Self-organized Nanodot Formation on InP(100) by Argon Ion Sputtering

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I. Introduction

➢ In recent years, the formation of nanostructures on semiconductor surfaces has attracted much interest due to their potential for applications in low-dimensional devices, particularly as ordered quantum nanodots for optoelectronics and quantum devices.

➢ Low energy ion sputtering using inert gases such as argon has been shown to be a promising non-lithographic, and hence simpler technique for the formation of surface nanostructures.

➢ Low energy argon ion sputtering has been used to form highly ordered self-assembling nanodots on GaSb,[1] InP[2] and Si(100)[3] surfaces.

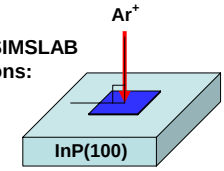
II. Objective

➢ Formation of self-organized ordered nanodots array on InP(100) surface by rastered Ar^+ beam sputtering at normal incidence.

III. Experiment

➢ Substrate : InP(100)

➢ The experiments were performed in VG ESCA MkII/SIMSLAB with EXO5 sputtering gun under the following conditions:
- ❖ Ion Beam : 1 keV Ar^+
- ❖ Incidence angle : Normal
- ❖ Raster Size : 2.57 × 3.35 mm^2
- ❖ Stage temperature, T = -110 °C, 23 °C and 36 °C.



IV. Results and Discussion

A. Dependent of nanodots formation on experimental conditions

1. Sputtering time
(j_{ion}= 23.3 μA cm^{-2}, T = 23 °C)

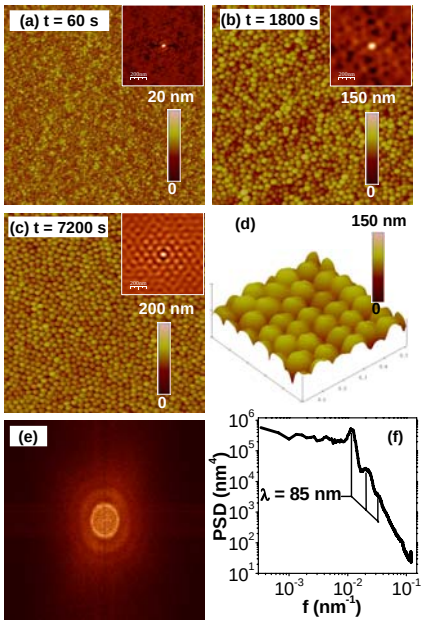


Fig. 1. 3 μm × 3 μm AFM image of Ar^+ sputtered InP surface at (a) t = 60 s, (b) t = 1800 s, and (c) t = 7200 s. (d) 500 nm × 500 nm 3D AFM topography from a magnified area of (c). Insets are the self-correlated image calculated from the 1 μm × 1 μm magnified area of the corresponding AFM image. (e) Fourier Transform spectrum (FFT) and (f) angular average PSD function calculated from (c).

➢ Ordering of the nanodots array increases with the increasing of sputtering duration.

➢ After 7200s of sputtering, a hexagonal nanodots array is formed, Fig. 1(C):
- ❖ Coherence length > 500 nm
- ❖ Mean inter-dot distance = 73 ± 10 nm
- ❖ Dot diameter = 73 ± 10 nm
- ❖ Dot density = 1.3 × 10^{12} dots/cm^2

➢ After 7200 s sputtering, the ordering of the nanodots does not improve, and is stable even after further sputtering.

2. Ion current density, j_{ion}
(ion dose = 1.05 × 10^{18} cm^{-2}, T = 23 °C)

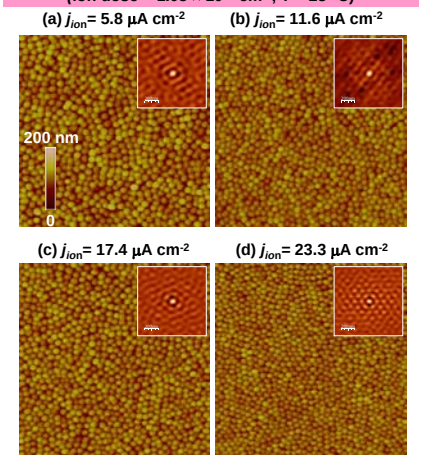
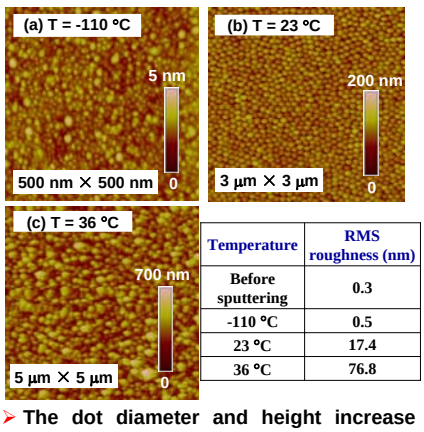


Fig. 2. 3 μm × 3 μm AFM image of InP(100) surface sputtered by 1 keV Ar^+ beam with different ion current density. Insets are the self-correlated image of 1 μm × 1 μm AFM image.

➢ Ordering of the nanodots array increases with the increasing of ion current density (ion flux).

➢ A highly regular hexagonal pattern is formed at 23.3 μA cm^{-2}.

3. Temperature
(j_{ion}= 23.3 μA cm^{-2}, ion dose = 1.05 × 10^{18} cm^{-2})



Temperature	RMS roughness (nm)
Before sputtering	0.3
-110 °C	0.5
23 °C	17.4
36 °C	76.8

➢ The dot diameter and height increase with the increasing of temperature

➢ Well ordered hexagonal nanodots can only form at a specific temperature window.

B. SEM and *in-situ* XPS analysis

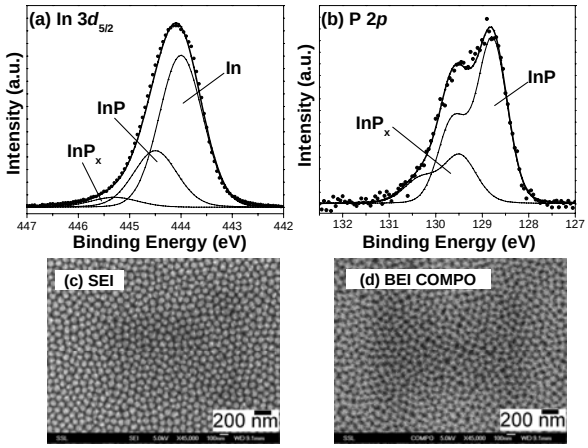


Fig. 4. (a) In $3d_{5/2}$ and (b) P 2*p* XPS spectra, (c) Secondary electron image (SEI) and (d) Backscattered electron composition image (COMPO) of nanodots array formed under 23.3 μA cm^{-2}, 1 keV Ar^+ beam sputtered for 7200 s.

XPS

➢ Elemental In and InP_x (x>1) are found on the sputtered surface.

➢ The ratio of In to P from the sputtered surface is 2.4.

SEM

➢ The bright areas on COMPO image, Fig. 4(d), are due to the backscattered electron by In atoms.

➢ Excess In atoms exist on the sputtered surface due to the preferential sputtering of P atoms.

D. Temporal evolution of sputtered surface

Scaling theory:
$\sigma(L, t) \sim L^{\alpha} f(t/L^{\alpha/\beta})$; L = system size,
$u \ll 1 : f(u) \sim u^{\beta}$ for, $u \gg 1 : f(u)$ = const

$t \ll t_c$: $\sigma(L, t) \sim t^{\beta}$
$t \gg t_c$, $\sigma sat(L) \sim L^{\alpha}$
$\lambda \sim t^{\gamma}$

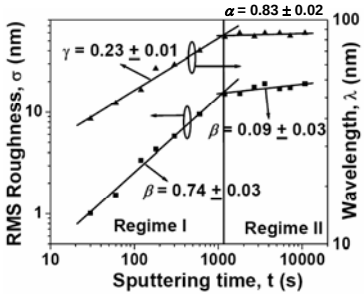


Fig. 5. RMS surface roughness (σ) and nanodot wavelength (λ) temporal evolution of InP surface sputtered at j_{ion}= 23.3 μA cm^{-2}, T = 23 °C.

Regime I : Coarsening

➢ Growth of nanodots.

➢ The lateral size and height of nanodot increase.

Regime II : Ordering

➢ Saturation of lateral size and height of nanodots.

➢ Ordering of the nanodots increases and formation of hexagonal array.

V. Conclusions

➢ Ordering of the nanodots formed under Ar^+ sputtering of InP(100) strongly dependent on experimental conditions such as temperature, ion flux, sputtering angle and sputtering duration.

➢ The nanodots surface are In-rich due to the preferential sputtering of P atoms.

➢ Using scaling theory, the evolution of the sputtered surface can be fitted into two different regimes: coarsening in the early-time regime and ordering in the late-time regime.

VI. References

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2. F. Frost, A. Schindler, and F. Bigl, Phys. Rev. Lett. 85, 4116 (2000).

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