

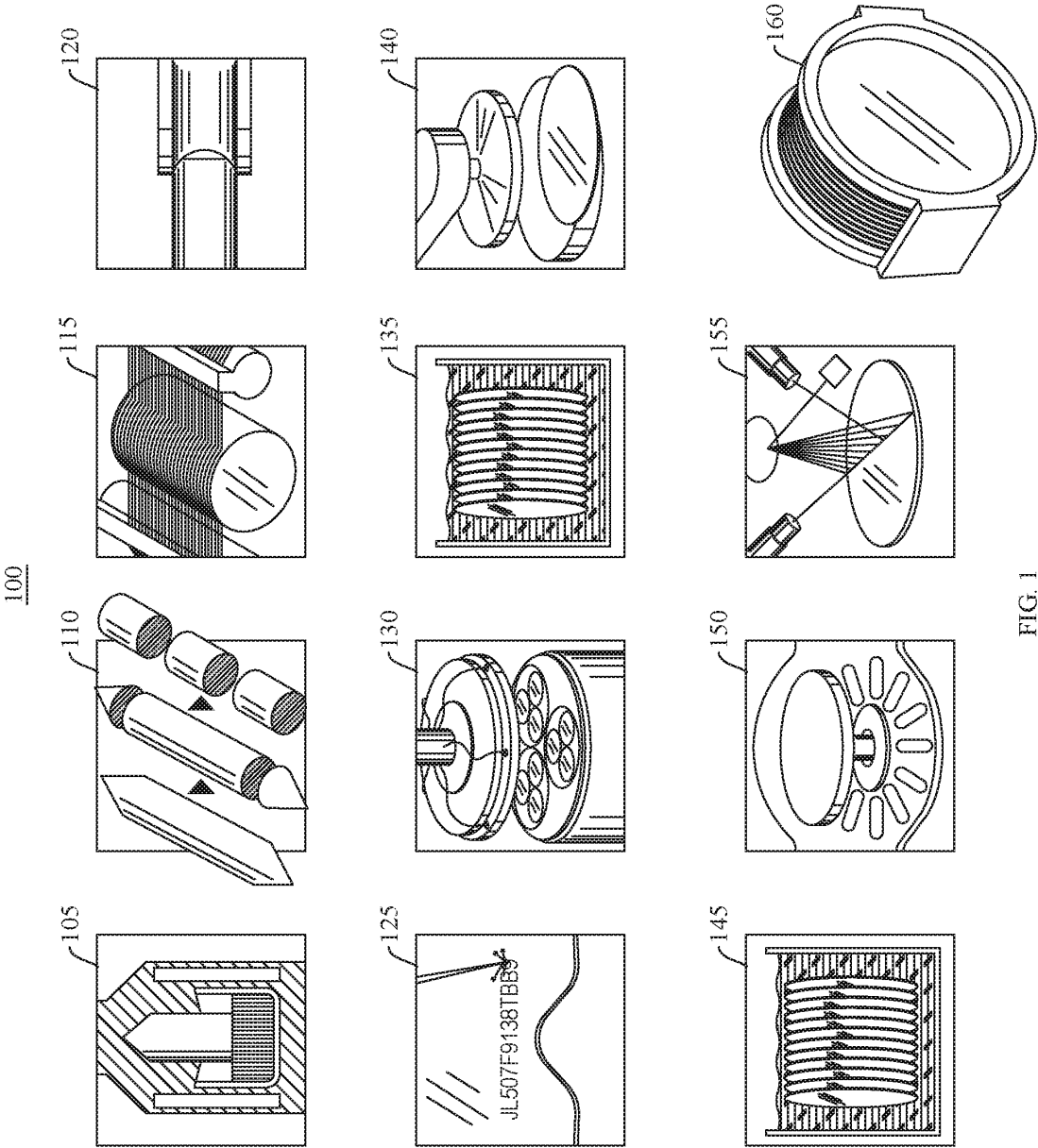


FIG. 1
PRIOR ART

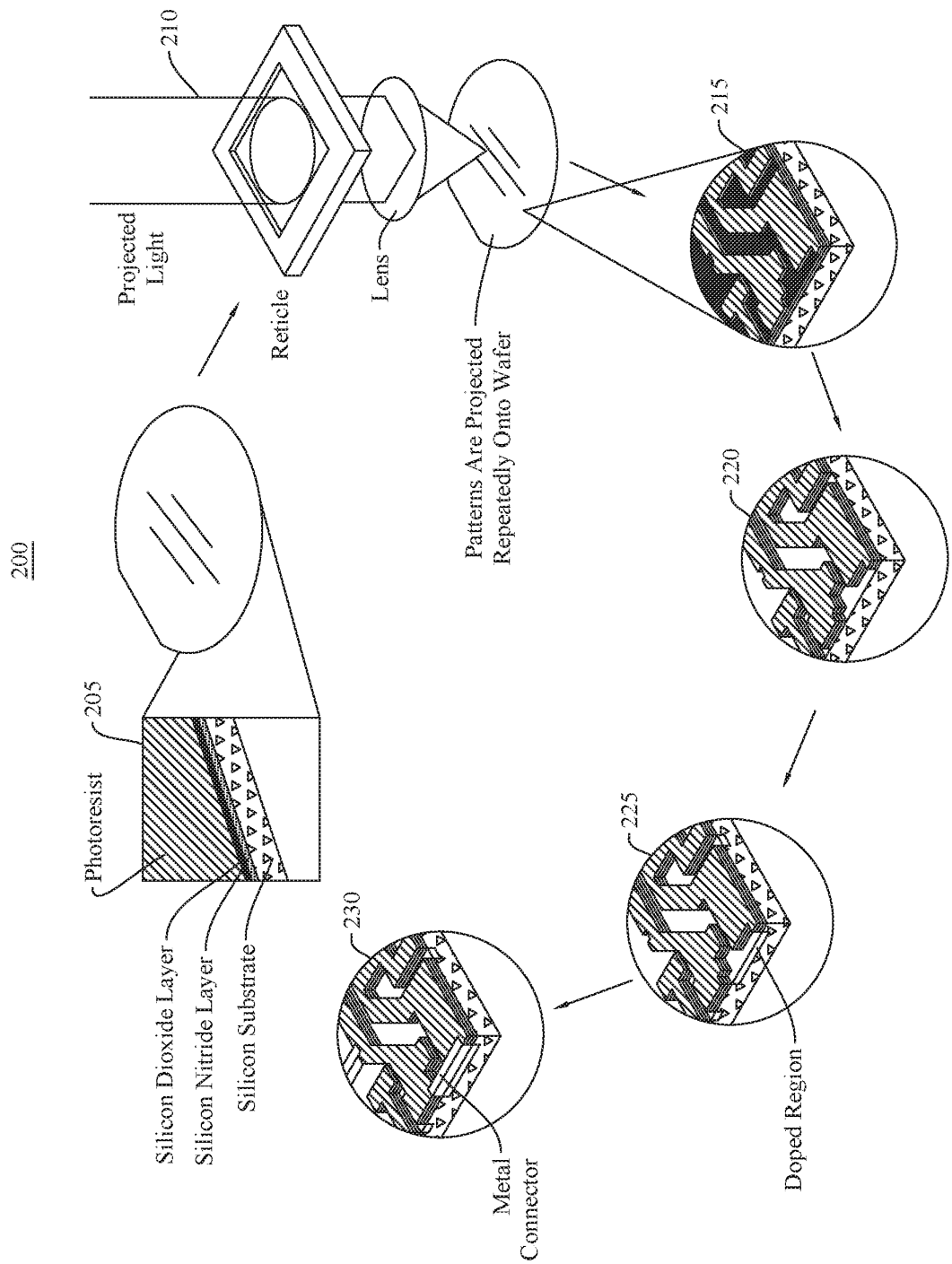


FIG. 2
PRIOR ART

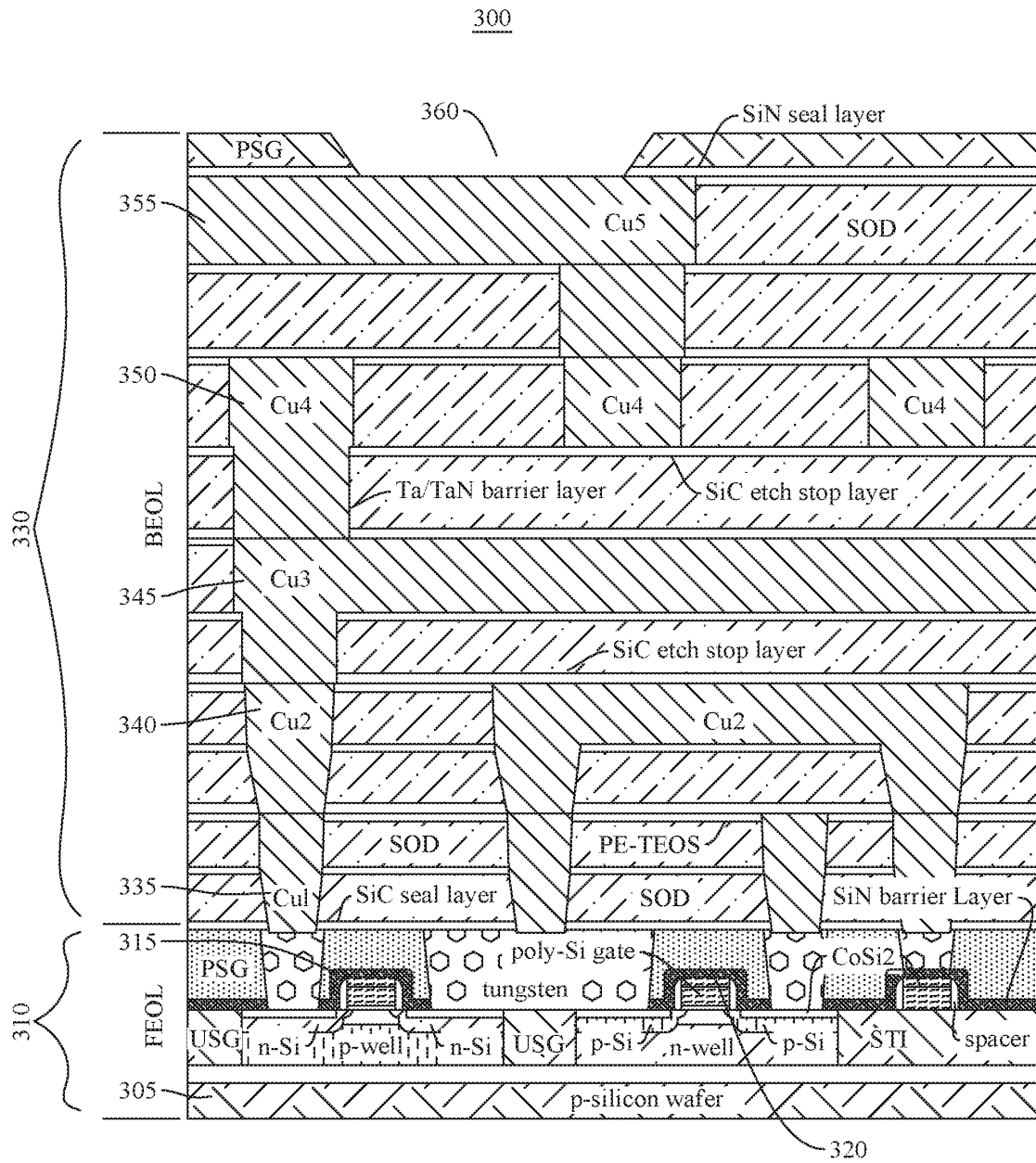
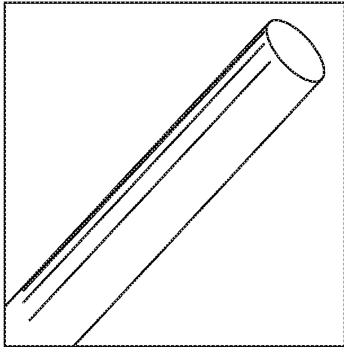


FIG. 3
PRIOR ART

400

Nd-YAG - Most Common Research Laser

- Nd³⁺-doped yttrium aluminum garnet (Y₃Al₅O₁₂)
- Solid-state
- Xe or Kr arc lamp or laser diode pumping
- IR wavelengths with ability to double, triple, quadruple
- Capable of tens of nanoseconds of pulse duration



Source	Makeup	Energy Input	λ (nm)	Pulse(s) Width	Pulse Rate(Hz)
Excimer	Noble+Reactive Gas: Kr-F, Xe-f, Ar ₂ , XeCl	Gas discharge or high energy electron beam	126 to 351	10 ⁻⁸	1 - 1000
Nd-YAG	Nd3+-doped T ₃ Al ₅ O ₁₂ or other crystal/glass	Xe or Kr arc lamp, or laser diode	$\frac{1064}{n}$, n = 1, 2, 3, 4	10 ⁻⁸	1 - 1000

FIG. 4

500

- Ti-Sapphire - Requires a second laser for operation
- Ti^{3+} -doped Al_2O_3
 - Solid-state
 - Laser-pumped
 - Tunable wavelength
 - Capable of tens of femtoseconds of pulse duration

Source	Makeup	Energy Input	λ (nm)	Pulse(s) Width	Pulse Rate(Hz)
Ti-Sapphire	Ti-doped Al_2O_3	Argon-ion or frequency-doubled Nd-YAG laser	650 to 1100	10^{-14} to 10^{-12}	$< 5 \times 10^4$

FIG. 5

600

Carbon dioxide - Used in high-power industrial applications

- 1:1:6 mix of CO₂:N₂:He
- Gas-phase
- Gas-discharge pumping
- Far IR wavelengths
- Capable of hundreds of nanoseconds pulse duration

Source	Makeup	Energy Input	λ (nm)	Pulse(s) Width	Pulse Rate(Hz)
CO ₂	CO ₂ , N ₂ , 6He mix	Gas discharge, requires effective cooling	9400 to 10600	10 ⁻⁷	1x10 ⁹

FIG. 6

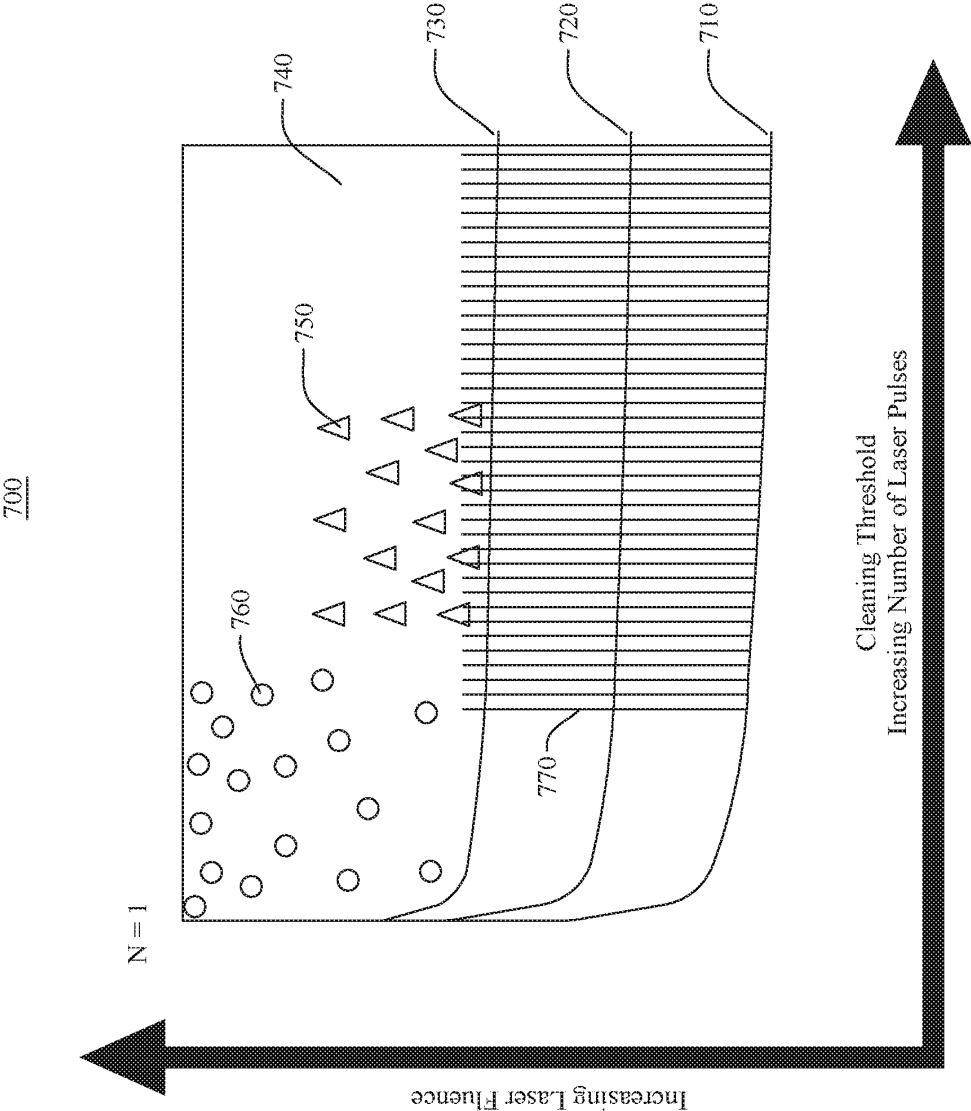


FIG. 7

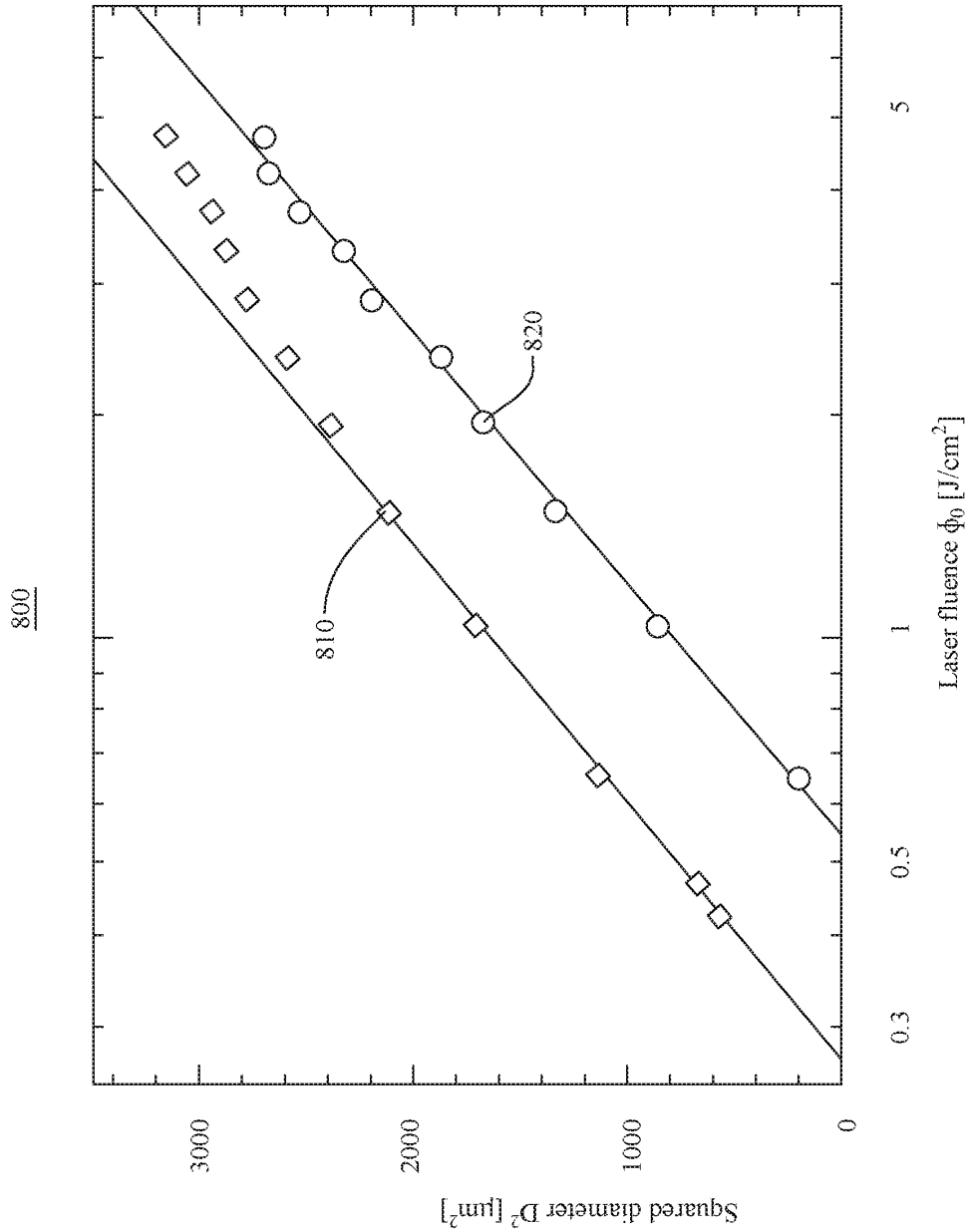


FIG. 8

900

Required laser pulse parameters depend on target material properties

- D_T
- a
- H_v
- p
- Thermal diffusivity
- Attenuation coefficient
- Heat of vaporization
- Density

Process Parameters

Pulse Duration	τ_L	s	10^{-15} to 10^{-7}
Fluence	F	J/cm ²	0.1 to 100
Beam Spot Size	r_b	m	10^{-3} to 10^{-7}
Ambient Medium	-	-	Air, vacuum, non-reactive gas/liquid

FIG. 9

1000

Two-temperature thermo-optical model

$$C_e \frac{\partial T_e}{\partial t} = \frac{\partial}{\partial z} \left(k_e \frac{\partial T_e}{\partial z} \right) - \Gamma_{e-p} (T_e - T_L) + (1 - R) \alpha I(t) e^{-\alpha z}$$

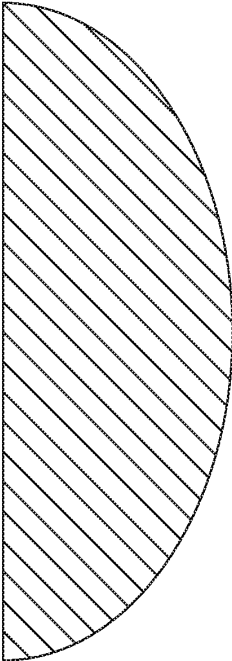
$$C \frac{\partial T_L}{\partial t} = \Gamma_{e-p} (T_e - T_L)$$

- T_e = Electron temperature
- T_L = Lattice temperature
- C_e = Electron volumetric heat capacity
- C = Lattice volumetric heat capacity
- k_e = Electron thermal conductivity
- Γ_{e-p} = Electron-lattice energy transfer coefficient
- α = Target attenuation coefficient
- R = Target reflectivity
- I = Laser intensity

Characteristic time scales

- τ_e = Electron cooling time
- τ_p = Lattice heating time
- τ_L = Pulse duration

FIG. 10



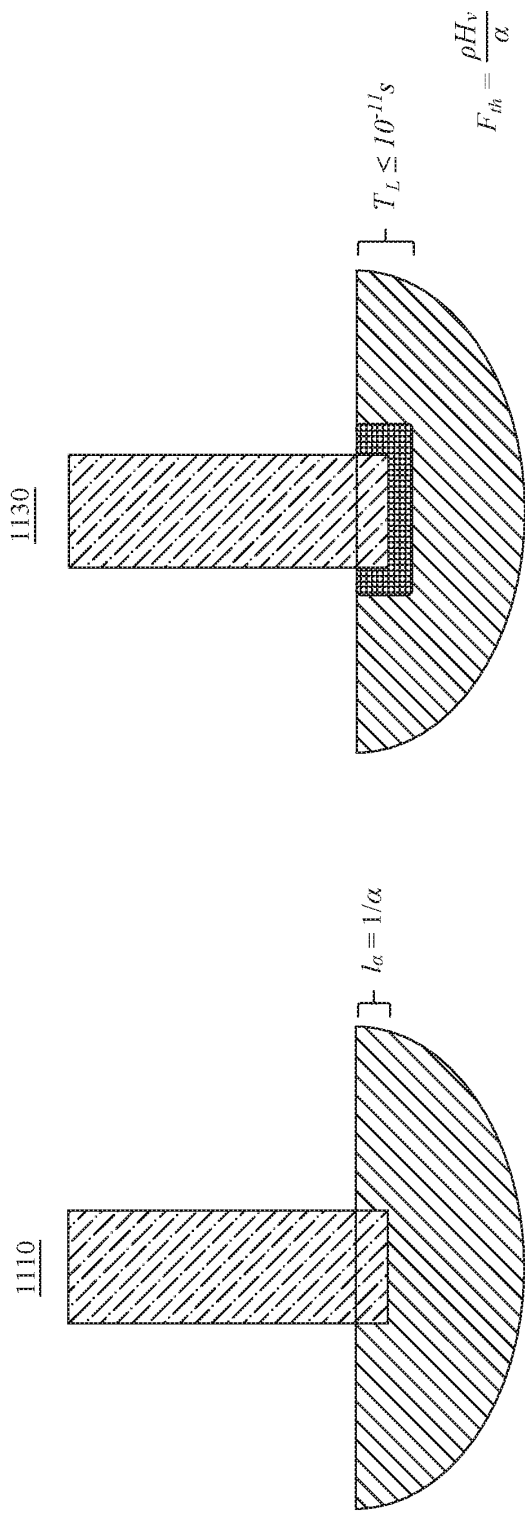


FIG. 11C

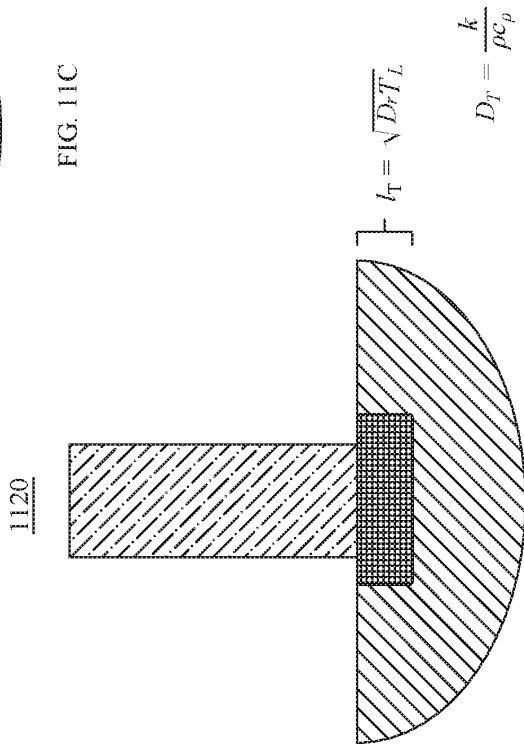


FIG. 11B

FIG. 11A

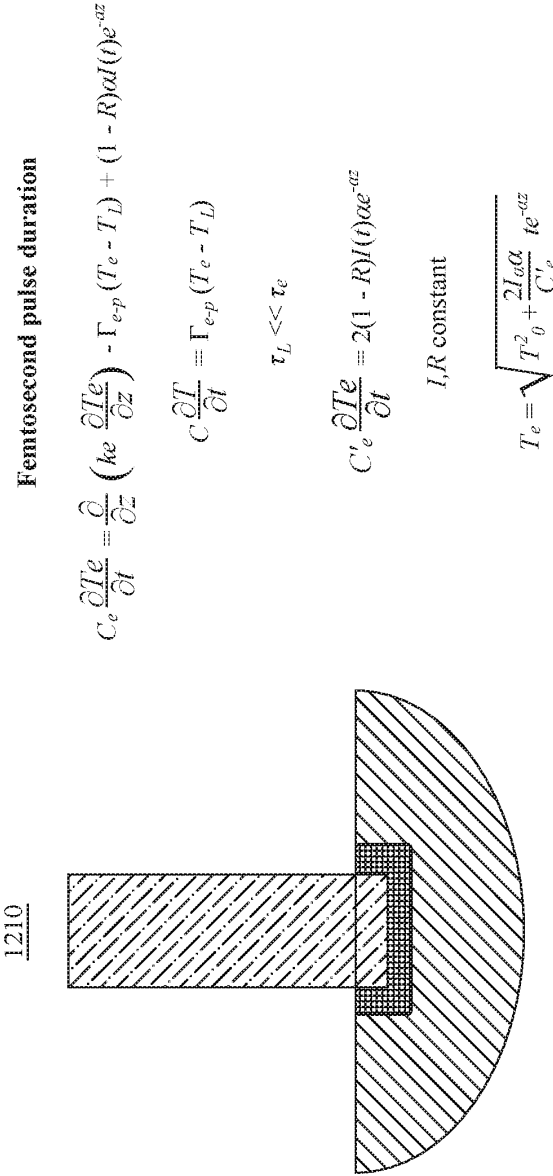
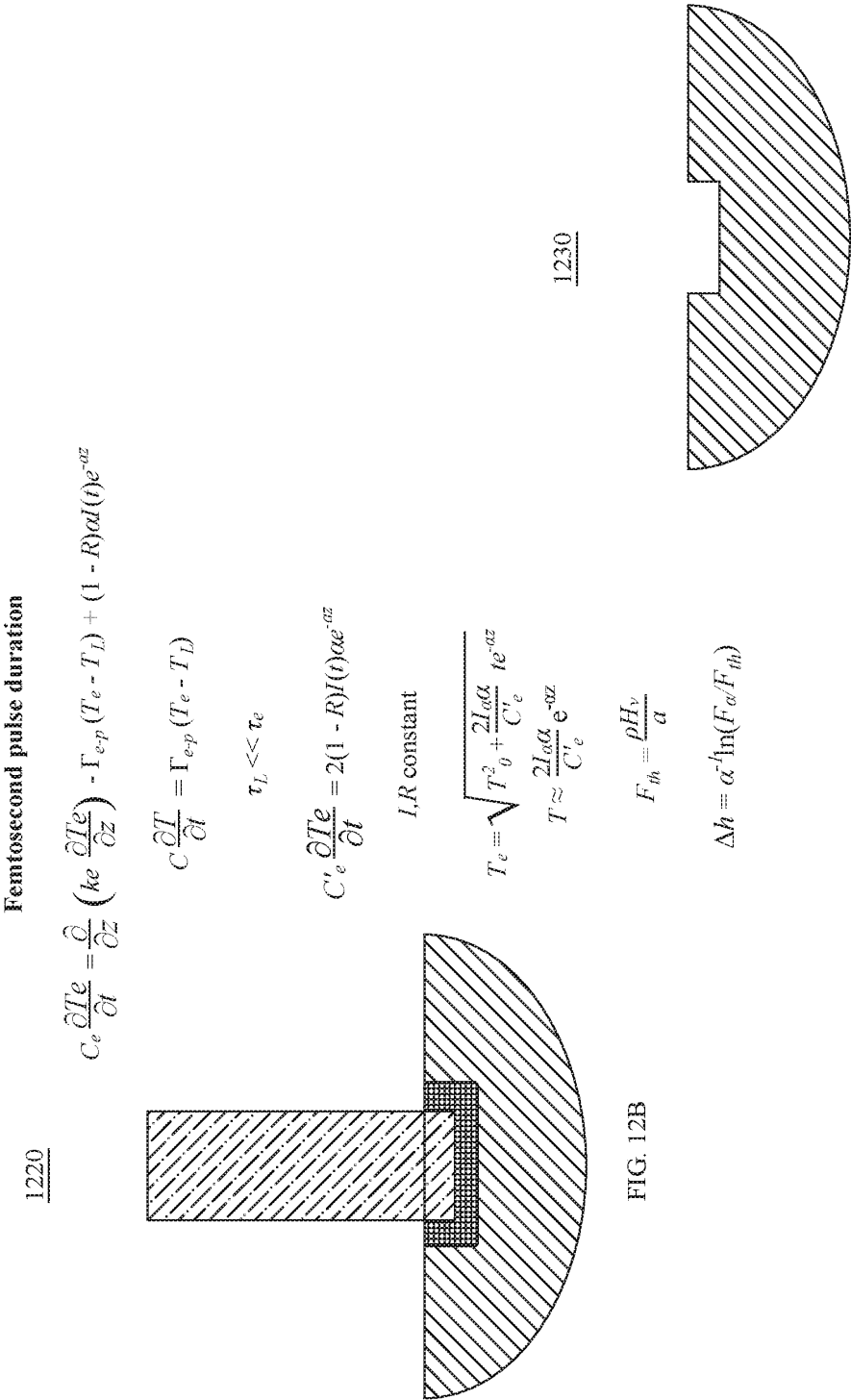


FIG. 12A



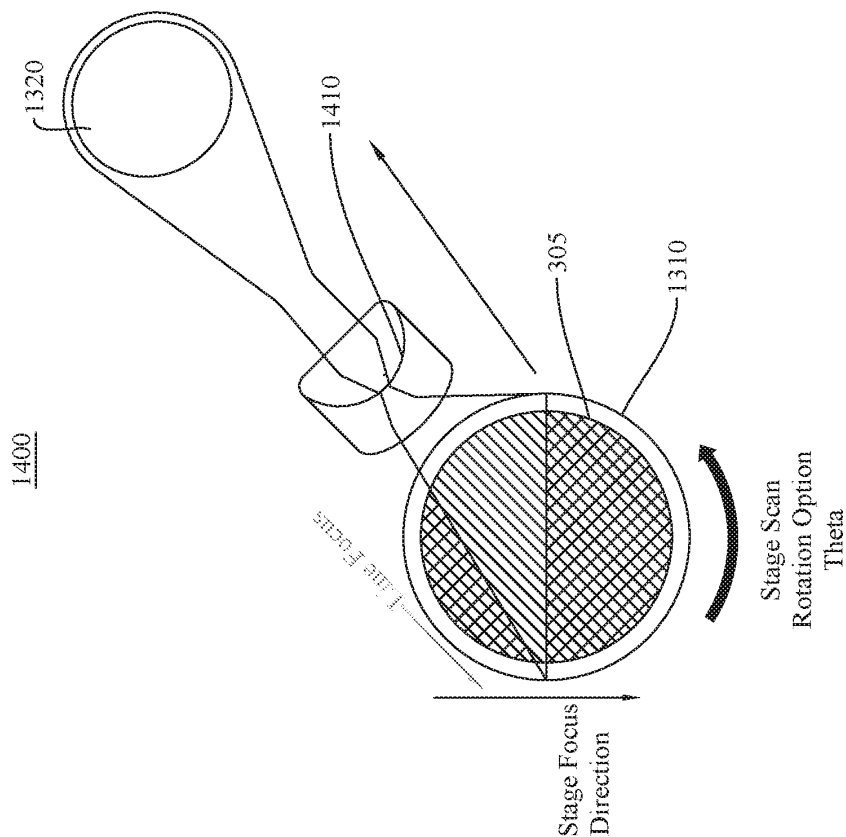


FIG. 14

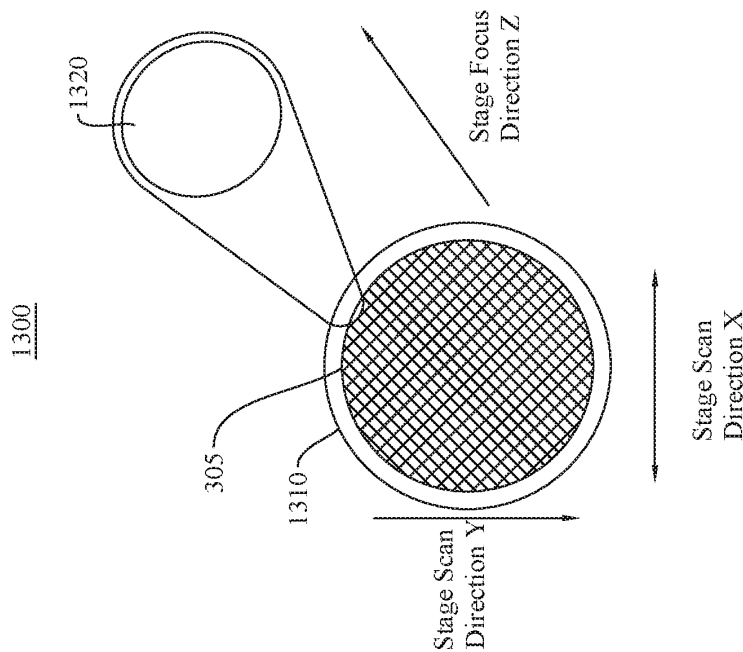


FIG. 13

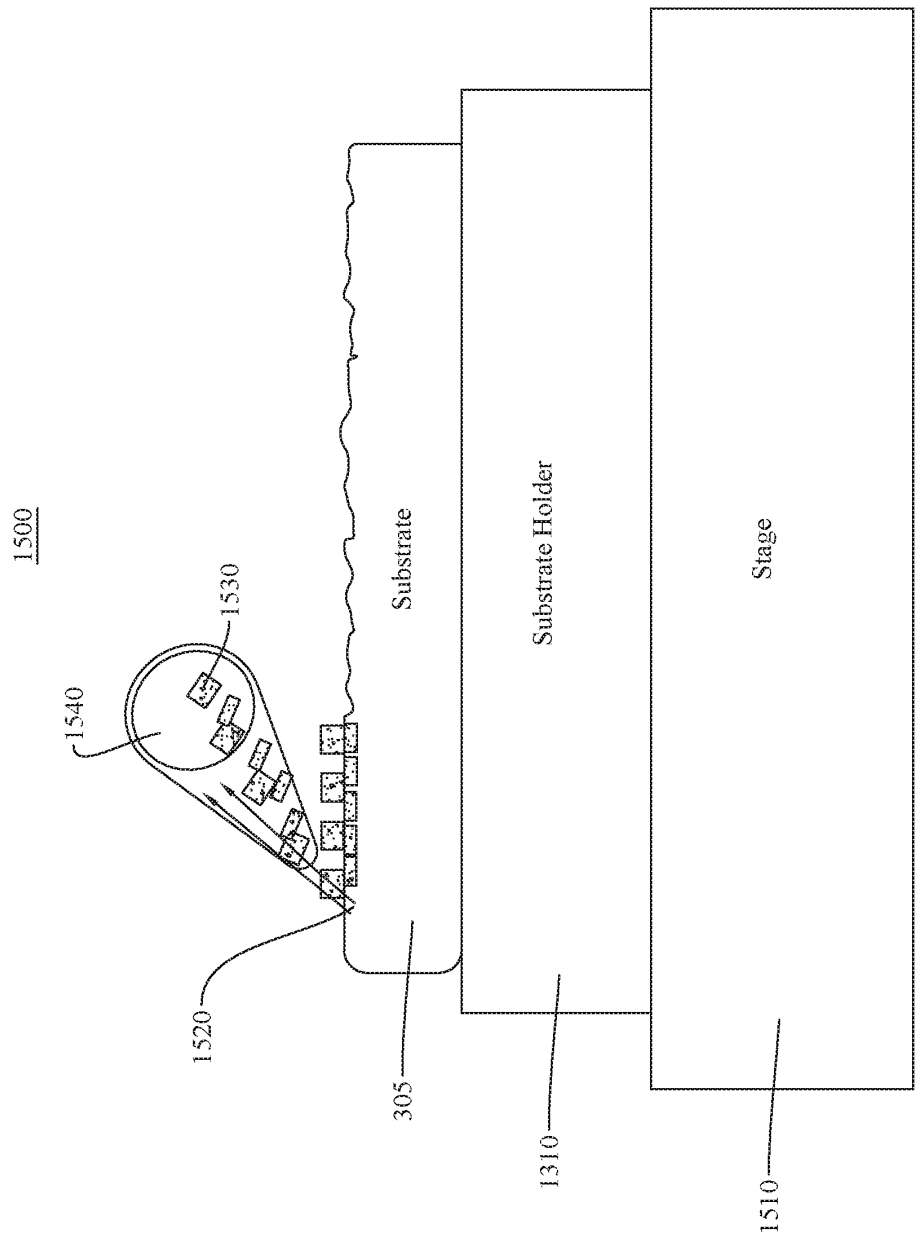
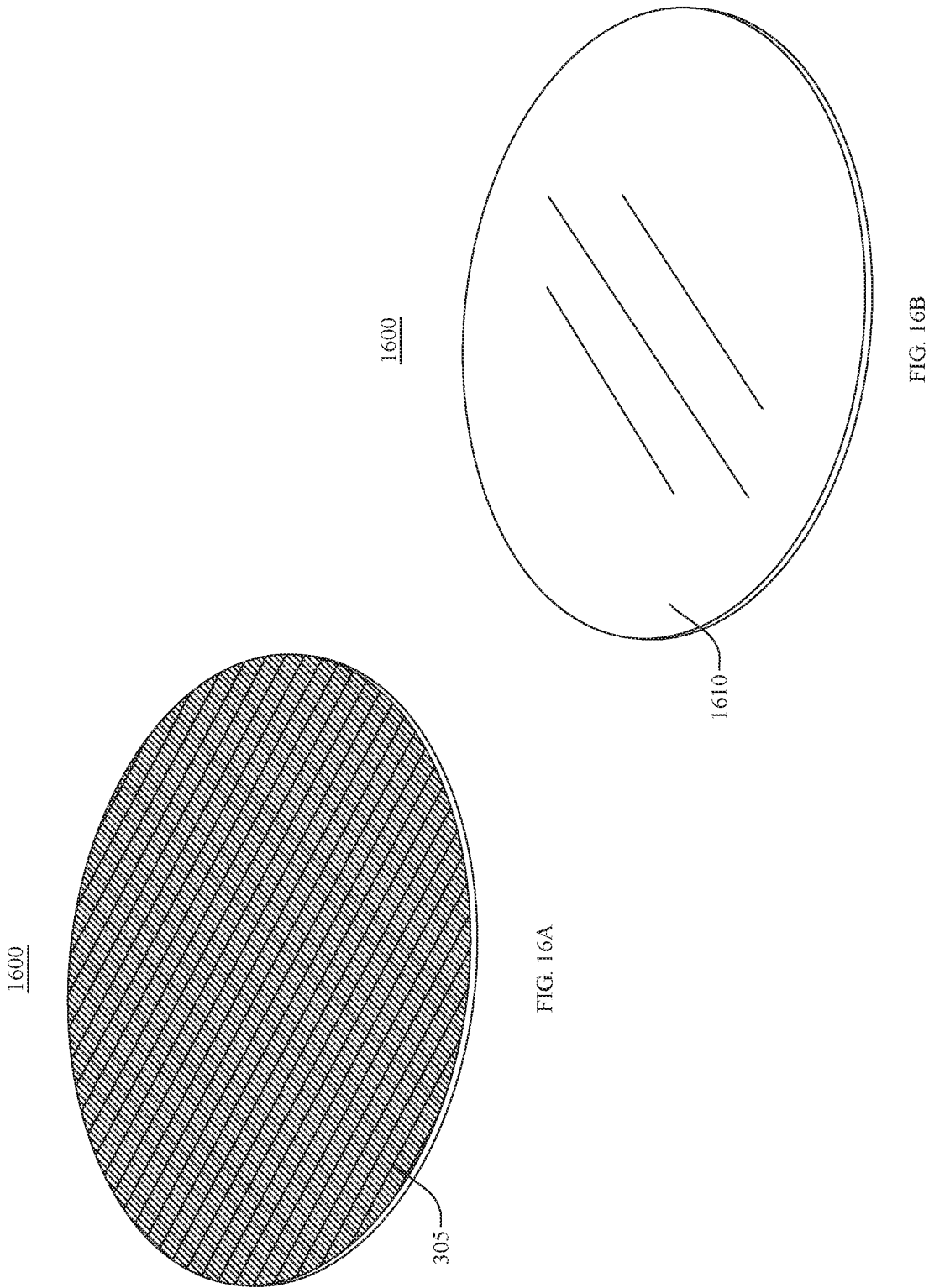
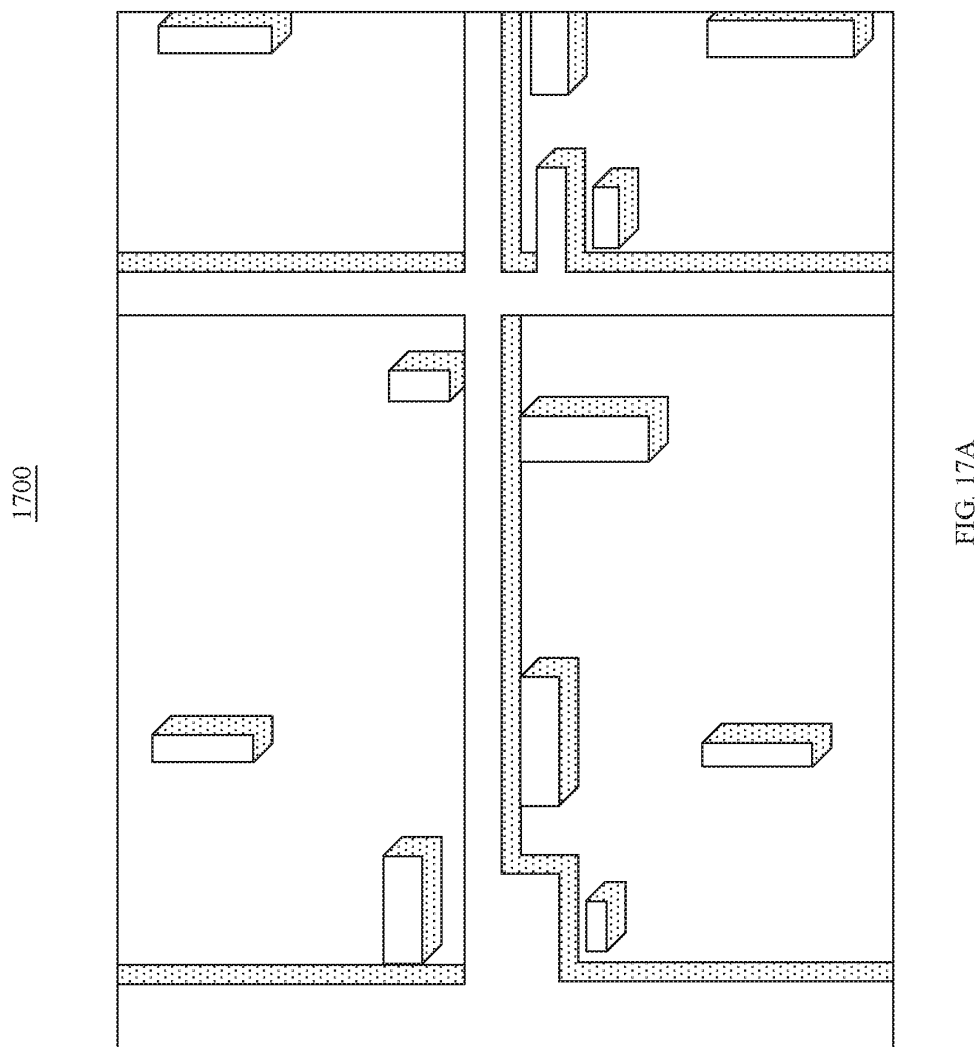


FIG. 15





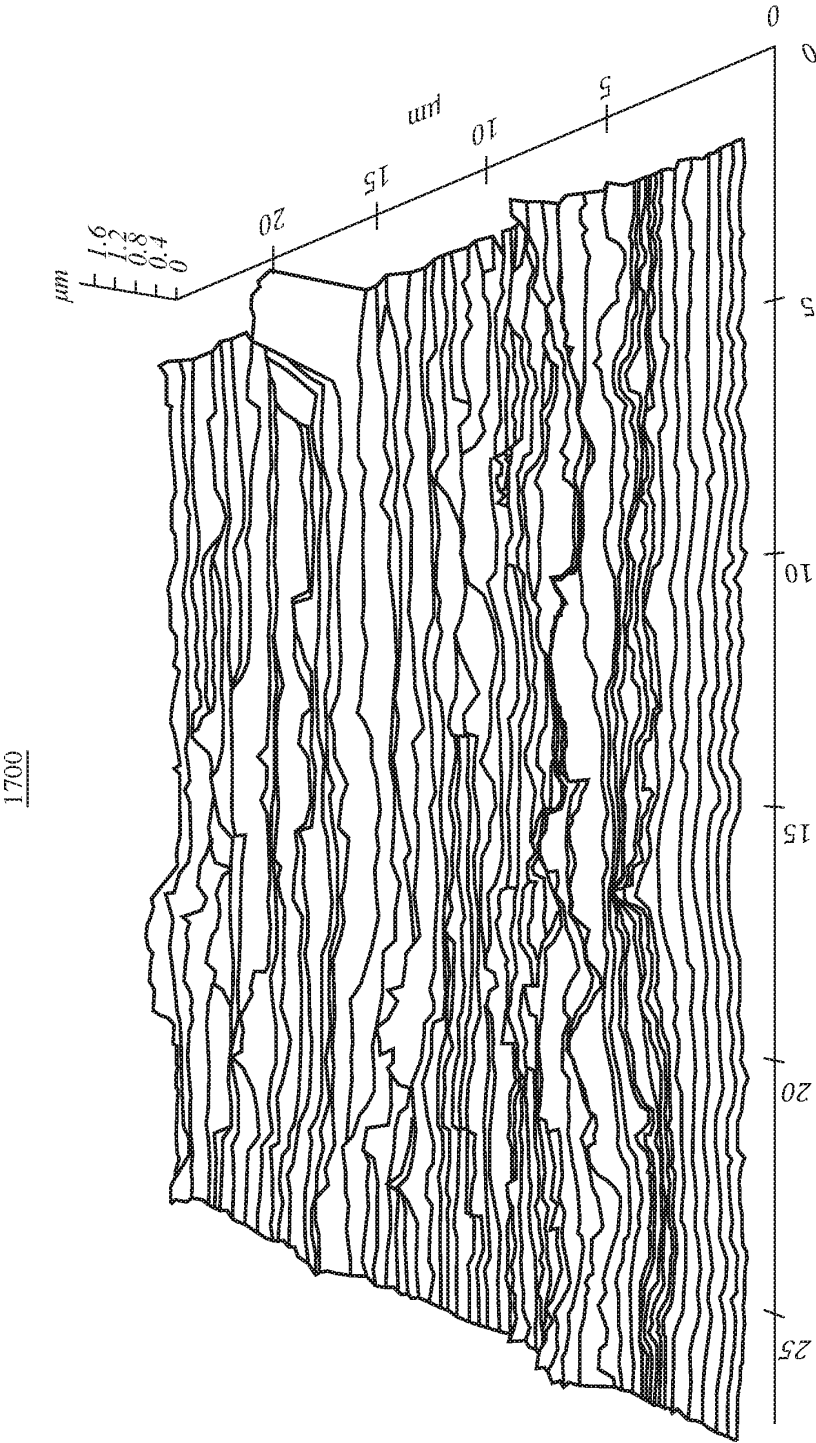


FIG. 17B