

A Simple Introduction to the Basic Principle of PLD

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References :

Douglas B. Chrisey, and Craham K. Hubler (1994), *Pulsed Laser Deposition of Thin Films*. John Wiley & Sons, Inc., 605 Third Avenue, New York, NY 10158-0012;

Duanming Zhang, Zhihua Li, et al(2010); *The Principle of Pulsed Laser Deposition*. Science Press, Beijing;

Outline

I. *The History of Pulsed Laser Deposition: A Chronological Overview*

1. 1960~1969;
2. 1970~1979;
3. 1980~1987;
4. 1987~1994;
5. 1994~

Outline

II. Equipment

- 1. Excimer Lasers;*
- 2. Optics;*
- 3. Deposition Systems;*
- 4. Safety and Facilities;*

III. PLD Three-Step Process ($\tau \sim ns$ && $I_0 \leq 10^8 W/cm^2$)

0. A Sketchy Description of PLD.

1. Laser-Target Interaction

1) Thermal Response

- 2) Laser-induced Periodic Surface Structures
- 3) Cone Formation
- 4) Effects on Film Deposition

Outline

2. Transport of the Vapor Plume

3. Film Growth on a substrate

IV. PLD Three-Step Process ($\tau < ps$ && $I_0 > 10^8 W/cm^2$)

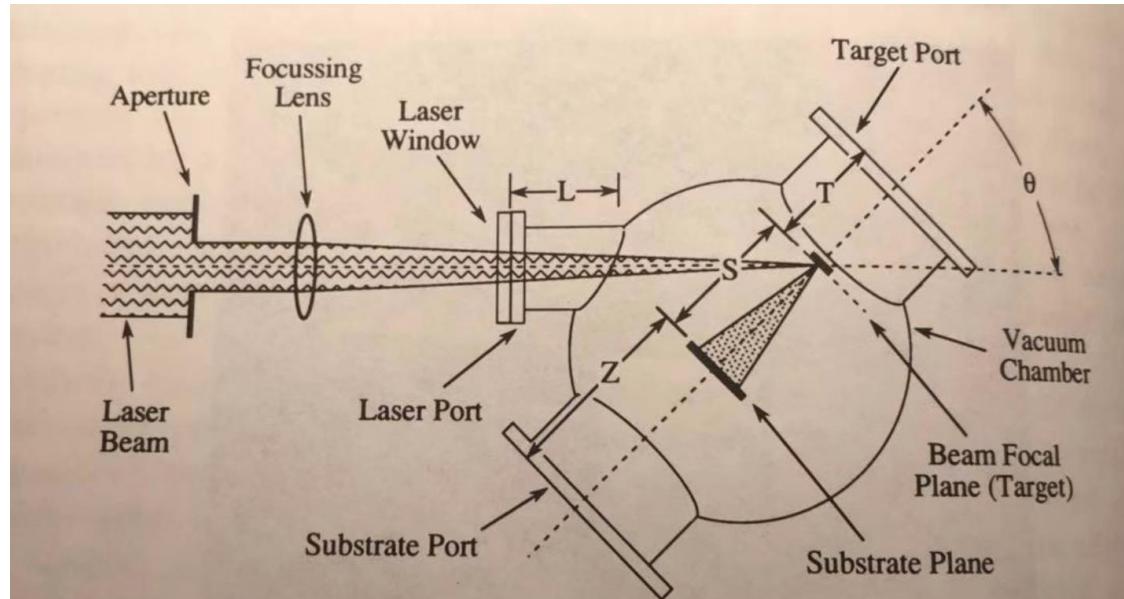
1. Laser-Target Interaction

2. Transport of the Vapor Plume

3. Film Growth on a substrate

V. PLD Applications in Film Growth

PLD Three-Step Process: Sketchy Description



Chamber, target manipulation, substrate holder, heater holder, pump, gas flow and vacuum gauging

First process:

set up target and substrate, use heater system to heat them and monitor their temperature; laser pulses are focused by lens and hit on target and interact with targets and produce plasma plume.

Second process:

Plume expands isothermally and adiabatically along the normal of target surface and arrives at substrate.

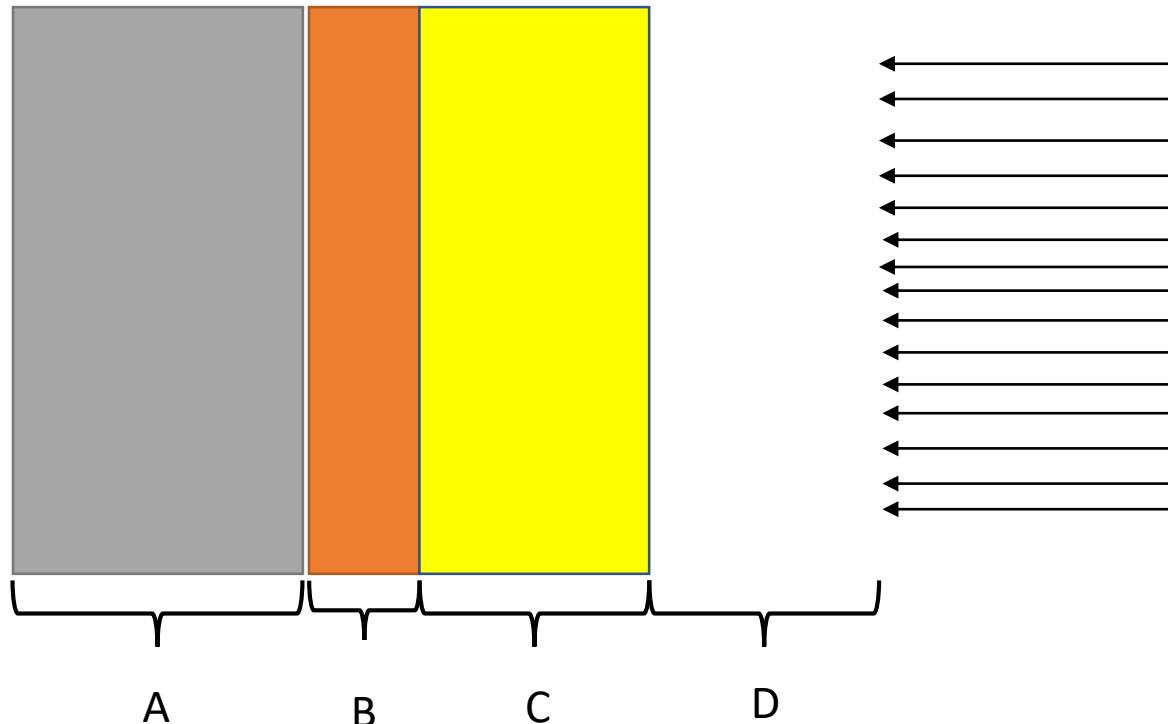
Third process:

Particles inside plasma deposit around nucleation centers (surface defects like atomic steps, point defects and dislocation intersections) and a lot of isolated clusters form, grow up gradually and combine into the whole film together

Laser-Target Interaction

Thermal Response

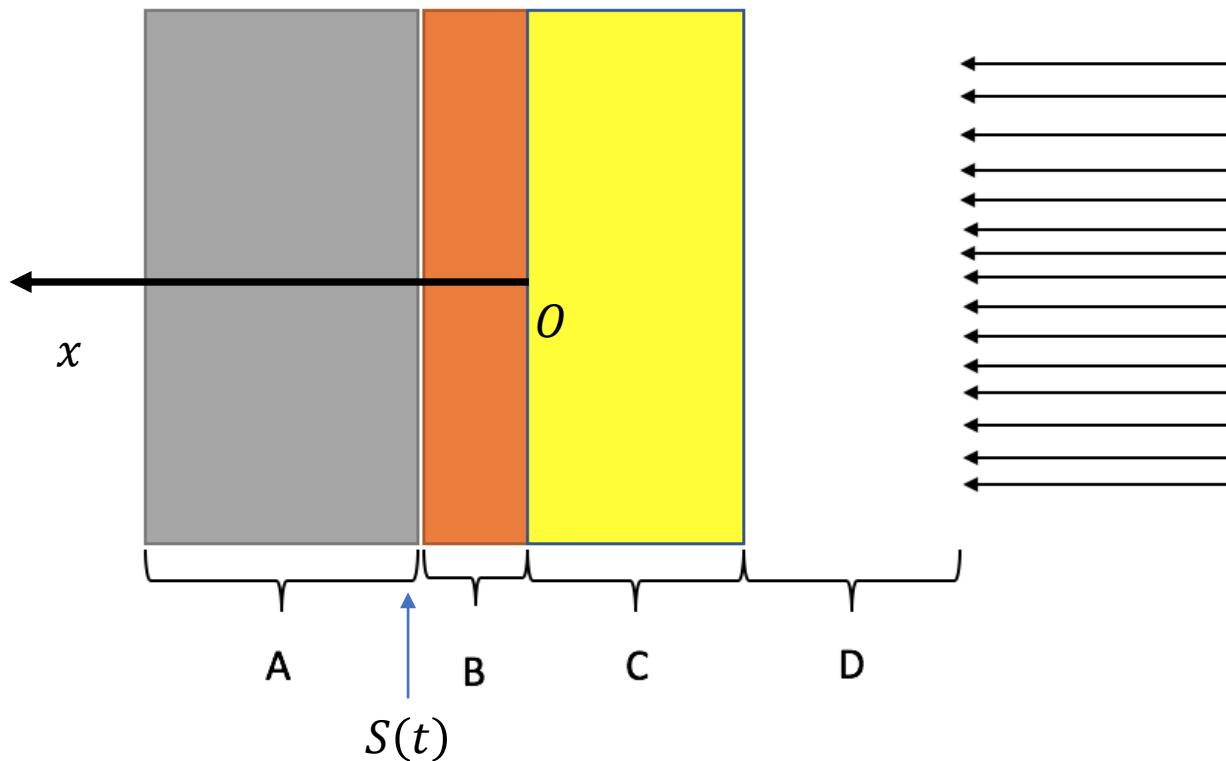
$$\tau \sim ns \quad \& \quad I_0 \leq 10^8 W/cm^2$$



- A: Solid Zone
- B: Melted Zone
- C+D: Plasma Zone
- C: Corona Zone
- D: Transparent Zone

Laser-Target Interaction

- Thermal Response



$$\tau \sim ns \quad \& \quad I_0 \leq 10^8 W/cm^2$$

Laser Spot Size $\sim mm^2$ Infinite plane

Melted Depth d $\sim \mu m \ll mm$

3-d thermal conduction Problem



1-d thermal conduction Problem

Laser-Target Interaction

A. Target dynamic absorption rate

$t - t + dt, x = 0$, Laser loses $\Delta E = I(0, t)\beta dt$;
target get $\Delta E' = \rho\delta(t)cdT(0, t)$

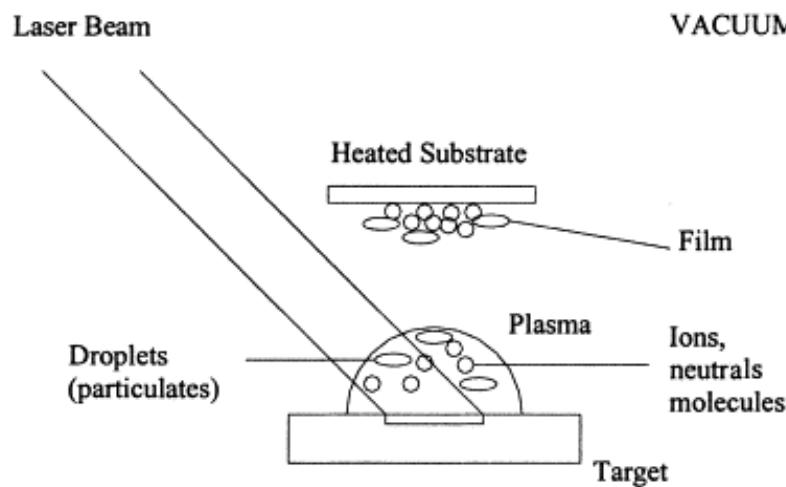
$$\Delta E = \Delta E' \Rightarrow \beta = \frac{\rho\delta(t)c}{I(0,t)} \frac{\partial T(0,t)}{\partial t}$$
$$\beta = A_0 + A_1 \left(Ct + \sqrt{C^2 t^2 + Dt} \right)$$

$\delta(t)$ depends on $T(0, t)$

$\frac{\partial T(0,t)}{\partial t}$ depens on $T(0, t)$ and $I(0, t)$

Laser-Target Interaction

- Vaporization term



Superheating: a liquid is heated to a temperature higher than its boiling point without boiling

Energy absorbed by vapor per unit area:

$$c_l \rho_l u(t) \frac{\partial T_l(x, t)}{\partial x}$$

$$u(t) = \frac{p}{\rho_l (2\pi k_B T/m)^{0.5}} C_s$$

Thermal Response

Thermal Conduction Problem

1) Before Melting ($0 < t < \tau_m$)

$$q_s = -k_s \frac{\partial T_s(x,t)}{\partial x}$$

$$c_s \rho_s \frac{\partial T_s(x,t)}{\partial t} = \frac{\partial}{\partial x} \left(k_s \frac{\partial T_s(x,t)}{\partial x} \right) + \beta(t) b I(x,t)$$

$$I(x,t) = I_0 e^{-bx} e^{-\frac{(t-\tau)^2}{2\sigma^2}}$$

$$\beta(t) = A_0 + A_1(Ct + \sqrt{C^2 t^2 + Dt}) \text{ Laser Absorption Rate}$$

$$T_s|_{t=0} = T_0$$

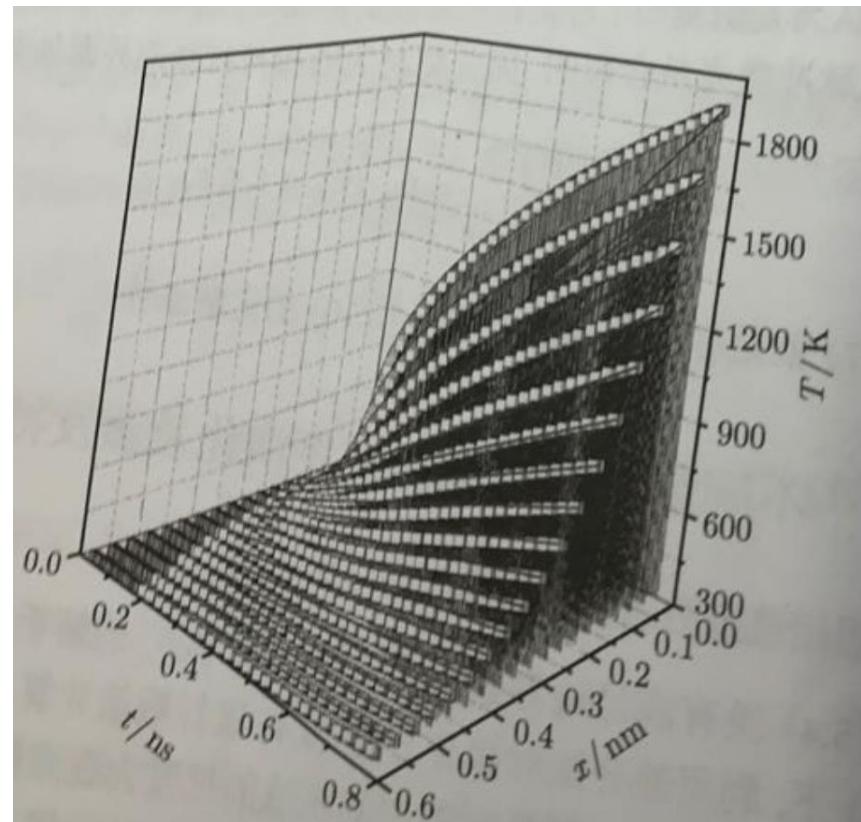
$$-k_s \frac{\partial T_s(x,t)}{\partial x} \Big|_{x=0} = \beta(t) I_0 e^{-\frac{(t-\tau)^2}{2\sigma^2}}$$

$$-k_s \frac{\partial T_s(x,t)}{\partial x} \Big|_{x=\delta} = 0$$

Thermal Response

1) Before Melting

$$\tau \sim 3\text{ns} \quad E_0 = 8.5 \text{ J/cm}^2, \quad T_0 = 300\text{K}$$



Si

$k_s / [\text{J}/(\text{s} \cdot \text{cm} \cdot \text{K})]$	$k_l / [\text{J}/(\text{s} \cdot \text{cm} \cdot \text{K})]$	$\rho_s / (\text{g}/\text{cm}^3)$	$\rho_l / (\text{g}/\text{cm}^3)$
1.35	0.6	2.3	2.5
$\Delta H_v / (\text{J/g})$	R	2	3
13722.0	0.72	1.0	0.9
		5	7

Thermal Response

- **Thermal Conduction Problem**

2) After Melting($\tau_m < t$)

$$c_s \rho_s \frac{\partial T_s(x,t)}{\partial t} = \frac{\partial}{\partial x} \left(k_s \frac{\partial T_s(x,t)}{\partial x} \right)$$
$$- k_s \frac{\partial T_s(x,t)}{\partial x} \Big|_{x=D} = 0$$

$$c_l \rho_l \frac{\partial T_l(x,t)}{\partial t} - c_l \rho_l u(t) \frac{\partial T_l(x,t)}{\partial x} = \frac{\partial}{\partial x} \left(k_s \frac{\partial T_l(x,t)}{\partial x} \right) + H(\tau - t) \beta(t) b I(x, t) e^{-(\sigma_{PI} + \sigma_{IB}) n_x H}$$

$T_l|_{t=\tau_m} = T_m$ melting temperature

$$- k_l \frac{\partial T_l(x,t)}{\partial x} \Big|_{x=0} = - L_v \rho_l u(t) + H(\tau - t) \beta(t) I_0 e^{-\frac{(t-\tau)^2}{2\sigma^2}} e^{-(\sigma_{PI} + \sigma_{IB}) n_x H}$$
$$- k_s \frac{\partial T_l(x,t)}{\partial x} \Big|_{x=S(t)} + k_l \frac{\partial T_l(x,t)}{\partial x} \Big|_{x=S(t)} = L_m \rho_s \frac{\partial S(t)}{\partial t}$$

$$T_s|_{x=S(t)} = T_l|_{x=S(t)} = T_m$$

Thermal Response

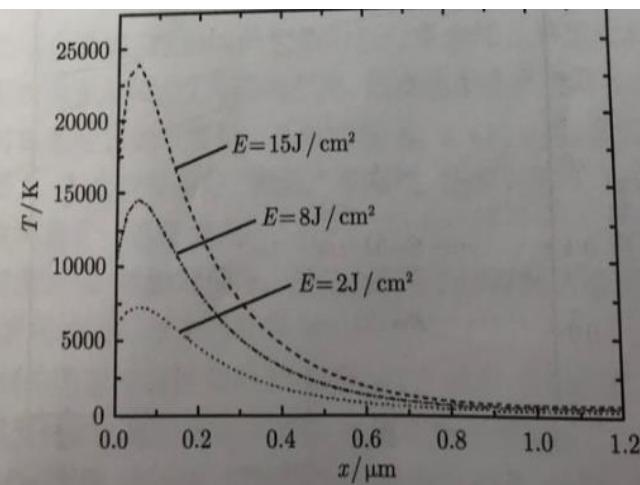
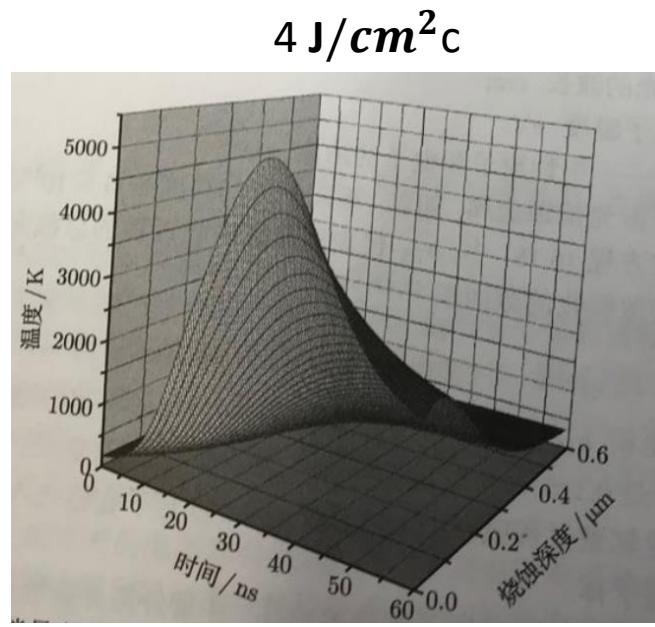


图 6.7 脉冲作用期间靶材温度随烧蚀深度的演化

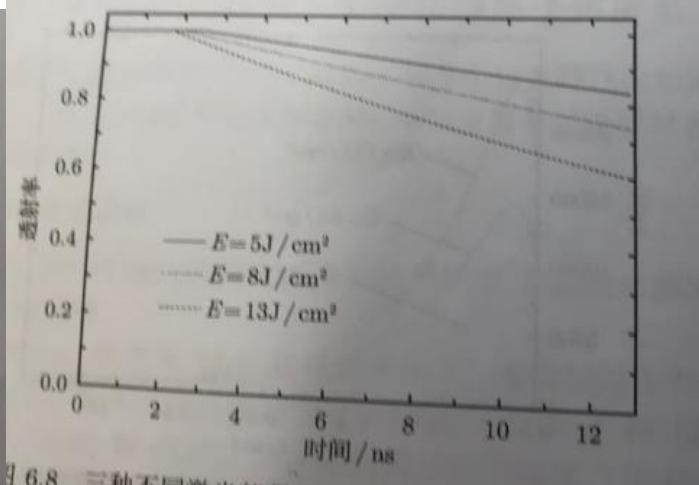
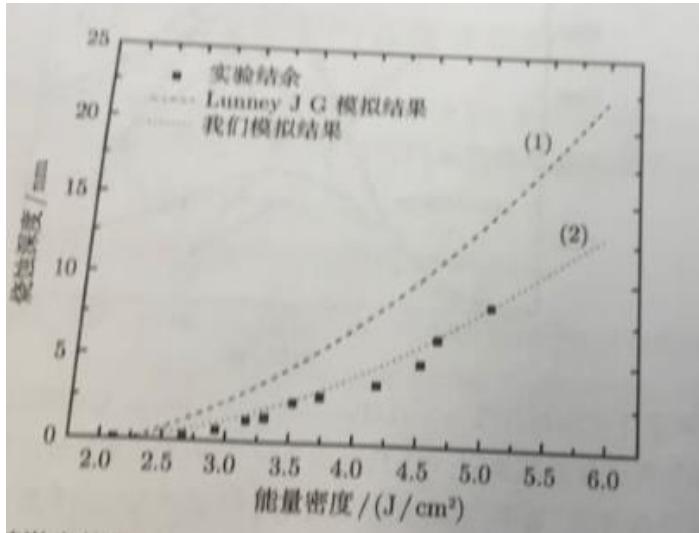


图 6.8 三种不同激光能量密度下的激光透射率的演化

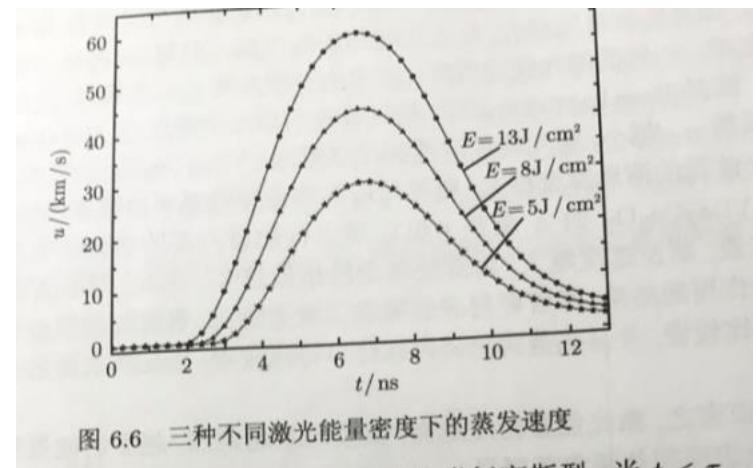


图 6.6 三种不同激光能量密度下的蒸发速度

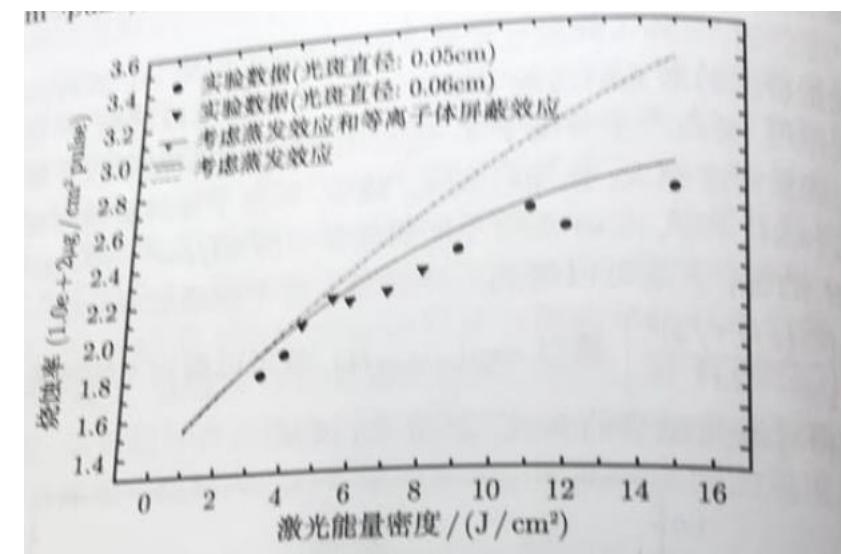


图 6.10 不同激光能量密度下的单脉冲激光烧蚀率

Thermal Response

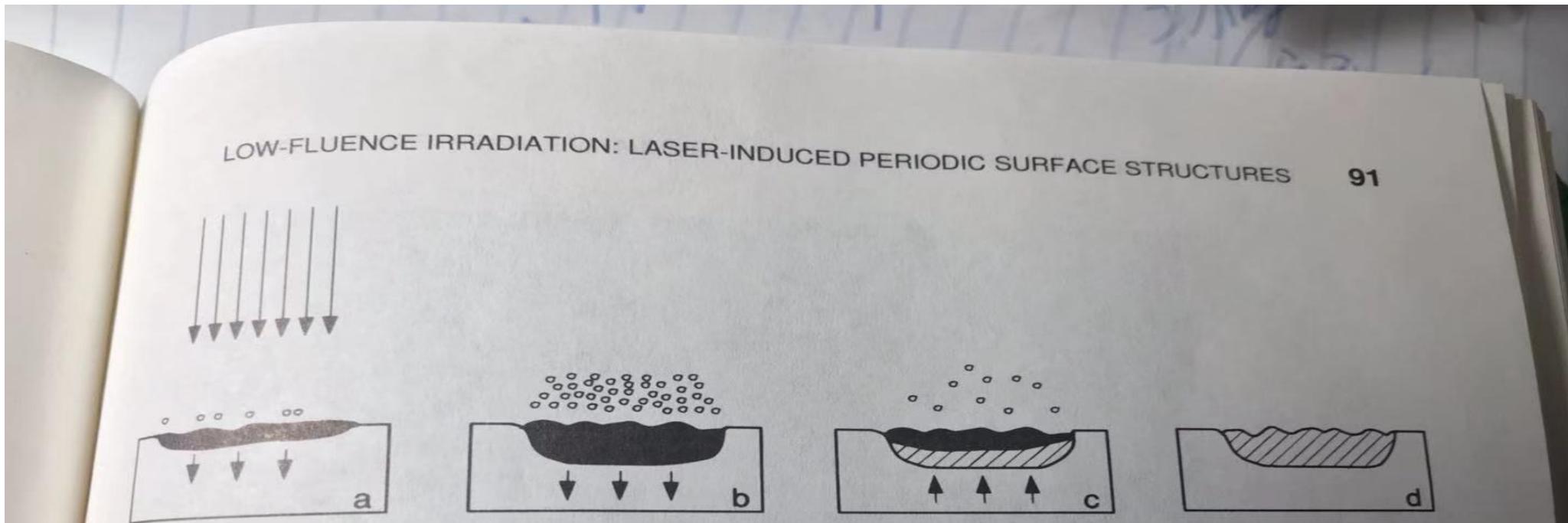


Figure 4.1. Schematic of the basic thermal cycle induced by a laser pulse. (a) Laser pulse is absorbed, melting and vaporization begin (shaded area indicates melted material, arrows indicate motion of the solid–liquid interface). (b) Melt front propagates into the solid, accompanied by vaporization. (c) Melt front recedes (cross-hatched area indicates resolidified material). (d) Solidification complete, frozen capillary waves alter surface topography. The next laser pulse will interact with some or all of the resolidified material.