國立臺灣科技大學
115學年度碩士班招生

試題

系所組別：0430材料科學與工程系碩士班丙組

科　　目：材料導論

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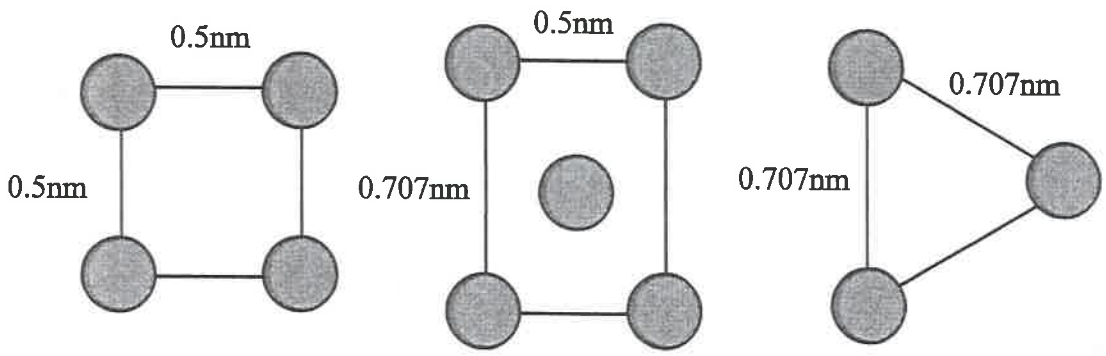
(總分為100分;所有試題務必於答案卷內頁依序作答)

1. (total 20%) X-ray diffraction is one of important techniques to determine the crystallographic structure of materials. (1) **(6%)** Please write down the question of Bragg's law and (2) **(4%)** define all the symbols. (3) **(10%)** Please explain why using a high diffraction angle (2θ) yields a more precise determination of the d-spacing compared to using a low diffraction angle.

2. (total 10%) The accompanying figure shows three different crystallographic planes for a unit cell of a hypothetical metal. The circles represent atoms. (1) **(4%)** To what crystal system does the unit cell belong and what is the corresponding lattice parameters? (2) **(2%)** What would this crystal structure be called?? (3) **(2%)** What is the relationship between the lattice parameter "a" and radius of its atom "R"? (4) **(2%)** What is the atomic packing factor (APF) of this unit cell?



3. (total 20%) (1) **(5%)** Please brief define ceramic materials. (2) **(15%)** Some of our modern kitchen cookware is made of ceramic materials, and please list three important characteristics required of a material to be used for this application.

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4. (25%) Read the following passages and answer the following multi-select questions. Points will only be awarded if all parts of the question are answered correctly.

As conventional FinFET scaling approaches fundamental electrostatic and variability limits below the 3 nm technology node, gate-all-around field-effect transistors (GAAFETs) have emerged as the leading architecture for continued CMOS scaling. By fully surrounding the channel with the gate, GAAFETs provide superior electrostatic control, reduced short-channel effects, and improved subthreshold swing compared with FinFETs. Nanosheet-based GAAFETs, in particular, allow effective channel width tuning through vertical stacking, enabling design flexibility without increasing footprint. However, the transition to GAAFETs introduces substantial process complexity, including selective channel release, inner spacer formation, and stringent control of nanosheet thickness and strain.

In parallel with front-end transistor innovations, advanced packaging technologies such as Chip-on-Wafer-on-Substrate (CoWoS) have become critical enablers of high-performance computing (HPC) and artificial intelligence (AI) systems. CoWoS integrates multiple dies—such as logic, high-bandwidth memory (HBM), and specialized accelerators—on a silicon interposer, significantly reducing interconnect length and power consumption while increasing bandwidth. This heterogeneous integration paradigm alleviates some limitations of traditional monolithic scaling by shifting performance gains toward system-level optimization.

Recent semiconductor development increasingly reflects a co-optimization of device architecture, process technology, and packaging. While GAAFETs address transistor-level scaling challenges, CoWoS and related 2.5D/3D integration strategies mitigate interconnect bottlenecks and yield constraints at the system level. Nonetheless, challenges remain, including thermal management, yield loss due to known-good-die requirements, and escalating fabrication costs. As a result, future semiconductor progress is expected to rely less on pure dimensional scaling and more on holistic integration across multiple technology domains.

(1) (5%) Which features contribute to the improved electrostatic control of GAAFETs compared with FinFETs?
(Select *all* that apply.)
A. Full gate enclosure of the channel
B. Reduced effective channel cross-section
C. Suppression of short-channel effects
D. Increased source/drain doping concentration
E. Vertical stacking of nanosheets

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(2) (5%) Which process or design advantages are associated with nanosheet-based GAAFETs?
(Select *all* that apply.)
A. Channel width tuning via vertical nanosheet stacking
B. Compatibility with strain engineering techniques
C. Elimination of selective channel release steps
D. Improved scalability without increasing planar footprint
E. Relaxed lithography overlay tolerance

(3) (5%) CoWoS technology primarily enables which system-level benefits?
(Select *all* that apply.)
A. Higher memory bandwidth
B. Reduced interconnect latency and power consumption
C. Improved gate electrostatics at the transistor level
D. Heterogeneous integration of logic and memory dies
E. Increased transistor switching speed through channel strain

(4) (5%) Which challenges are commonly associated with CoWoS-based or similar advanced packaging approaches?
(Select *all* that apply.)
A. Thermal management across densely integrated dies
B. Yield loss due to known-good-die requirements
C. Increased short-channel effects in scaled transistors
D. Higher fabrication and integration cost
E. Interposer-related parasitic resistance and capacitance

(5) (5%) According to the passage, future semiconductor progress is expected to rely on which strategies?
(Select *all* that apply.)
A. Continued innovation in device architectures such as GAAFETs
B. Advanced packaging and heterogeneous integration
C. Exclusive dependence on lithographic scaling
D. Cross-domain co-optimization of devices, processes, and systems
E. Complete replacement of silicon CMOS with compound semiconductors

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5. (25%) Read the following passages and answer the following multi-select questions. Points will only be awarded if all parts of the question are answered correctly.

High-entropy metals (HEMs) are a class of materials composed of multiple principal metallic elements—typically five or more—present in near-equiatomic proportions. Unlike conventional alloys, which are based on one dominant element, HEMs derive their stability from high configurational entropy, which can suppress the formation of brittle intermetallic phases and favor simple solid-solution structures such as face-centered cubic (FCC), body-centered cubic (BCC), or hexagonal close-packed (HCP) lattices.

The unique compositional complexity of HEMs leads to several notable physical effects, including severe lattice distortion, sluggish diffusion, and complex local chemical environments. These characteristics can result in exceptional mechanical strength, thermal stability, and resistance to radiation damage. For example, lattice distortion enhances solid-solution strengthening, while sluggish diffusion improves high-temperature creep resistance.

Beyond structural applications, high-entropy metals have attracted increasing attention for functional applications, such as catalysis, hydrogen storage, and electrical interconnects. Their tunable electronic structure and diverse active sites make them promising candidates for electrocatalytic reactions. However, challenges remain in terms of phase predictability, scalable synthesis, and precise control of microstructure-property relationships. As research progresses, understanding the interplay between entropy, enthalpy, and kinetics is essential for rational HEM design.

(1) (5%) Which characteristics define high-entropy metals (HEMs)?
(Select *all* that apply.)
A. Multiple principal elements in near-equiatomic ratios
B. Dominance of a single base metal
C. High configurational entropy
D. Tendency toward simple crystal structures
E. Compositionally complex atomic environments

(2) (5%) High configurational entropy in HEMs can lead to which phase-related effects?
(Select *all* that apply.)
A. Stabilization of FCC, BCC, or HCP solid solutions
B. Suppression of brittle intermetallic compounds
C. Mandatory formation of amorphous phases
D. Enhanced phase stability at elevated temperatures
E. Reduction of Gibbs free energy through entropic contribution

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(3) (5%) Which mechanisms contribute to the mechanical robustness of many high-entropy metals? (Select *all* that apply.)

A. Severe lattice distortion

B. Solid-solution strengthening

C. Sluggish atomic diffusion

D. Grain boundary embrittlement

E. Enhanced resistance to high-temperature creep

(4) (5%) Why are high-entropy metals promising for catalytic and other functional applications? (Select *all* that apply.)

A. Diverse local chemical environments

B. Tunable electronic structures

C. Chemically uniform and identical active sites

D. Potential for multiple reaction pathways

E. Enhanced surface activity from compositional complexity

(5) (5%) Which challenges limit the widespread deployment of high-entropy metals? (Select *all* that apply.)

A. Difficulty in predicting phase stability

B. Limited control over microstructure–property relationships

C. Inherent lack of thermal stability

D. Challenges in scalable and reproducible synthesis

E. Complex interactions between entropy, enthalpy, and kinetics