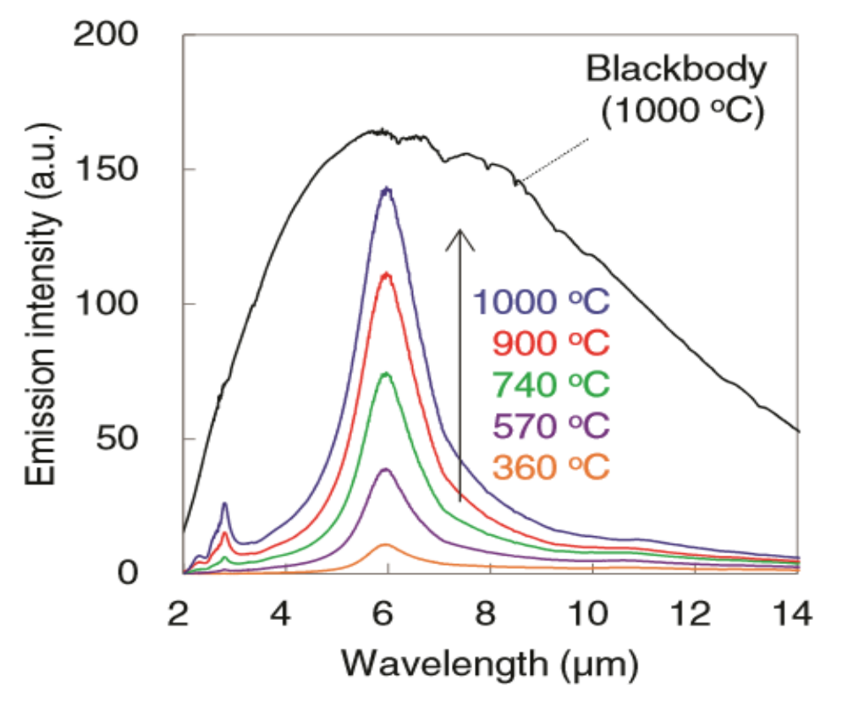


MIM
(Metal-Insulator-Metal structure)

MIM – Molypden [7]



- High tunability by changing: Disk diameter
- Working at high temperature (1000°C in vacuum)

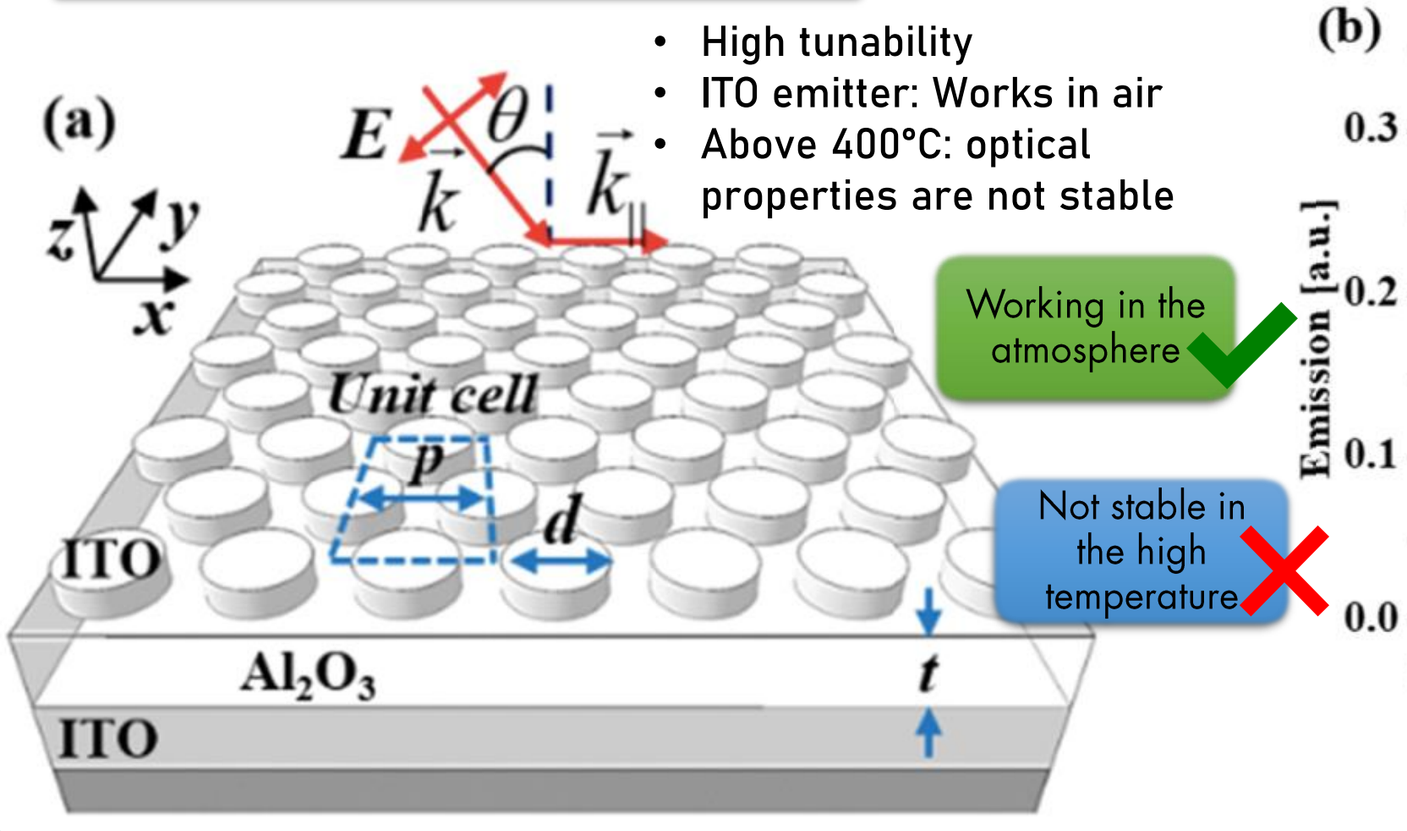


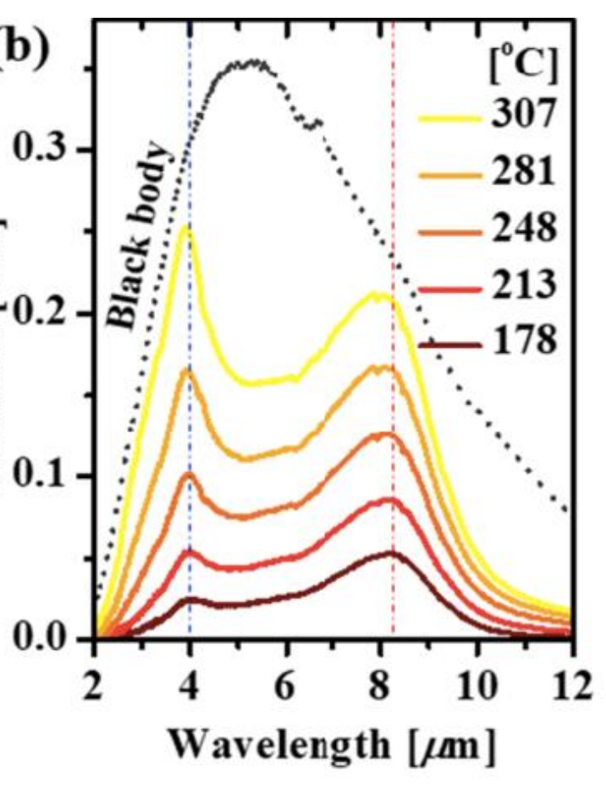
Before annealing in Furnace (room temperature)

Oxidized at 600°C

MIM – ITO (Indium Tin Oxide) [8]

- High tunability
- ITO emitter: Works in air
- Above 400°C: optical properties are not stable





NiAl FILM FABRICATION

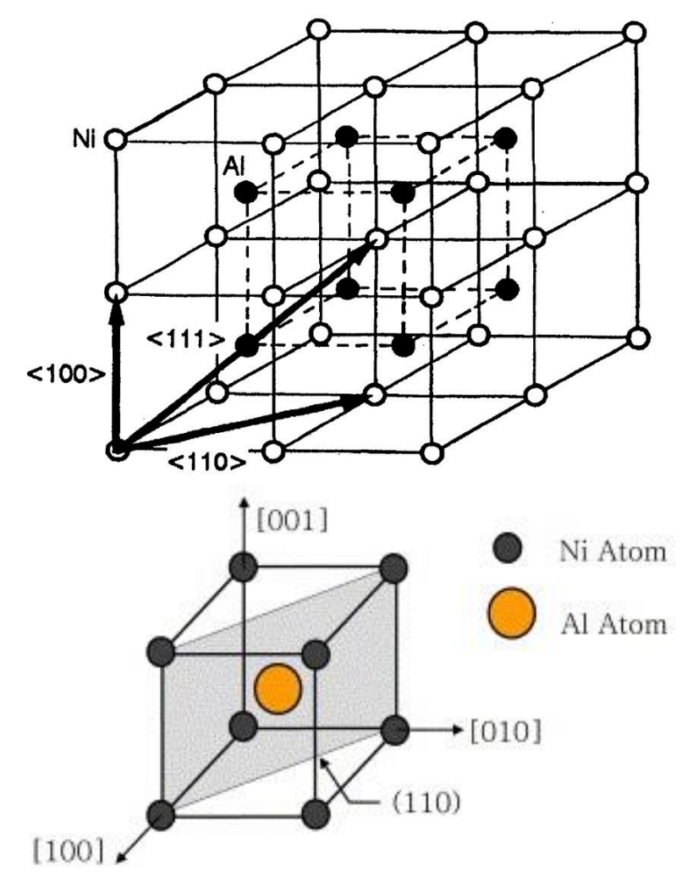
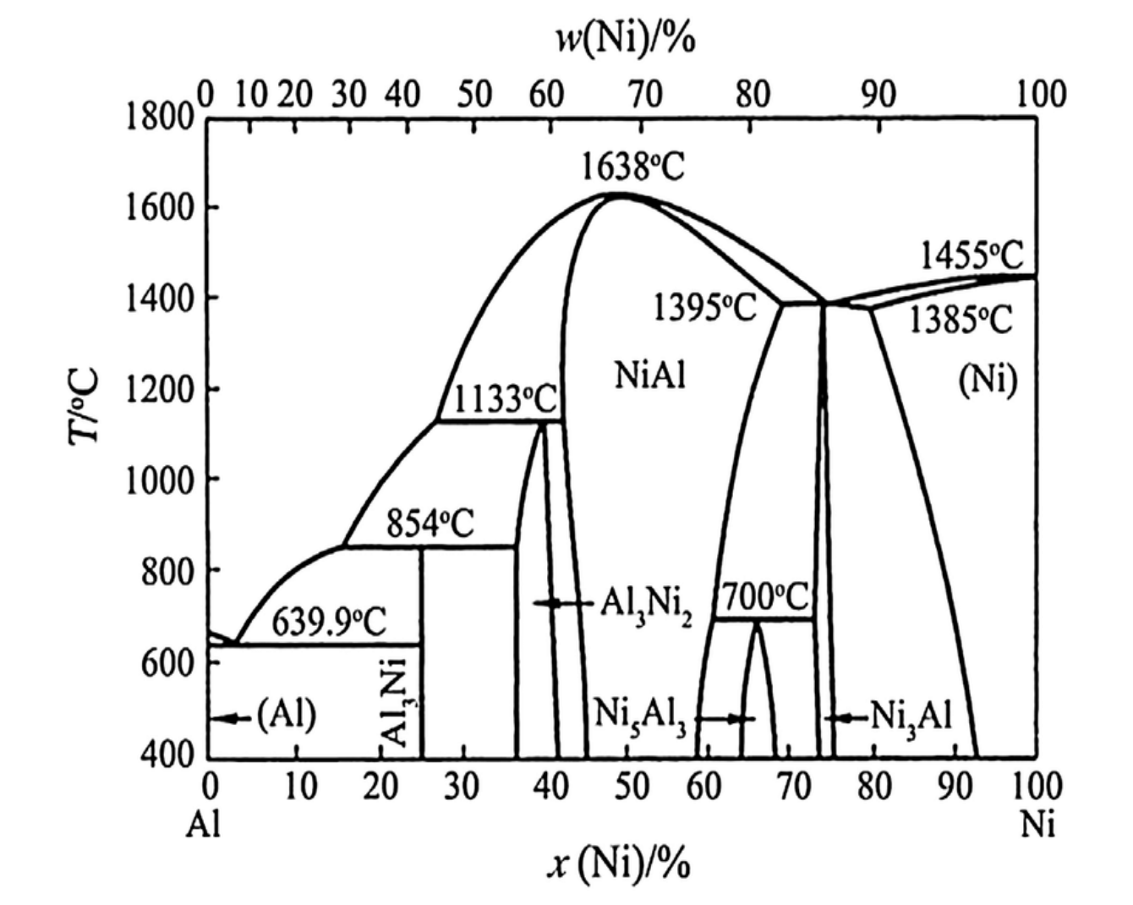
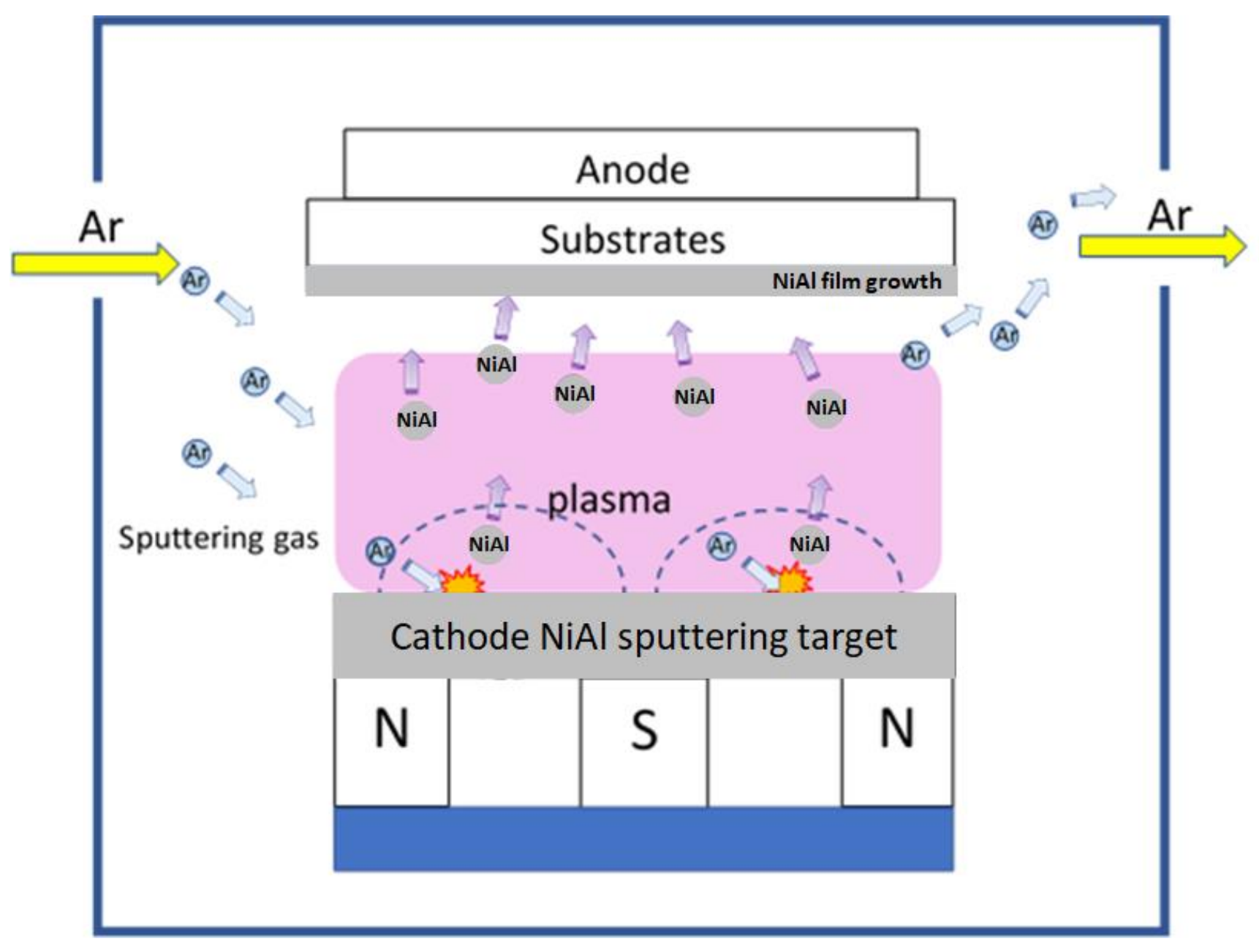


Illustration of the crystal structure for NiAl



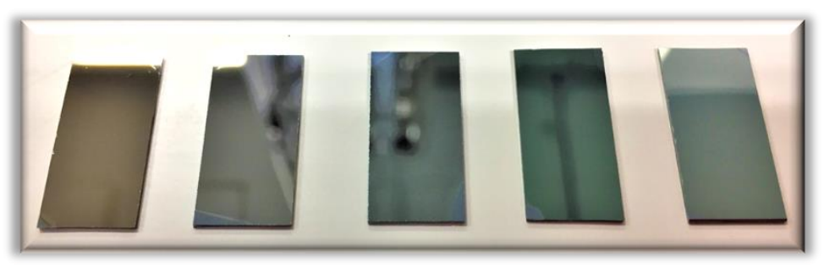
Phase diagram of the system Al – Ni, the intermetallic phase NiAl shows a wide homogeneity region.



The schematic diagram of NiAl film DC magnetron sputtering.

- NiAl DC sputtering
- In situ Heating
- Substrates: Si (100)
- Target – Substrates distance ~ 11 cm.

NiAl Target

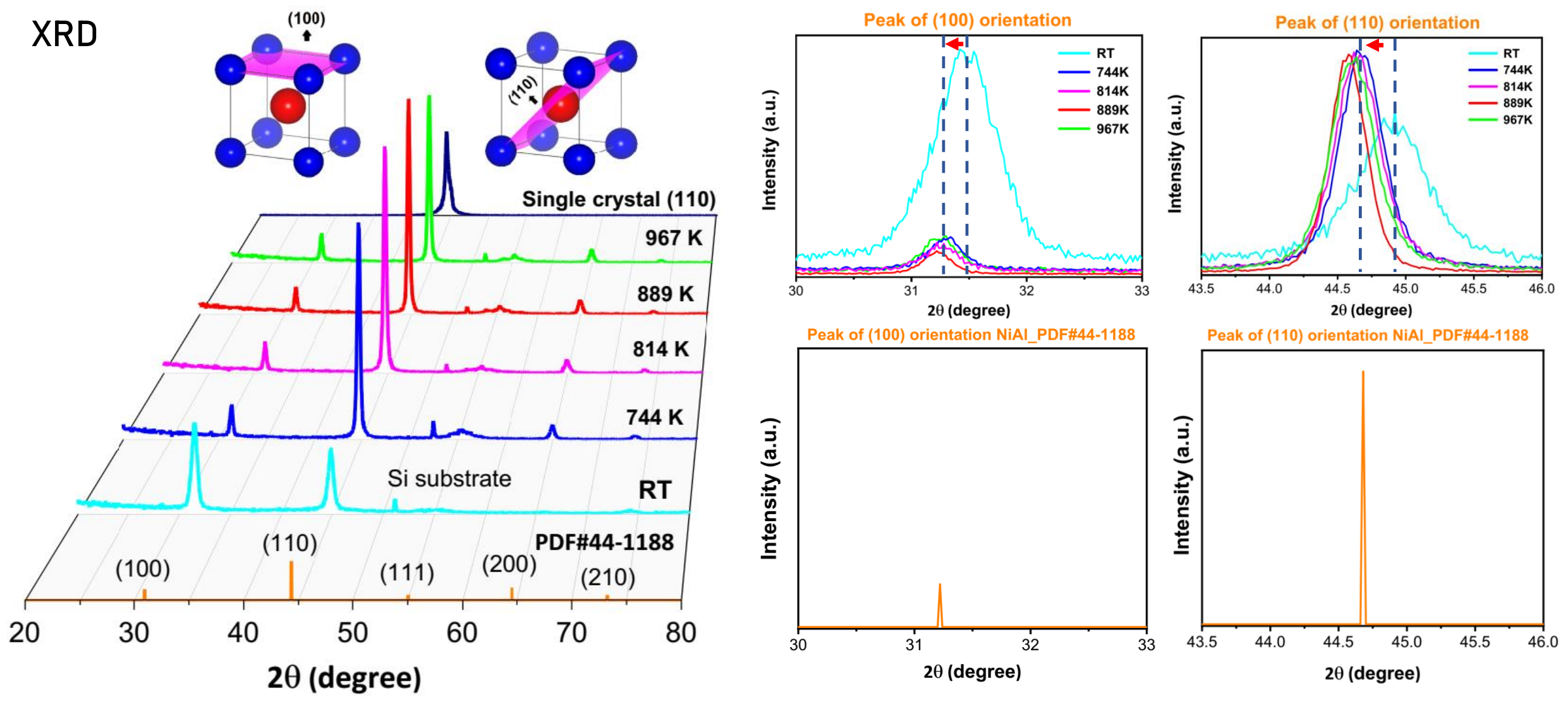


NiAl film on Silicon sustrates

MAIN RESULTS

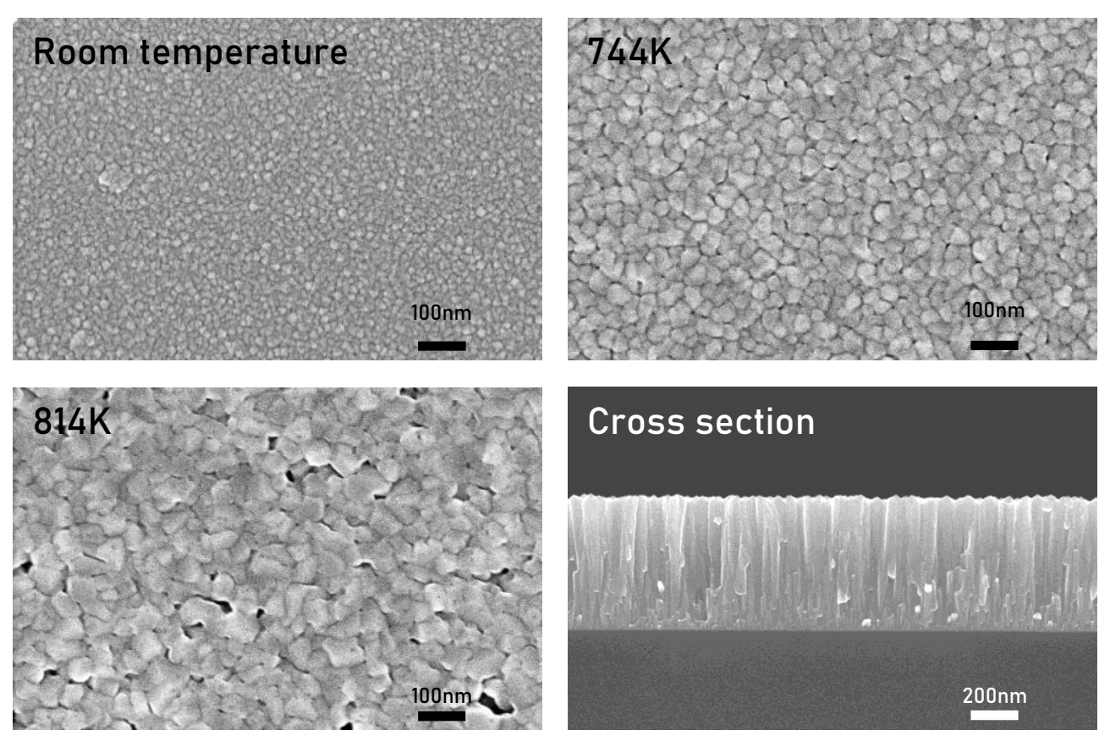
CRYSTAL STRUCTURE & MORPHOLOGY

XRD

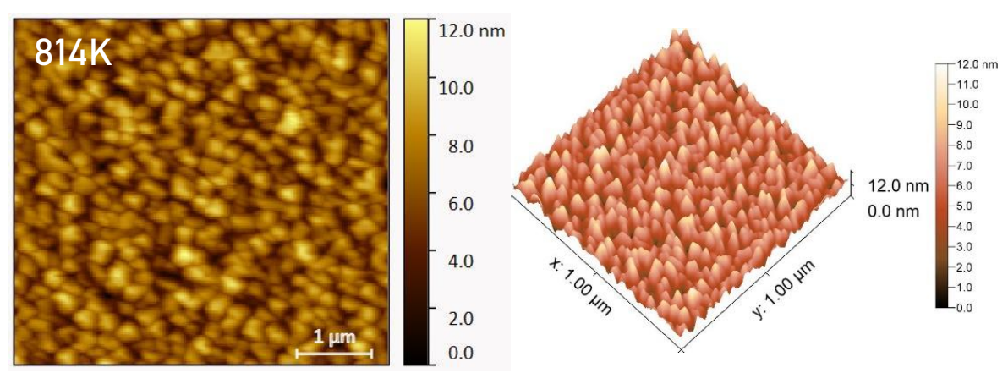


XRD patterns of NiAl films on Si (100) substrates at different temperatures. Standard diffraction pattern of NiAl at the bottom. Inset: unit cell of NiAl with an aluminium atom at the center and surrounding nickel atoms.

SEM



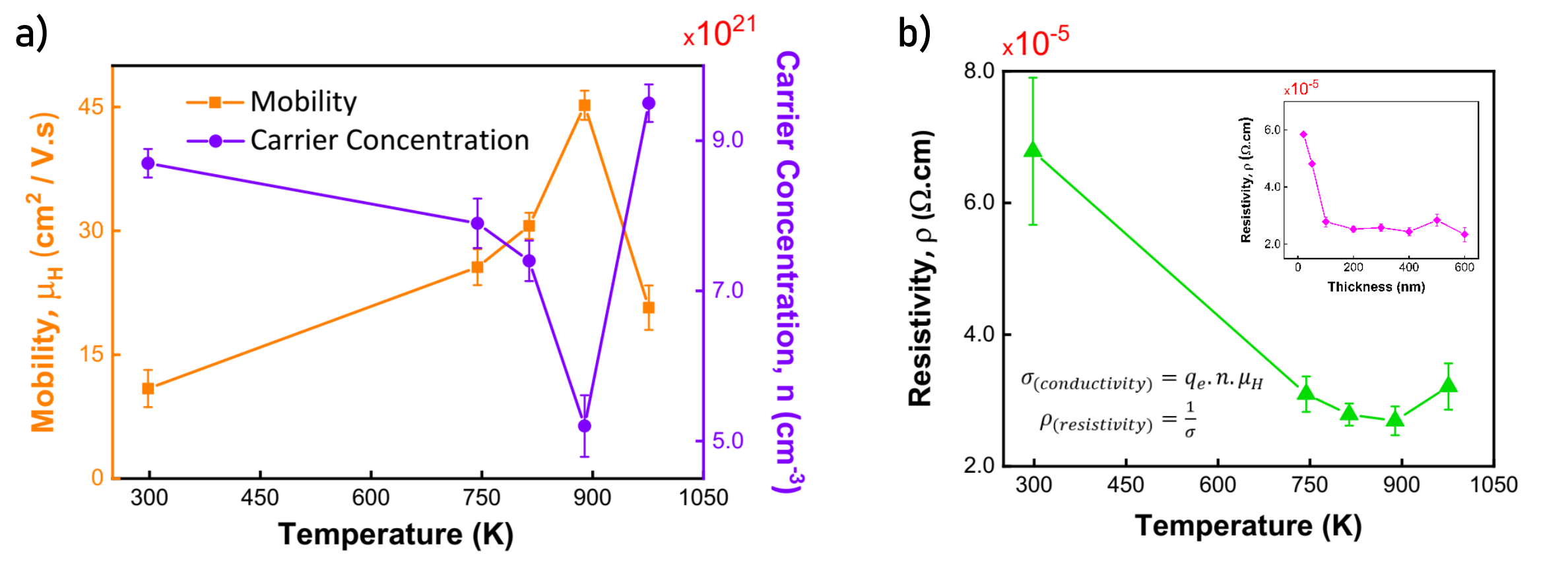
AFM



- Higher temperatures promoted better crystallinity and grain growth.
- The cross- sectional image indicated that the growth mode shifted from dense fine columnar structure to tight grain boundary columns.

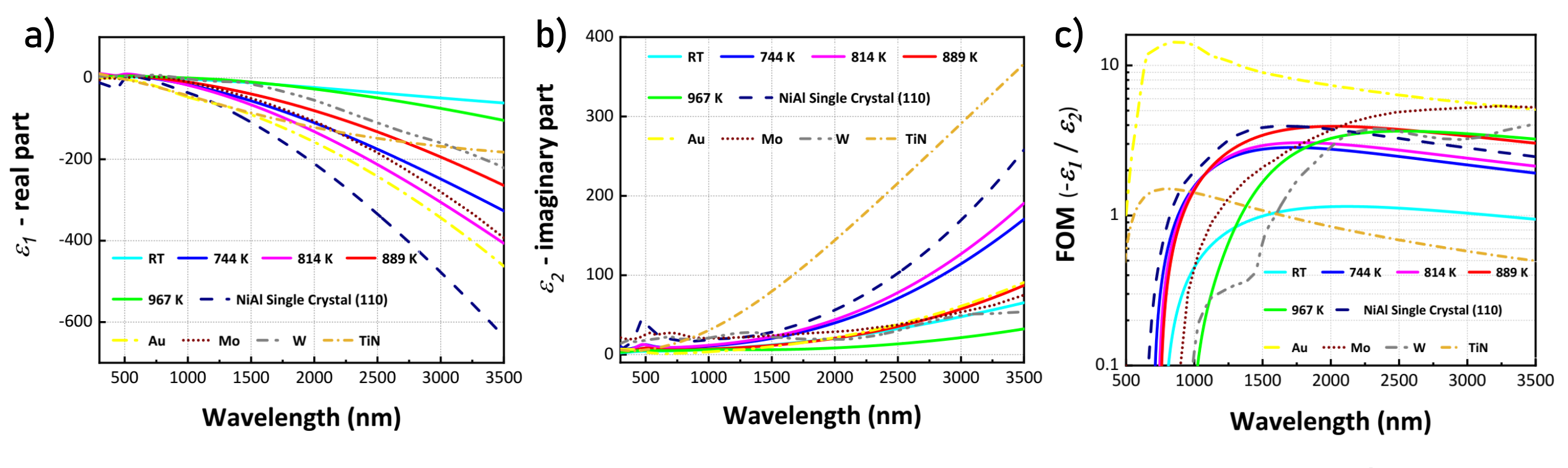
ELECTRICAL & OPTICAL PROPERTIES

HALL MEASUREMENT



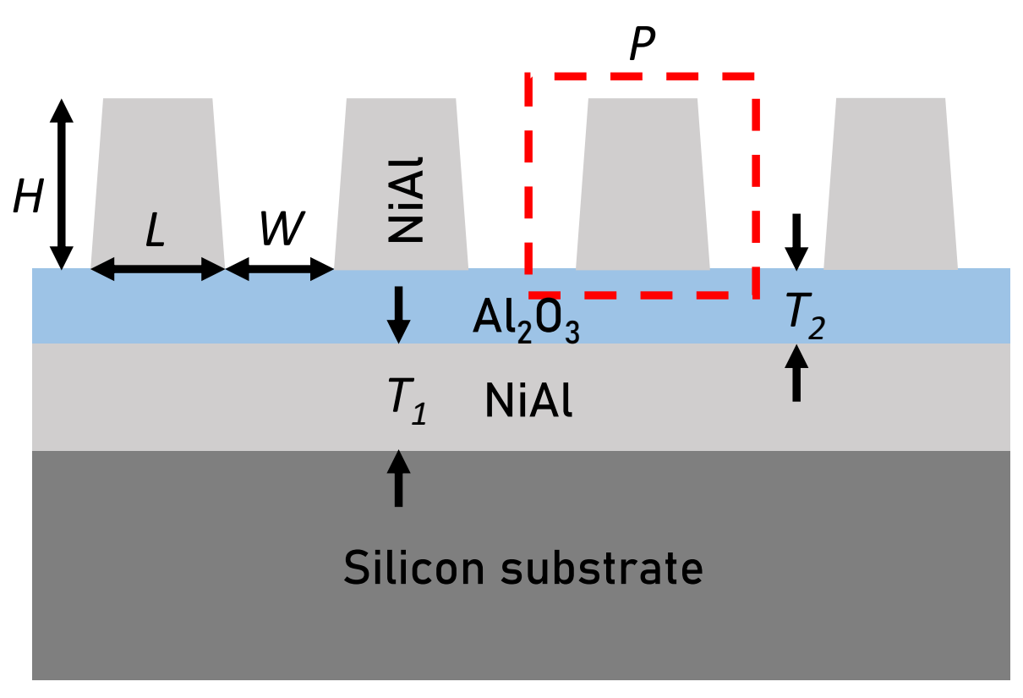
(a) Mobility and carrier concentration versus growth temperature, and (b) resistivity versus growth temperature, and effect of film thickness on the resistivity.

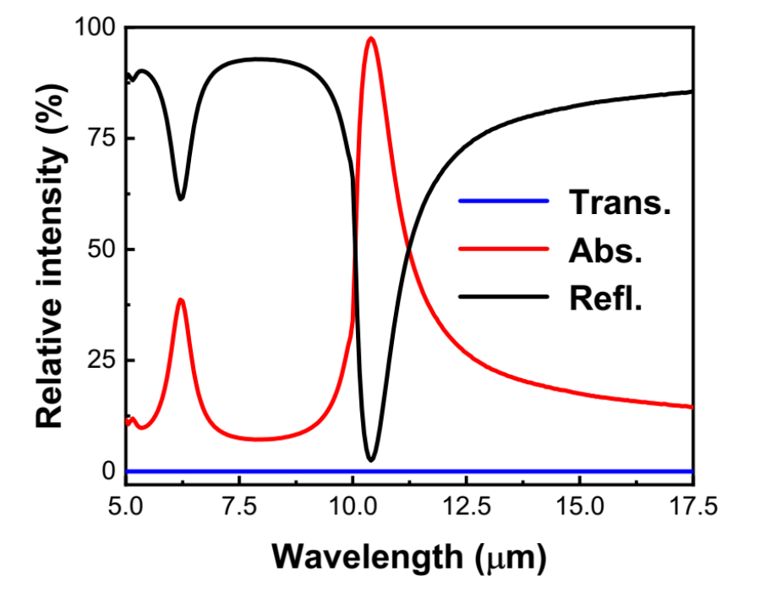
SPECTROSCOPIC ELLIPSOMETRY



Comparison of the measured complex permittivities and figure of merit (FOM) $-\varepsilon_1/\varepsilon_2$ of the NiAl films deposited at different temperatures of deposition against NiAl single crystal, Au, W, Mo, and TiN. (a) Real part; (b) imaginary part and (c) FOM.

MIM-NiAl STRUCTURE (FUTURE)





Simulated optical spectra including absorptivity (red curve), transmittance (blue curve) and reflectance (black curve) of NiAl thermal emmitter

CONCLUSION

High-quality growth of NiAl film sputtered directly onto Si(100) from a single NiAl target with *in situ* heating from room temperature to 967K was reported. All films exhibited intense, sharp peaks of (110) preferential orientation in tight grain boundary. High carrier concentrations of ~10^{21} cm^{-3} and lowest resistivity of 2.67×10^{-5} Ω.cm were achieved. Figure of merits of NiAl films showed better performance than commonly used refractory optical materials like molybdenum, tungsten and even titanium nitride. Surprisingly, the NiAl film deposited at 889K achieved comparable FOM values to NiAl single crystal in visible and near infrared regions, exhibiting even more superior performance at longer wavelengths. We believe that developed NiAl (110) films could be a material-of-choice for various NiAl-based refractory photonic applications.

ACKNOWLEDGEMENTS

We appreciate technical assistss from Mr. N. Furuhata and Mrs. K. Okano, also the staff members of the MANA Foundry in NIMS for their technical supports, especially Dr. A. Ohi and Mr. N. Ikeda. This work was partially supported by JSPS KAKENHI (16H06364), and CREST "Phase Interface Science for Highly Efficient Energy Utilization" (JPMJCR13C3), Japan Science and Technology Agency.

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