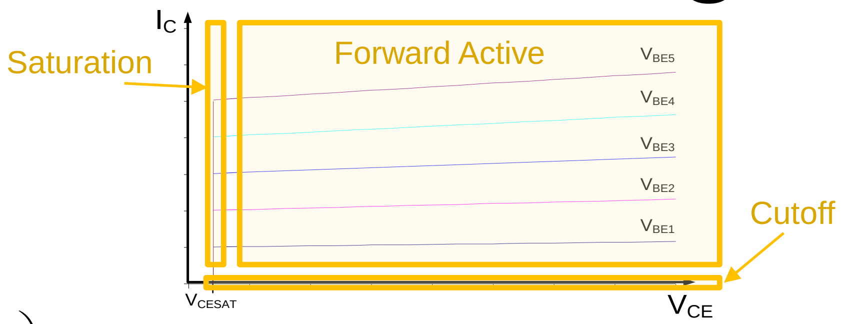
EE 330
Lecture 21

- Bipolar Process

Review from Last Lecture

Simplified Multi-Region Model



$$I_C = J_S A_E e^{\frac{V_{BE}}{V_t}}\left(1+\frac{V_{CE}}{V_{AF}}\right)$$

$$I_B = \frac{J_S A_E}{\beta} e^{\frac{V_{BE}}{V_t}} \qquad V_t = \frac{kT}{q}$$

Forward Active

V_{BE}=0.7V
V_{CE}=0.2V

Saturation

I_C=I_B=0

Cutoff

- This is a piecewise model suitable for analytical calculations
- Can easily extend to reverse active mode but of little use
- Still need conditions for operating in the 3 regions

Review from Last Lecture

Simplified Multi-Region Model

Alternate equivalent model

	Conditions	
$I_C = \beta I_B\left(1+\frac{V_{CE}}{V_{AF}}\right)$ $I_B = \frac{J_S A_E}{\beta} e^{\frac{V_{BE}}{V_t}}$ $V_t = \frac{kT}{q}$	$V_{BE}>0.4V$ $V_{BC}<0$	Forward Active
$V_{BE}=0.7V$ $V_{CE}=0.2V$	$I_C<\beta I_B$	Saturation
$I_C=I_B=0$	$V_{BE}<0$ $V_{BC}<0$	Cutoff

A small portion of the operating region is missed with this model but seldom operate in the missing region

Review from Last Lecture

Further Simplified Multi-Region dc Model

Equivalent Further Simplified Multi-Region Model

$I_C = \beta I_B$ $V_{BE} = 0.6V$ $V_t = \frac{kT}{q}$	$V_{BE}>0.4V$ $V_{BC}<0$	Forward Active
$V_{BE}=0.7V$ $V_{CE}=0.2V$	$I_C<\beta I_B$	Saturation
$I_C=I_B=0$	$V_{BE}<0$ $V_{BC}<0$	Cutoff

A small portion of the operating region is missed with this model but seldom operate in the missing region

Bipolar Process Description

p-substrate epi

Components Shown

- Vertical npn BJT
- Lateral pnp BJT
- JFET
- Diffusion Resistor
- Diode (and varactor)

Note: Features intentionally not to scale to make it easier to convey more information on small figures

- Much processing equipment is same as used for MOS processes so similar minimum-sized features can be made
- But will see that there are some fundamental issues that typically make bipolar circuits large

TABLE 2C.1
Process scenario of major process steps in typical bipolar process[a]

1.	Clean wafer (p-type)	
2.	GROW THIN OXIDE	
3.	Apply photoresist	
4.	PATTERN n^+ BURIED LAYER	(MASK #1)
5.	Develop photoresist	
6.	DEPOSITION AND DIFFUSION OF n-BURIED LAYER	
7.	Strip photoresist	
8.	Strip oxide	
9.	GROW EPITAXIAL LAYER (n-type)	
10.	Grow oxide	
11.	Apply photoresist	
12.	PATTERN p^+ ISOLATION REGIONS	(MASK #2)
13.	Develop photoresist	
14.	Etch oxide	
15.	DEPOSITION AND DIFFUSION OF p^+ ISOLATION	
16.	Strip photoresist	
17.	Grow oxide	
	Optional high-resistance p-diffusion	
	A.1 Apply photoresist	
	A.2 PATTERN p-RESISTORS	(MASK #A)
	A.3 Develop photoresist	
	A.4 Etch oxide	
	A.5 DEPOSITION AND DIFFUSION OF p-RESISTORS	
	A.6 Strip photoresist	
	A.7 Grow oxide	
18.	Apply photoresist	
19.	PATTERN BASE REGIONS	(MASK #3)
20.	Develop photoresist	
21.	Etch oxide	
22.	DEPOSITION AND DIFFUSION OF p-TYPE BASE	
23.	Strip photoresist	
24.	Grow oxide	
25.	Apply photoresist	

26. PATTERN n-TYPE EMITTER REGIONS (MASK #4)
27. Develop photoresist
28. Etch Oxide
29. n^+ DEPOSITION AND DIFFUSION
30. Strip photoresist
31. Grow oxide
32. Apply photoresist
33. PATTERN CONTACT OPENINGS (MASK #5)
34. Develop photoresist
35. Etch oxide
36. Strip Photoresist
37. APPLY METAL
38. Apply photoresist
39. PATTERN METAL (MASK #6)
40. Develop photoresist
41. ETCH METAL
42. Strip photoresist
43. APPLY PASSIVATION
44. Apply photoresist
45. PATTERN PAD OPENINGS (MASK #7)
46. Develop photoresist
47. Etch passivation
48. Strip photoresist
49. ASSEMBLE, PACKAGE, AND TEST

- Small number of masks
- Most not critical alignment / size

TABLE 2C.2
Design rules for a typical bipolar process ($\lambda = 2.5\ \mu$)
(See Table 2C.3 in color plates for graphical interpretation)

	Dimension
1. n^+ buried collector diffusion (Yellow, Mask #1)	
1.1 Width	3λ
1.2 Overlap of p-base diffusion (for vertical npn)	2λ
1.3 Overlap of n^+ emitter diffusion (for collector contact of vertical npn)	2λ
1.4 Overlap of p-base diffusion (for collector and emitter of lateral pnp)	2λ
1.5 Overlap of n^+ emitter diffusion (for base contact of lateral pnp)	2λ
2. Isolation diffusion (Orange, Mask #2)	
2.1 Width	4λ
2.2 Spacing	24λ
2.3 Distance to n^+ buried collector	14λ
3. p-base diffusion (Brown, Mask #3)	
3.1 Width	3λ
3.2 Spacing	5λ
3.3 Distance to isolation diffusion	14λ
3.4 Width (resistor)	3λ
3.5 Spacing (as resistor)	3λ
4. n^+ emitter diffusion (Green, Mask #4)	
4.1 Width	3λ
4.2 Spacing	3λ
4.3 p-base diffusion overlap of n^+ emitter diffusion (emitter in base)	2λ
4.4 Spacing to isolation diffusion (for collector contact)	12λ
4.5 Spacing to p-base diffusion (for base contact of lateral pnp)	6λ
4.6 Spacing to p-base diffusion (for collector contact of vertical npn)	6λ

- Note some features have very large design rules
- Will discuss implication of this later

5. Contact (Black, Mask #5)

5.1 Size (exactly)	$4\lambda \times 4\lambda$
5.2 Spacing	2λ
5.3 Metal overlap of contact	λ
5.4 n^+ emitter diffusion overlap of contact	2λ
5.5 p-base diffusion overlap of contact	2λ
5.6 p-base to n^+ emitter	3λ
5.7 Spacing to isolation diffusion	4λ

6. Metalization (Blue, Mask #6)

6.1 Width	2λ
6.2 Spacing	2λ
6.3 Bonding pad size	$100\ \mu \times 100\ \mu$
6.4 Probe pad size	$75\ \mu \times 75\ \mu$
6.5 Bonding pad separation	$50\ \mu$
6.6 Bonding to probe pad	$30\ \mu$
6.7 Probe pad separation	$30\ \mu$
6.8 Pad to circuitry	$40\ \mu$
6.9 Maximum current density	0.8 mA/μ width

7. Passivation (Purple, Mask #7)

7.1 Minimum bonding pad opening	$90\ \mu \times 90\ \mu$
7.2 Minimum probe pad opening	$65\ \mu \times 65\ \mu$

TABLE 2C.4

Process parameters for a typical bipolar process[a]

Parameter	Typical	Tolerance[b]	Units
	Ebers-Moll model parameters		
β_F (forward β)			
npn—vertical	100	50 to 200	
pnp—lateral			
(at I_C = 500 μA)	10	±20%	
(at I_C = 200 μA)	6	±20%	
β_R (reverse β)			
npn—vertical	1.5	±0.5	
pnp—lateral			
(at I_C = 500 μA)	5	±20%	
(at I_C = 200 μA)	3	±20%	
V_{AF} (forward Early voltage)			
npn—vertical	100	±30%	V
pnp—lateral	150	±30%	V
V_{AR} (reverse Early voltage)			
npn—vertical	150	±30%	V
pnp—lateral	150	±30%	V
J_S (saturation current density)			
npn—vertical	2.6×10^{-7}	−50%to + 100%	pA/μ^2
pnp—lateral	1.3×10^{-5}	−50%to + 100%	pA/μ emitter perimeter

Parameter	Typical	Tolerance[b]	Units
Doping			
n^+ emitter	10^4	±30%	$10^{16}/cm^3$
p-base			
Surface	10^5	±20%	$10^{16}/cm^3$
Junction	1	±20%	$10^{16}/cm^3$
Epitaxial layer	0.3	±20%	$10^{16}/cm^3$
Substrate	0.08	±25%	$10^{16}/cm^3$
Physical feature size			
Diffusion depth			
n+ emitter diffusion	1.3	±5%	μ
p-base diffusion	2.6	±5%	μ
p-resistive diffusion	0.3	±5%	μ
n-epitaxial layer	10.4	±5%	μ
n^+ buried collector diffusion			
Into epitaxial	3.9	±5%	μ
Into substrate	7.8	±5%	μ
Oxide thickness			
Metal to epitaxial	1.4	±30%	μ
Metal to p-base	0.65	±30%	μ
Metal to n^+ emitter	0.4	±30%	μ

Capacitances

Metal to epitaxial	0.022	±30%	fF/μ^2
Metal to p-base diffusion	0.045	±30%	fF/μ^2
Metal to n^+ emitter diffusion	0.078	±30%	fF/μ^2
n^+ buried collector to substrate (junction, bottom)	0.062	±30%	fF/μ^2
Epitaxial to substrate (junction, bottom)	0.062	±30%	fF/μ^2
Epitaxial to substrate (junction, sidewall)	1.6	±30%	fF/μ perimeter
Epitaxial to p-base diffusion (junction, bottom)	0.14	±30%	fF/μ^2
Epitaxial to p-base diffusion (junction, sidewall)	7.9	±30%	fF/μ perimeter
p-base diffusion to n^+ emitter diffusion (junction, bottom)	0.78	±30%	fF/μ^2
p-base diffusion to n^+ emitter diffusion (junction, sidewall)	3.1	±30%	fF/μ perimeter

Parameter	Typical	Tolerance[b]	Units
Resistance and resistivity			
Substrate resistivity	16	±25%	Ω · cm
n^+ buried collector diffusion	17	±35%	Ω / □
Epitaxial layer	1.6	±20%	Ω · cm
p-base diffusion	160	±20%	Ω / □
p-resistive diffusion (optional)	1500	±40%	Ω / □
n^+ emitter diffusion	4.5	±30%	Ω / □
Metal	0.003		Ω / □
Contacts ($3\mu \times 3\mu$)	<4		Ω
Metal-n^+ emitter (contact plus series resistance to BE junction)	<1		Ω
Metal-p-base[c] (contact plus series resistance)	70		Ω
Metal-Epitaxial[d] (contact plus series resistance to BC junction)	120		Ω
Breakdown voltages, leakage currents, migration currents, and operating conditions			
Reverse breakdown voltages			
n^+ emitter to p-base	6.9	±50 mV	V
p-base to epitaxial	70	±10	V
Epitaxial to substrate	>80		V
Maximum operating voltage	40		V
Substrate leakage current	0.16		fA/μ^2
Maximum metal current density	0.8		mA/μ width
Maximum device operating temperature (design)	125		°C
Maximum device operating temperature (physical)	225		°C

SPICE model parameters of typical bipolar process

Parameter[a,b,c]	Vertical npn	Lateral pnp	Units
IS[c]	0.1	0.78	fA
BF	80	225	
NF	1	1	
VAF	100	150	V
IKF	100	0.1	mA
ISE	0.11	0.15	fA
NE	1.44	1.28	
BR	1.5		
NR	1	1	
VAR[b]	19	38	V
ISC		1.5	fA
NC	1.44	1.28	
RB	70	250	Ω
RE	1	4	Ω
RC	120	130	Ω
CJE	0.62	0.48	pF
VTE	0.69	0.65	V
MJE	0.33	0.40	
TF	0.45	40	ns
CJC	1.9	0.48	pF
VJC	0.65	0.65	V
MJC	0.4	0.4	
XCJC	0.5	0	
TR	22.5	2000	ns
CJS[d]	1.30	0	pF
VJS	0.49	0	pF
MJS	0.38	0	

Recall: Simplified Multi-Region Model

"Forward" Regions : $\beta=\beta_F$

	Conditions	
$I_C = J_S A_E e^{\frac{V_{BE}}{V_t}}\left(1+\frac{V_{CE}}{V_{AF}}\right)$ $I_B = \frac{J_S A_E}{\beta} e^{\frac{V_{BE}}{V_t}}$	$V_{BE}>0.4V$ $\quad V_{BC}<0$	Forward Active
$V_{BE}=0.7V$ $V_{CE}=0.2V$	$I_C<\beta I_B$	Saturation
$I_C=I_B=0$	$V_{BE}<0$ $\quad V_{BC}<0$	Cutoff

Process Parameters: $\{J_S, \beta, V_{AF}\}$ $\qquad V_t = \frac{kT}{q}$ $\qquad$ Design Parameters: $\{A_E\}$

- Process parameters highly process dependent
- J_S highly temperature dependent as well, β modestly temperature dependent
- This model is dependent only upon emitter area, independent of base and collector area !
- Currents scale linearly with A_E and not dependent upon shape of emitter
- A small portion of the operating region is missed with this model but seldom operate in the missing region

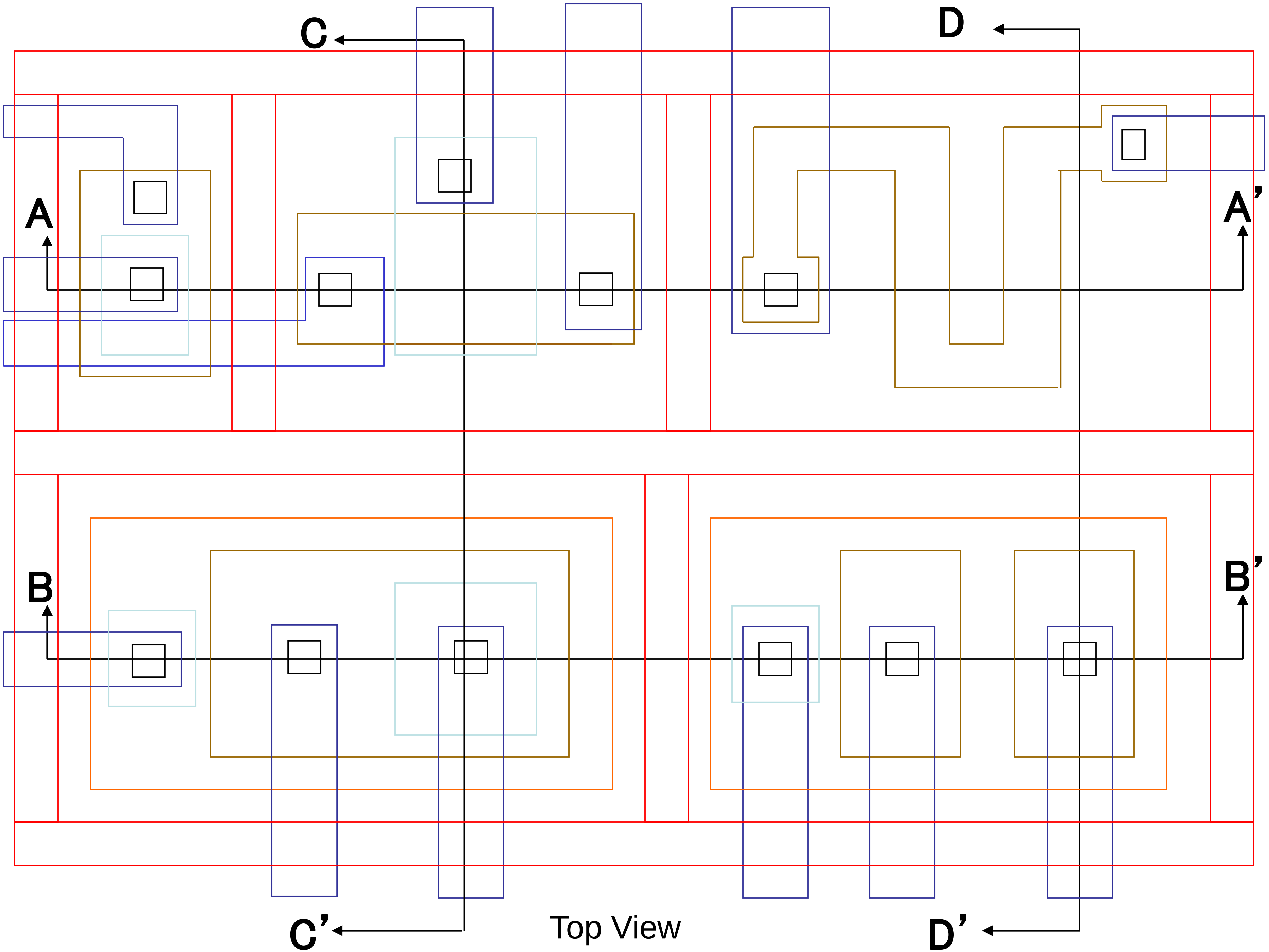
[a] Parameters are defined in Chapters 3 and 4.

[b] Some of these Gummel-Poon parameters differ considerably from those given in Table 2C.4. They have been obtained from curve fitting and should give good results with computer simulations. The parameters of Table 2C.4 should be used for hand analysis.

[c] Parameters that are strongly area-dependent are based upon an npn emitter area of 390 μ^2 and perimeter of 80 μ, a base area of 2200 μ^2 and perimeter of 200 μ, and a collector area of 10,500 μ^2 and perimeter of 425 μ. The lateral pnp has rectangular collectors and emitters spaced 10 μ apart with areas of 230 μ^2 and perimeters of 60 μ. The base area of the pnp is 7400 μ^2 and the base perimeter is 345 μ.

[d] CJS is set to zero for the lateral transistor because it is essentially nonexistent. The parasitic capacitance from base to substrate, which totals 1.0 pF for this device, must be added externally to the BJT.

- In contrast to the MOSFET where process parameters are independent of geometry, the bipolar transistor model is for a specific transistor !
- Area emitter factor is used to model other devices
- Often multiple specific device models are given and these devices are used directly
- Often designer can not arbitrarily set A_E but rather must use parallel combinations of specific devices and layouts



Top View

Layer Mappings

n^+ buried collector

isolation diffusion (p^+)

p-base diffusion

n^+ emitter

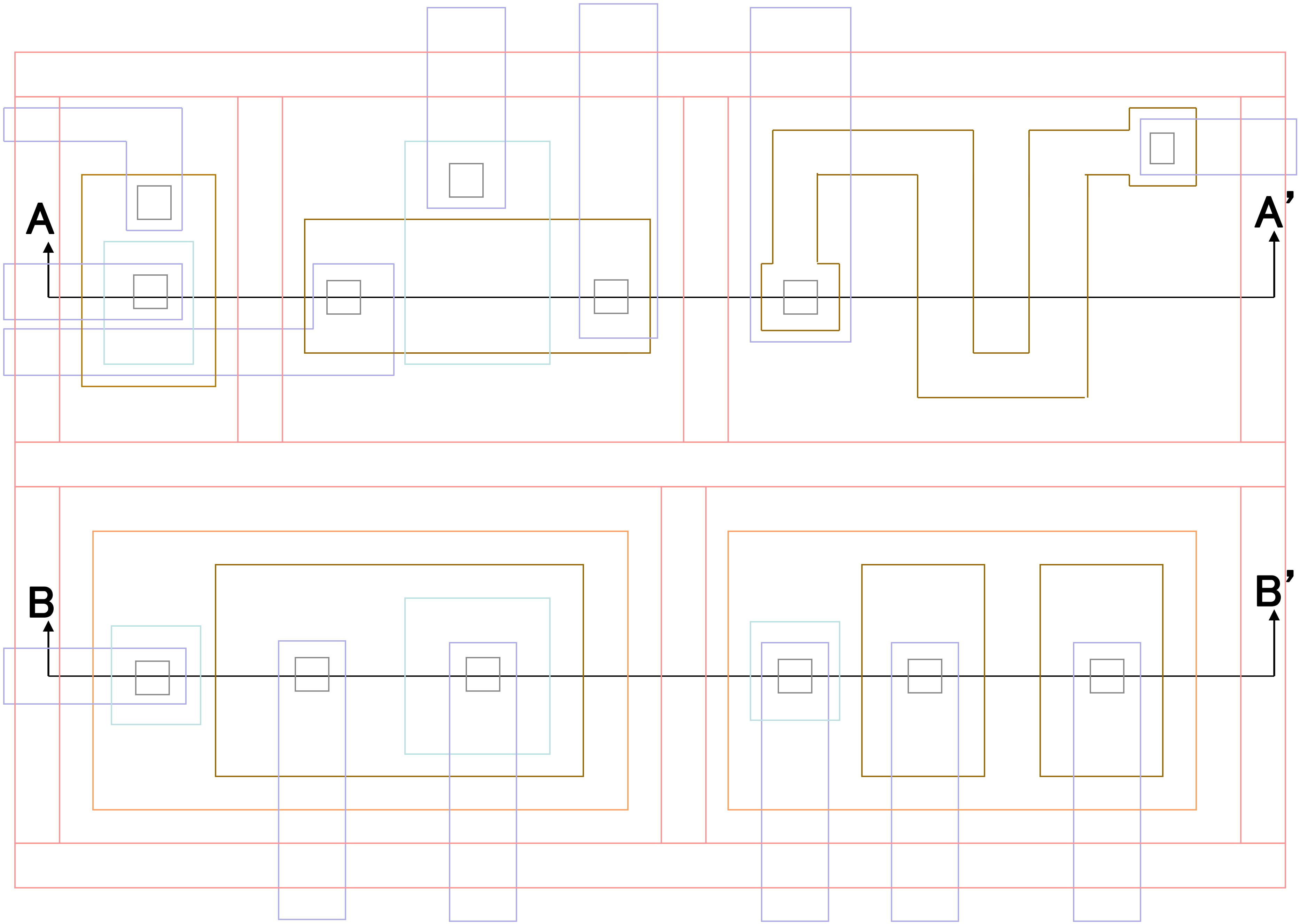
contact

metal

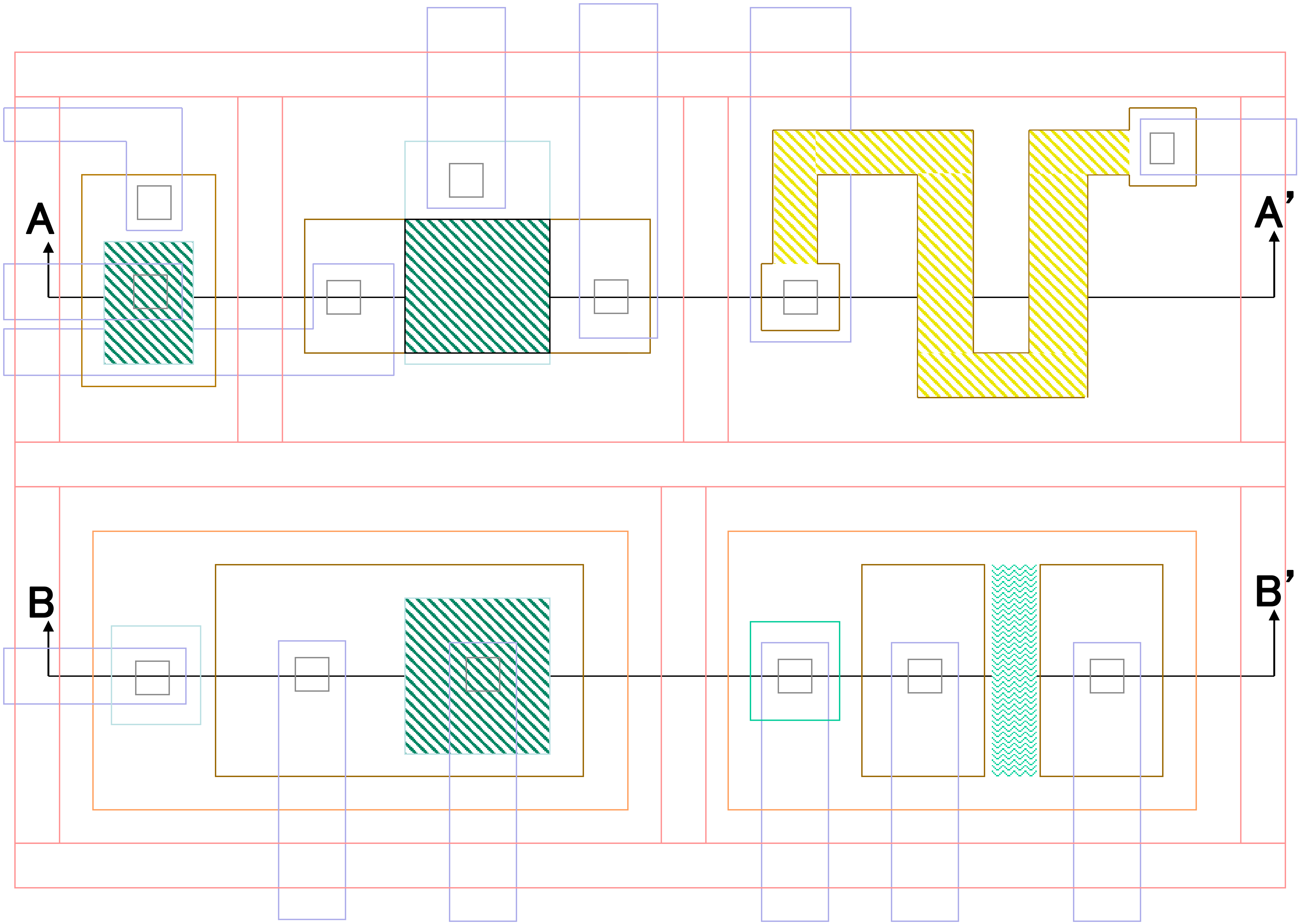
passivation opening

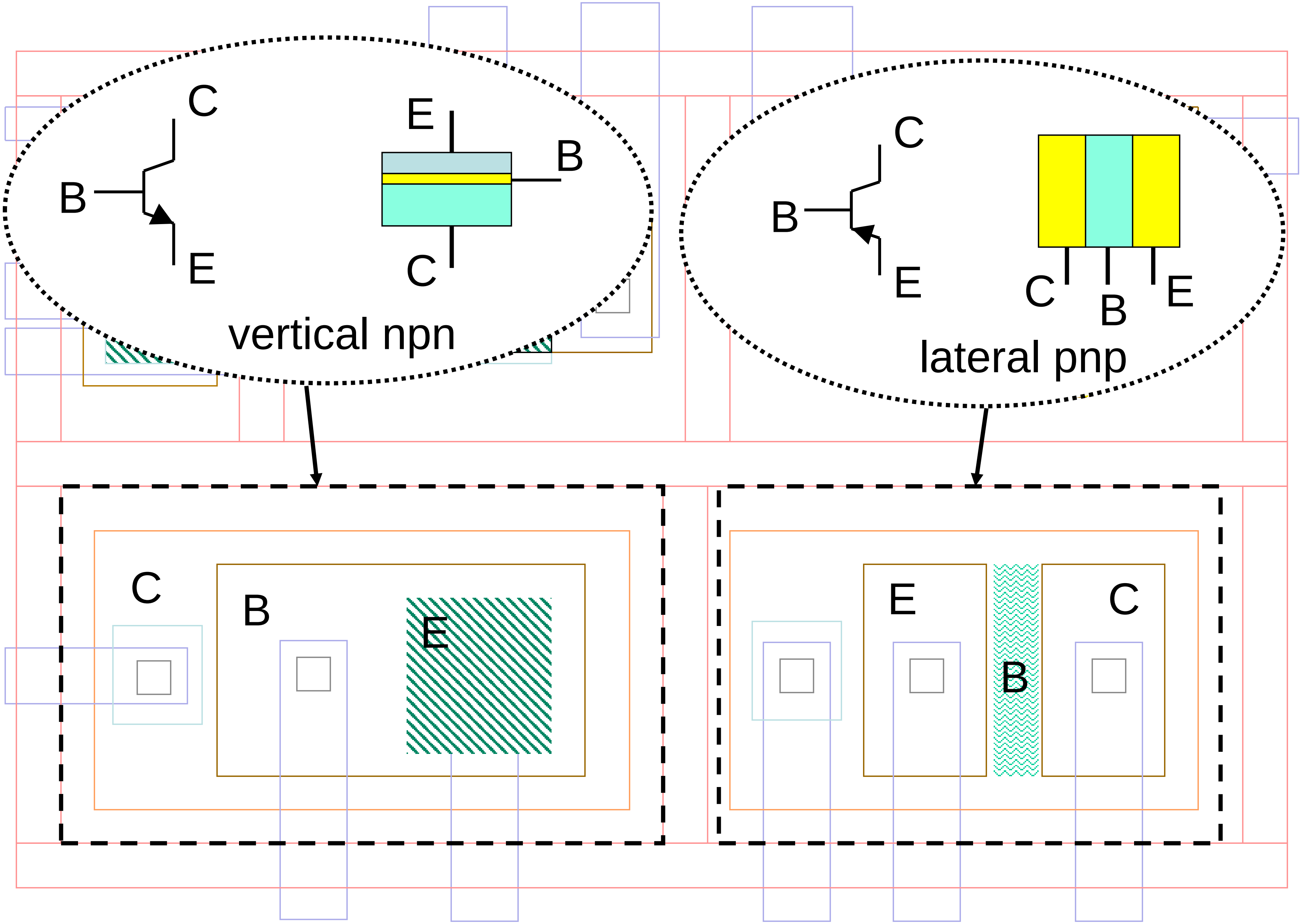
Notes:

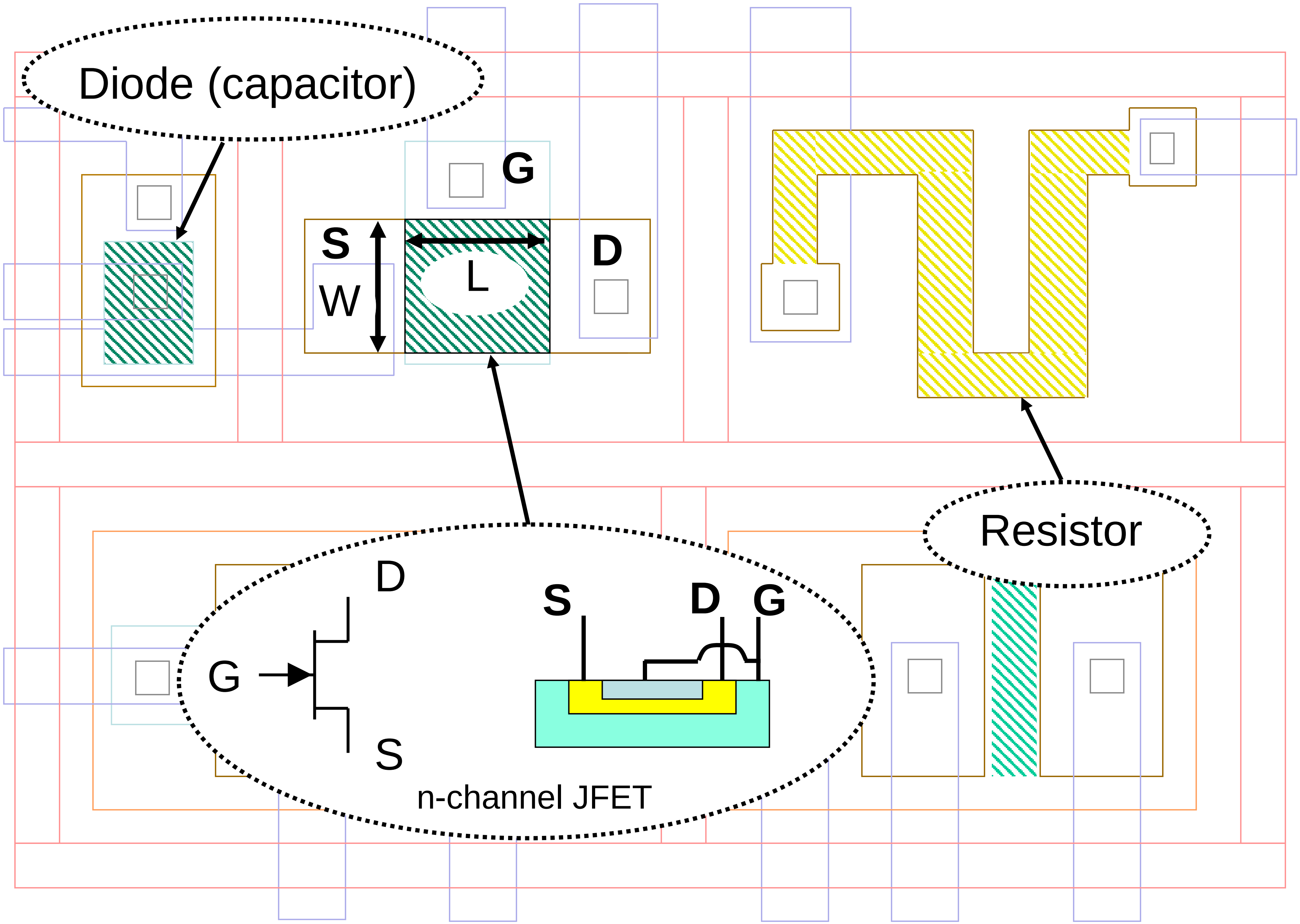
- passivation opening for contacts not shown
- isolation diffusion intentionally not shown to scale



Dimmed features with A-A' and B-B' cross sections


A
A'
B
B'


C
B
E
E
B
C
vertical npn
C
B
E
C
B
E
lateral pnp
C
B
E
E
B
C



Diode (capacitor)
G
S
W
L
D
Resistor
D
G
S
S
D
G
n-channel JFET

Detailed Description of First Photolithographic Steps Only

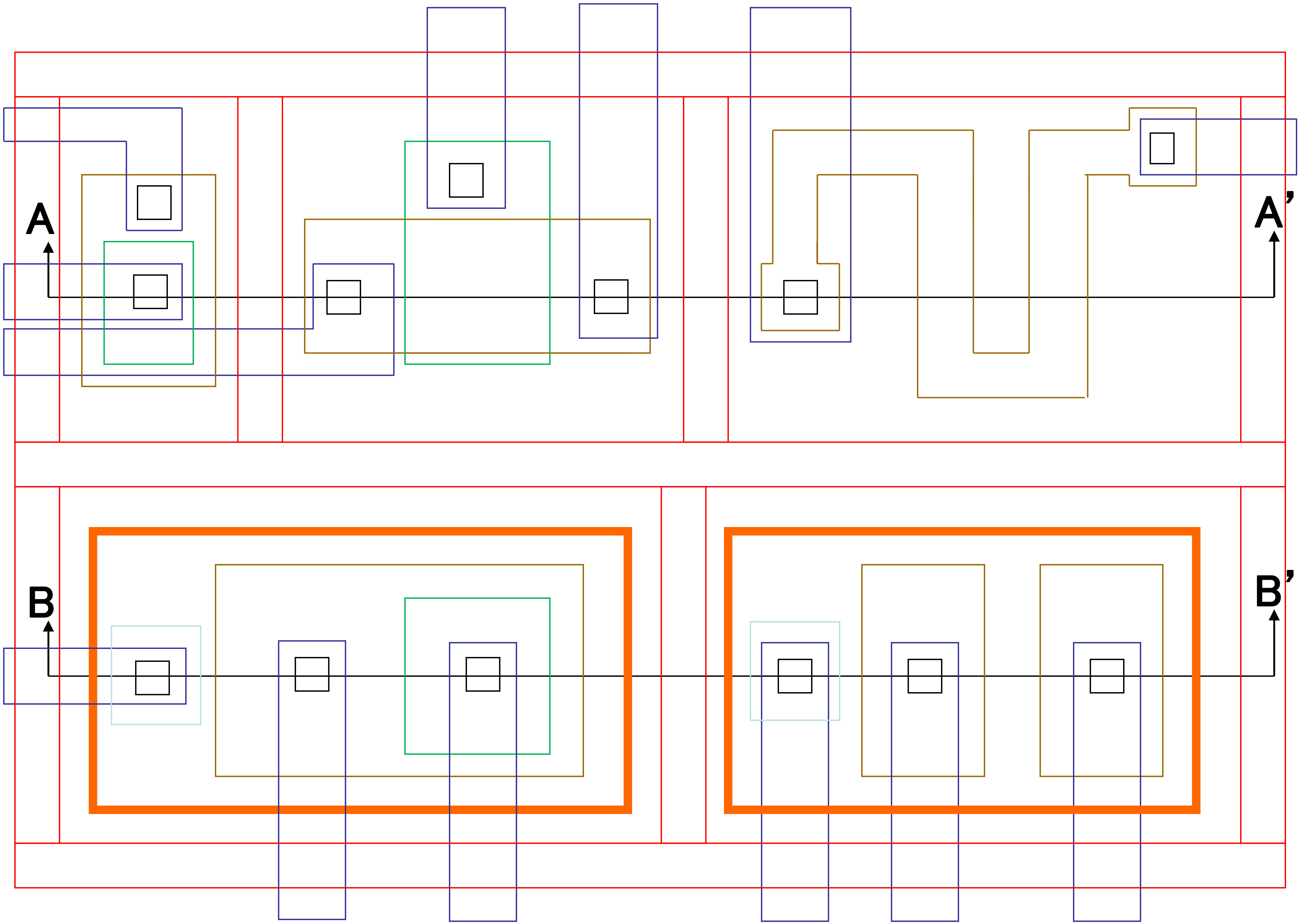
- Top View
- Cross-Section View

Mask Numbering and Mappings

Mask 1	n^+ buried collector
Mask 2	isolation diffusion (p^+)
Mask 3	p-base diffusion
Mask 4	n^+ emitter
Mask 5	contact
Mask 6	metal
Mask 7	passivation opening

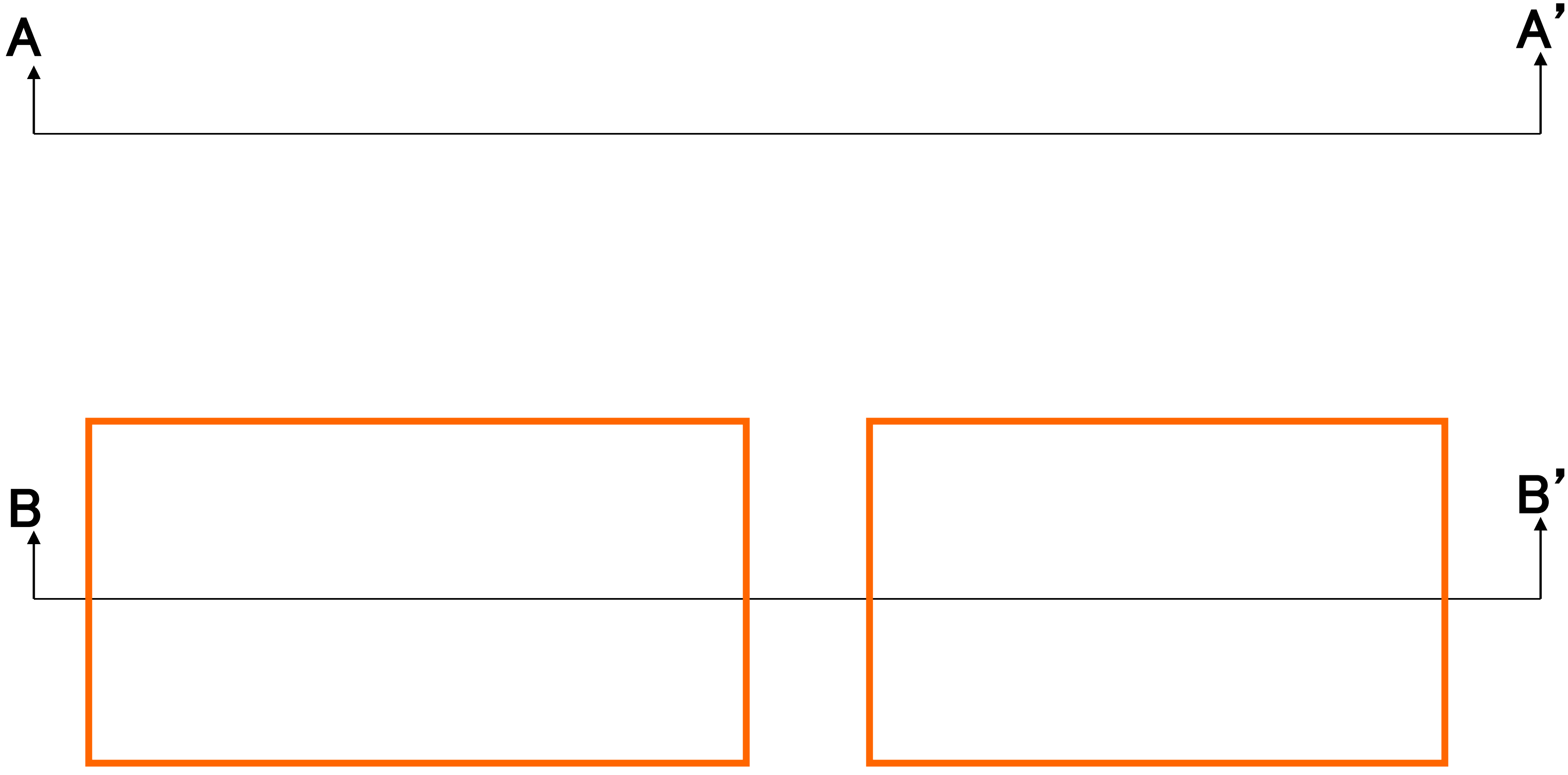
Notes:

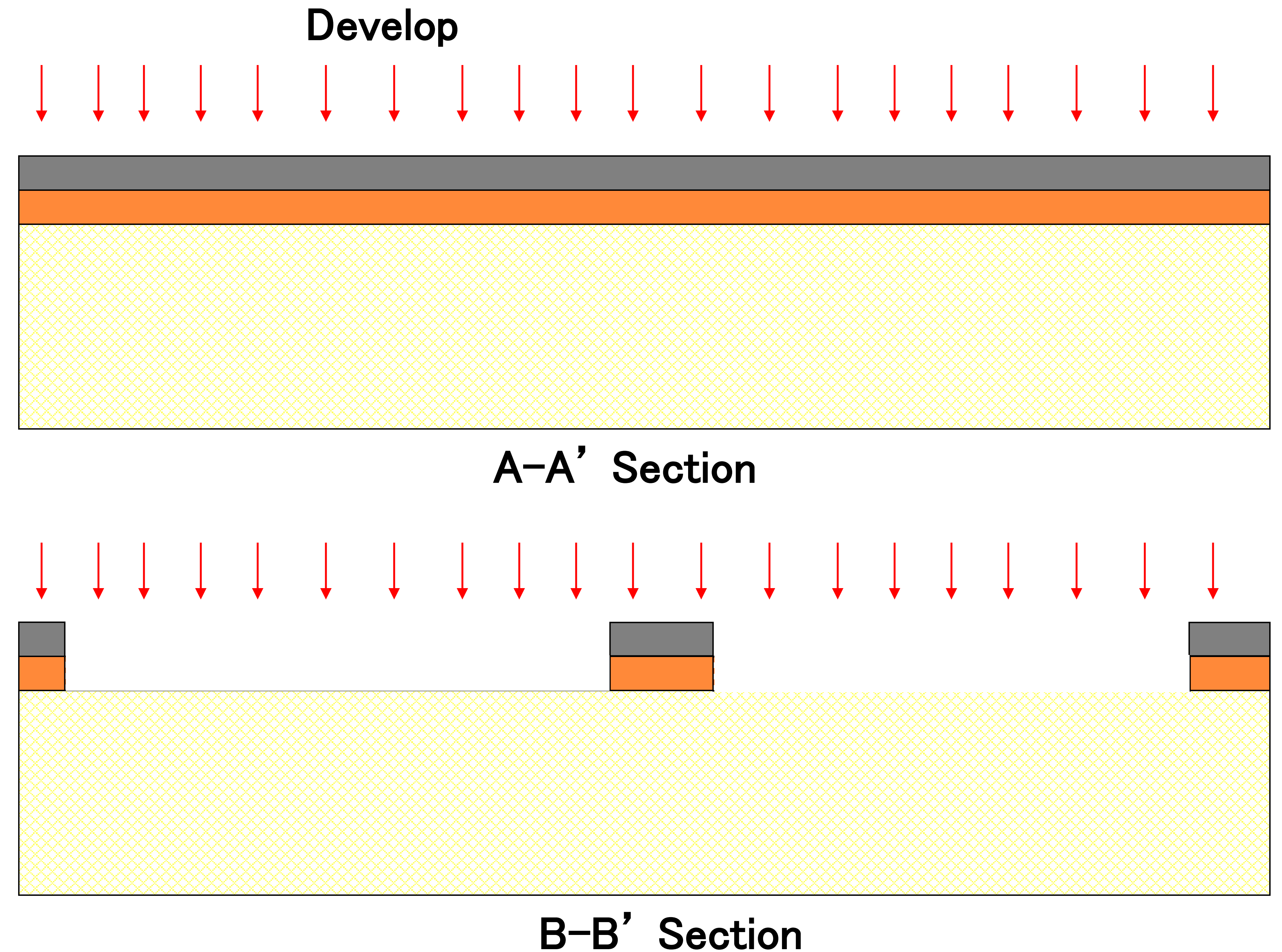
- passivation opening for contacts not shown
- isolation diffusion intentionally not shown to scale



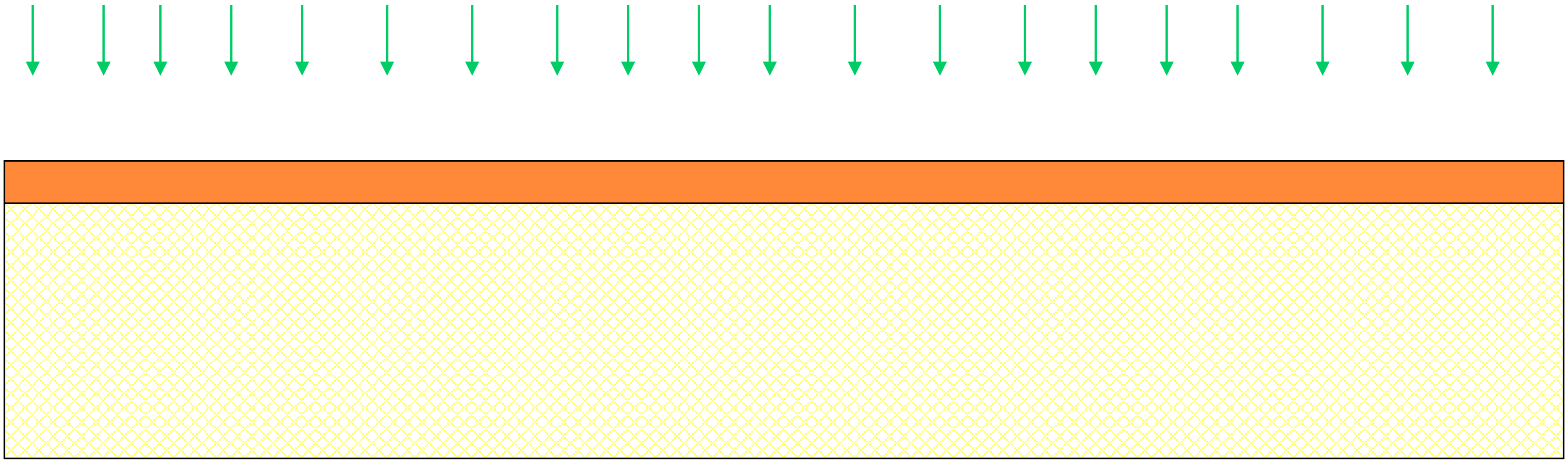
n$^+$ buried collector

Mask 1: n$^+$ buried collector

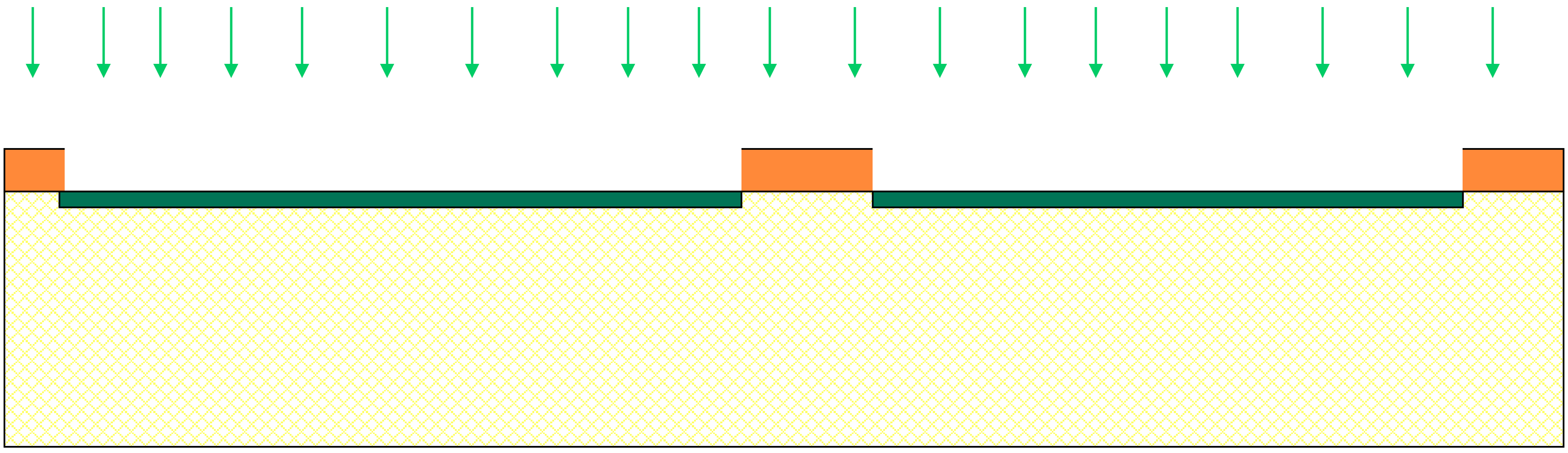



Develop
A–A' Section
B–B' Section

Implant

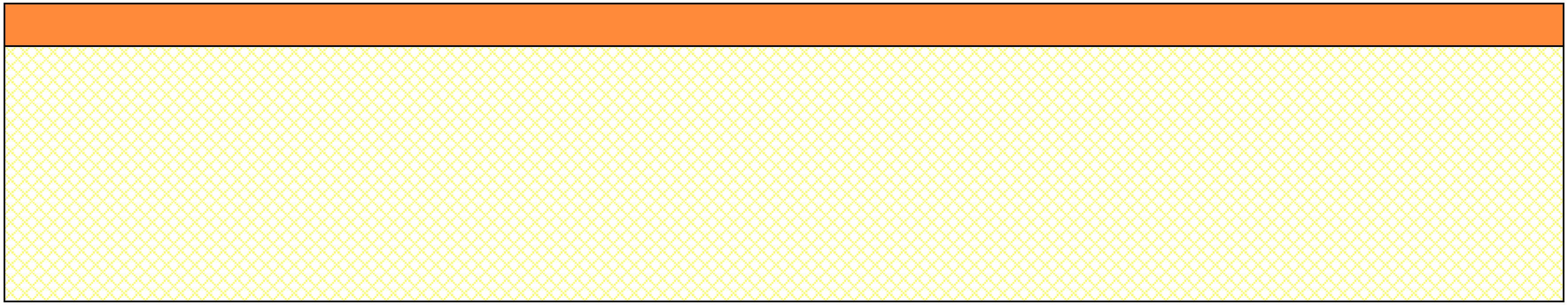


A-A' Section

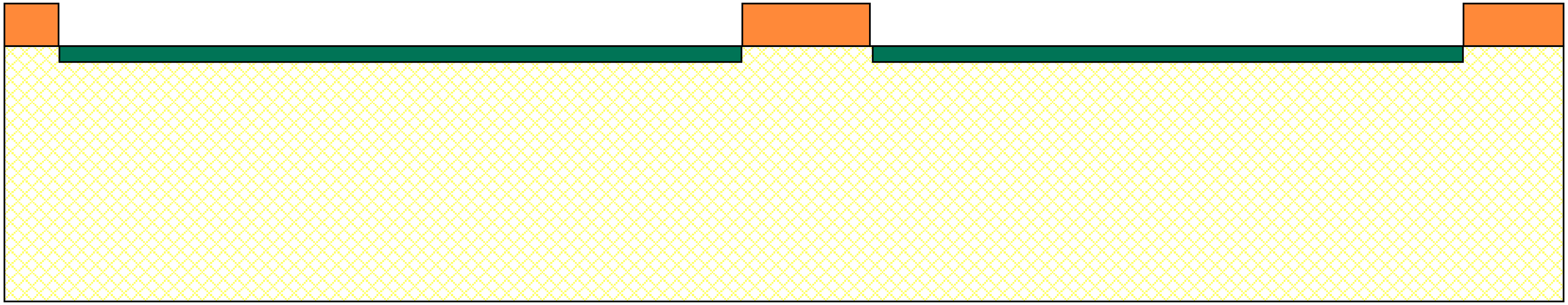


B-B' Section

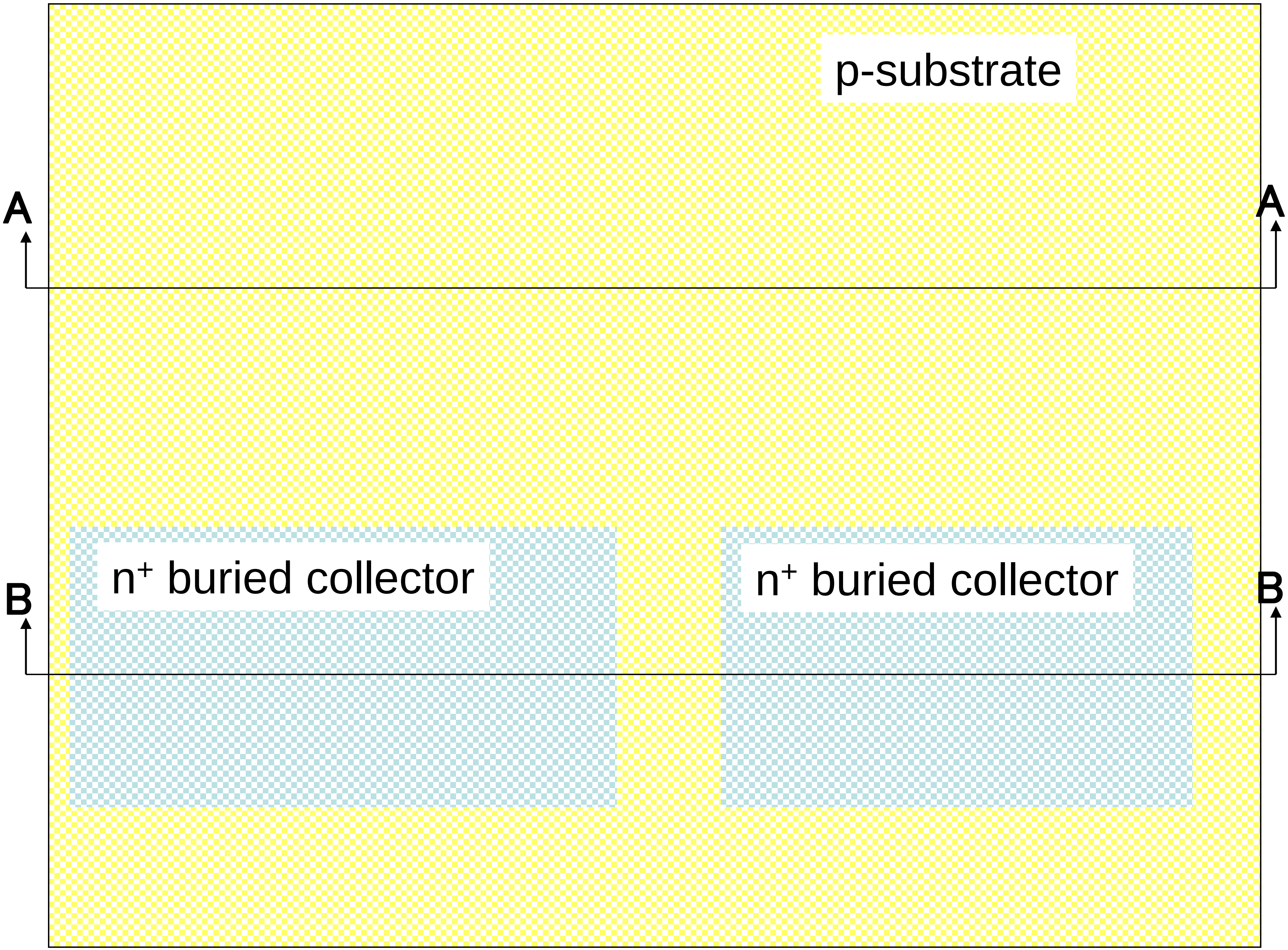
Strip Photoresist



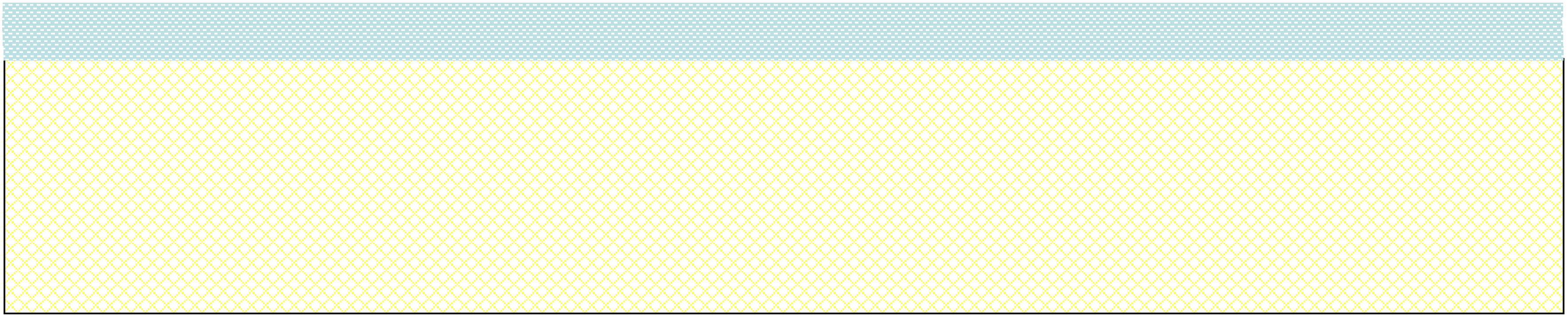
A–A’ Section



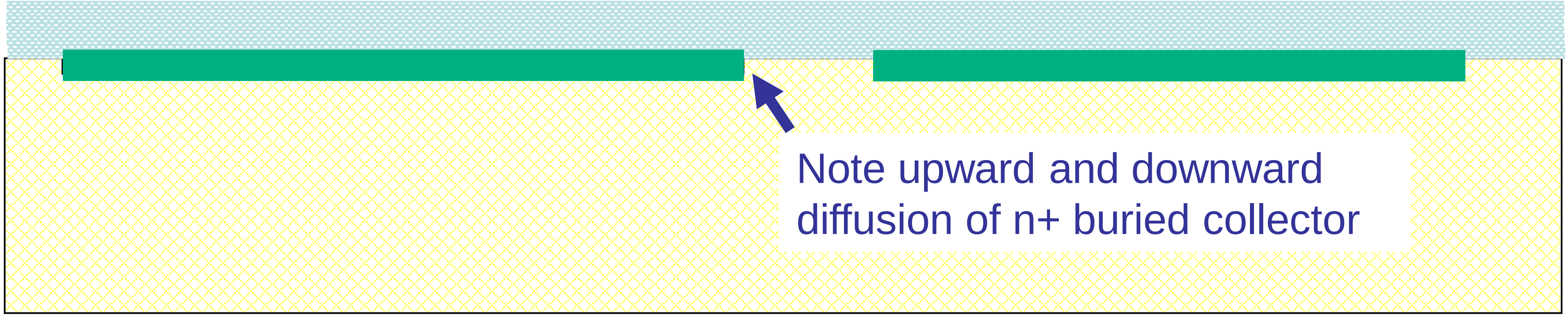
B–B’ Section


p-substrate
A
A’
n+ buried collector
n+ buried collector
B
B’

Grow Epitaxial Layer

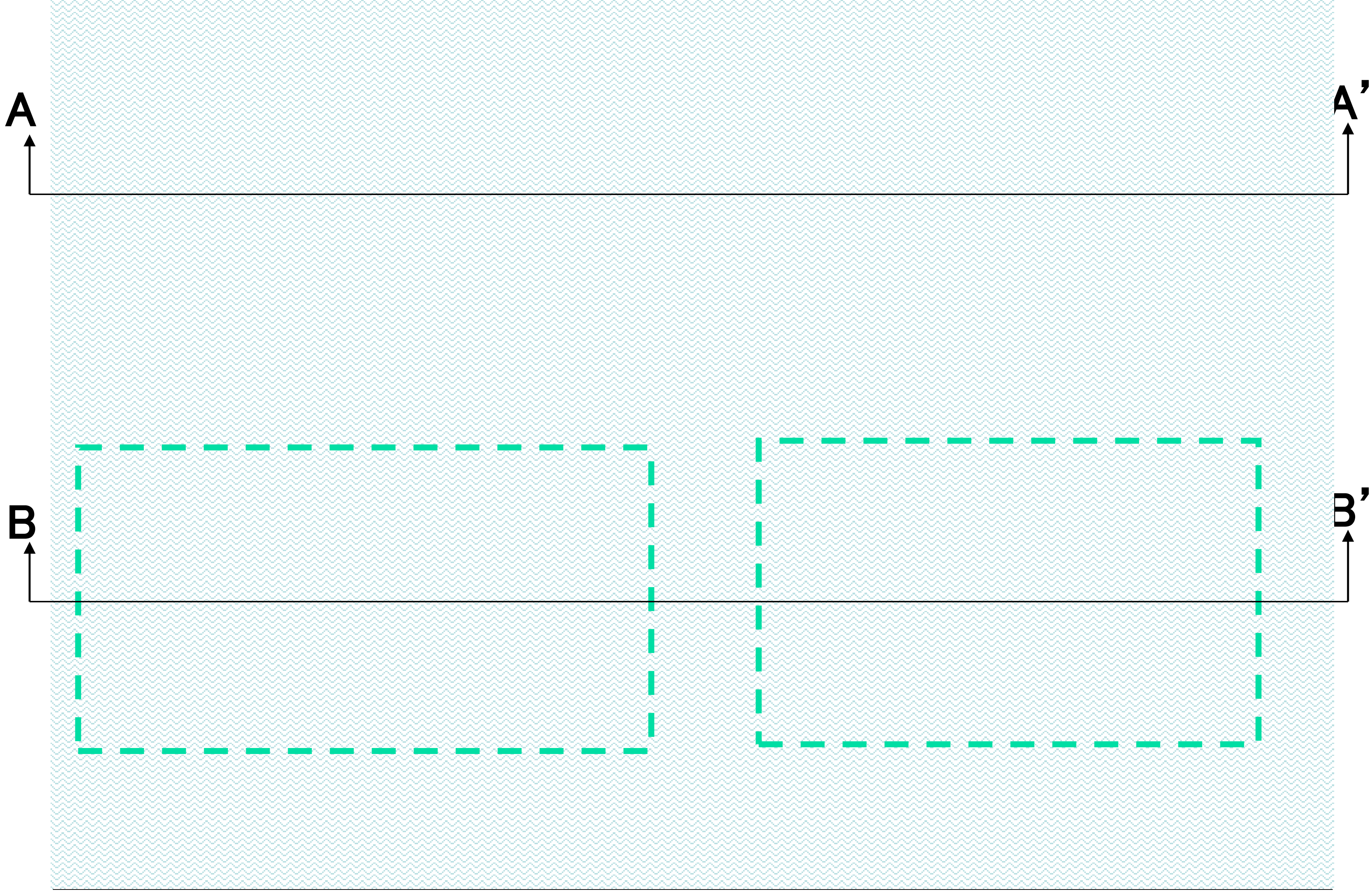


A–A' Section



B–B' Section

Grow Epitaxial Layer

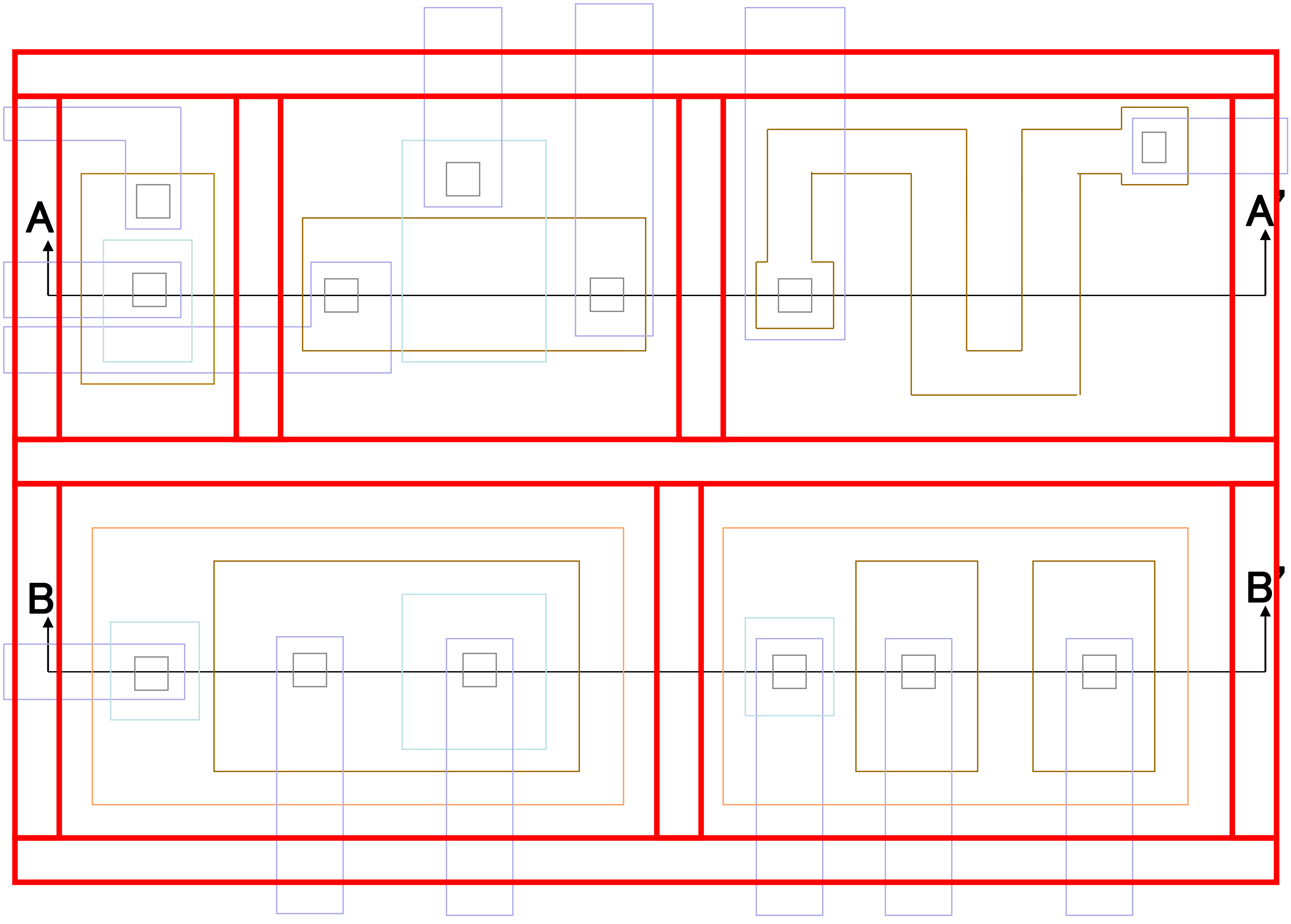


Mask Numbering and Mappings

Mask 1	n^+ buried collector
Mask 2	isolation diffusion (p^+)
Mask 3	p-base diffusion
Mask 4	n^+ emitter
Mask 5	contact
Mask 6	metal
Mask 7	passivation opening

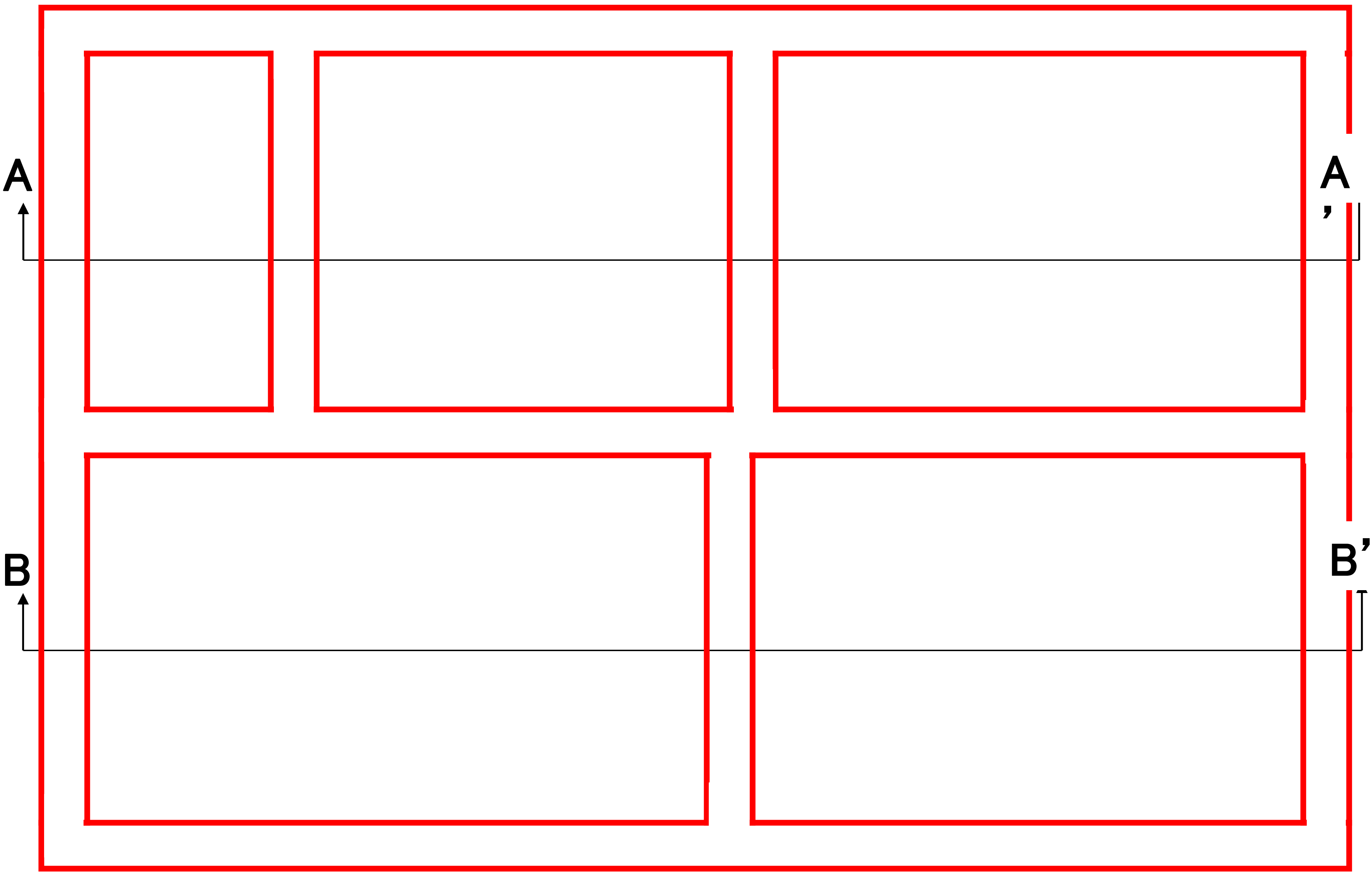
Notes:

- passivation opening for contacts not shown
- isolation diffusion intentionally not shown to scale



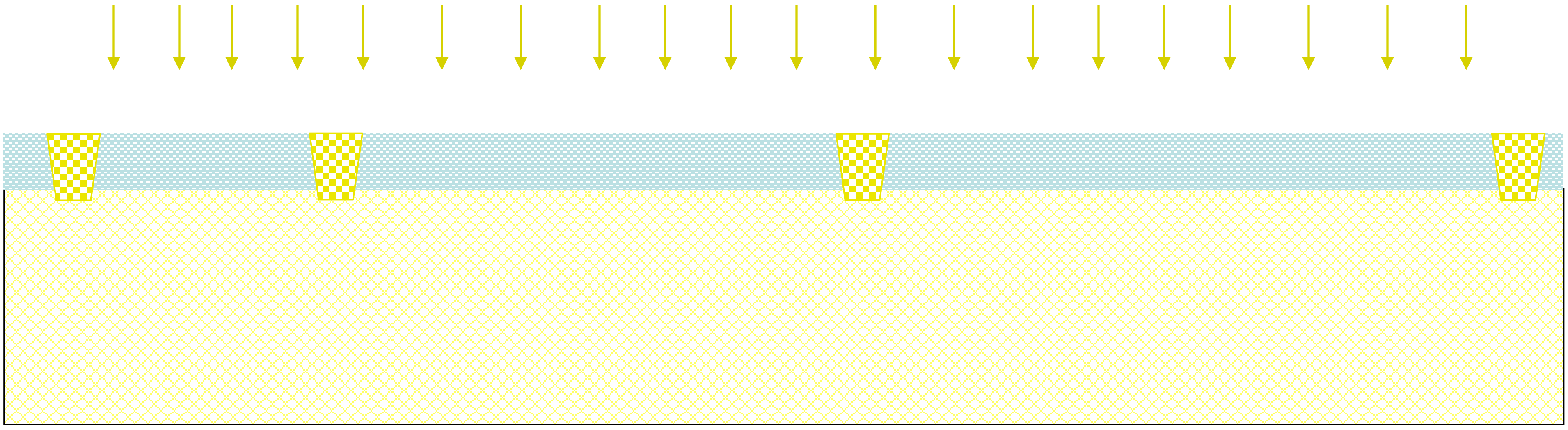
Isolation Diffusion

Mask 2: Isolation Deposition/Diffusion

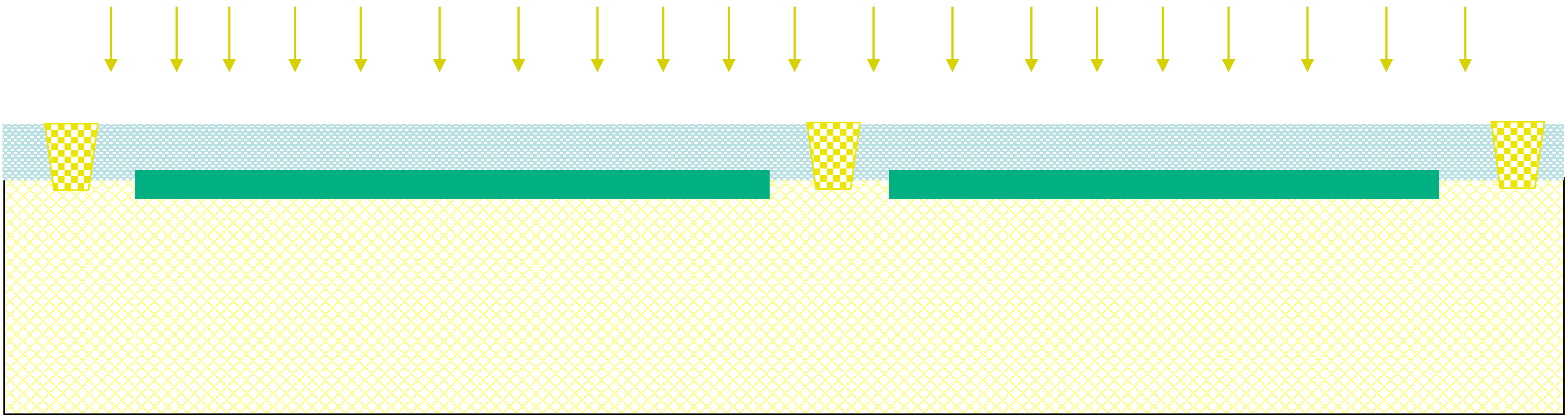


Isolation Deposition/Diffusion

- Photoresist present but not shown
- Deposition and diffusion combined in slides

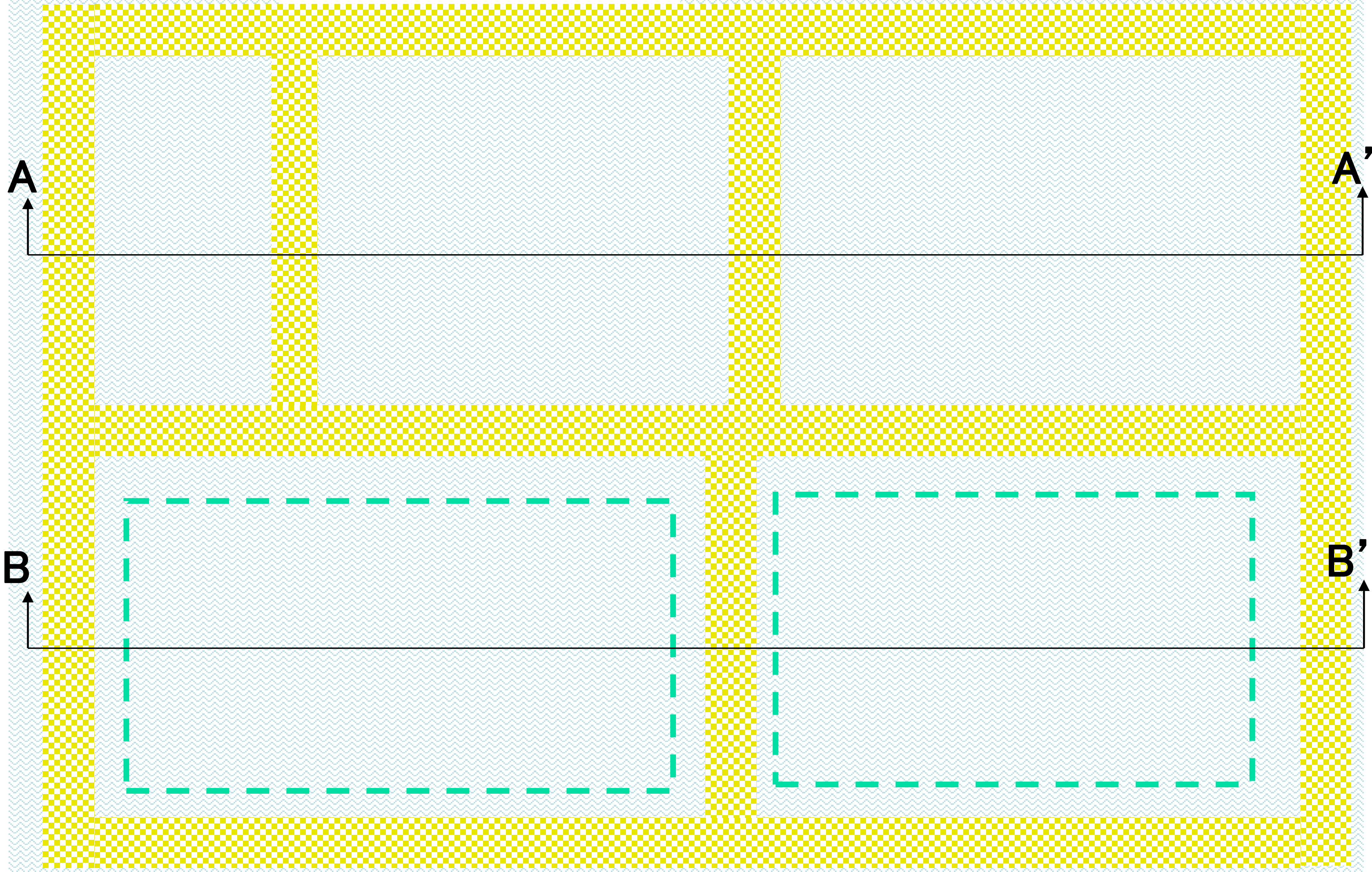


A–A' Section



B–B' Section

Isolation Diffusion



Have created 5 "islands" of n^- material on top of p^{--} substrate

Mask Numbering and Mappings

Mask 1	n^+ buried collector
Mask 2	isolation diffusion (p^+)
Mask 3	p-base diffusion
Mask 4	n^+ emitter
Mask 5	contact
Mask 6	metal
Mask 7	passivation opening

Notes:

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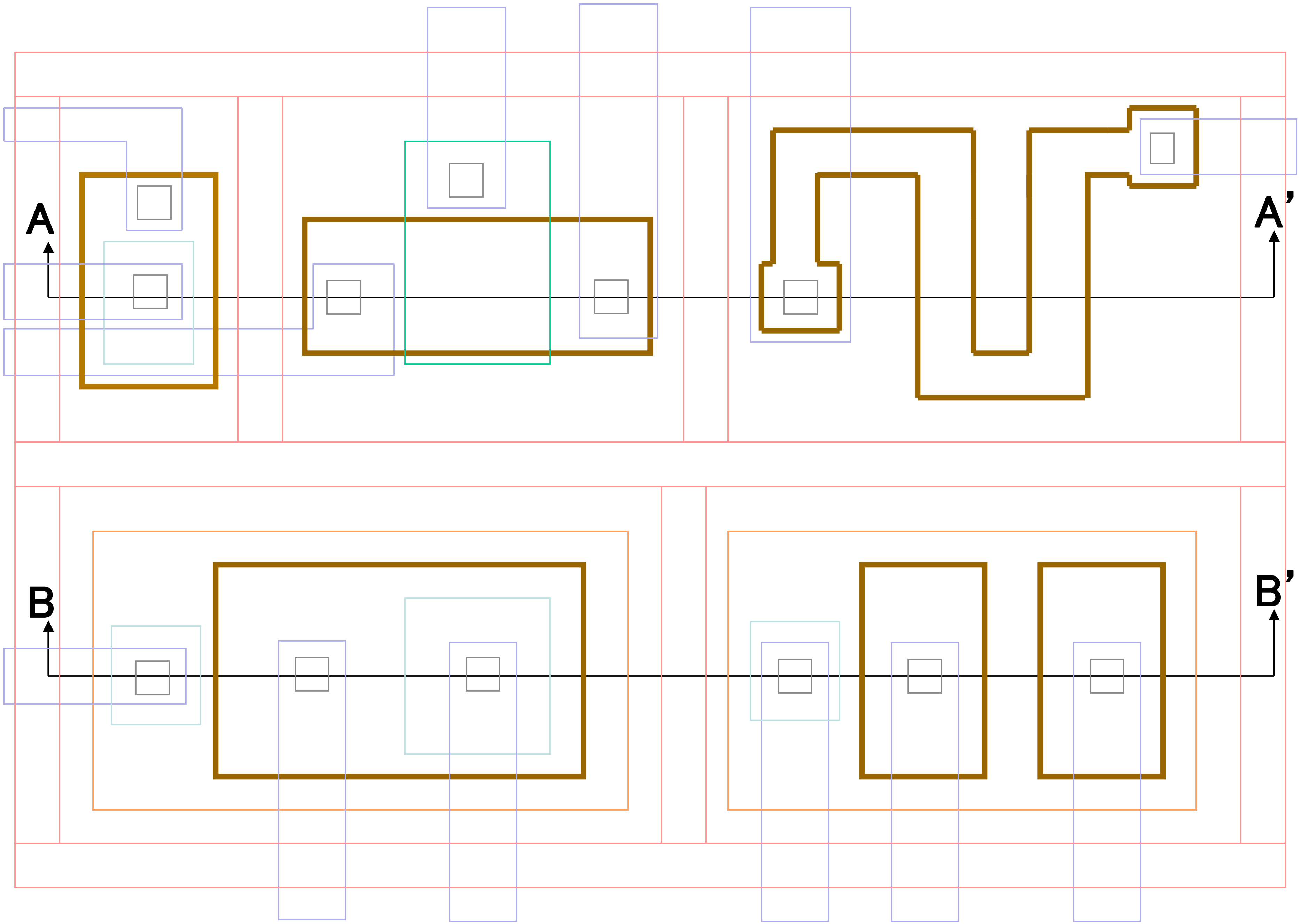
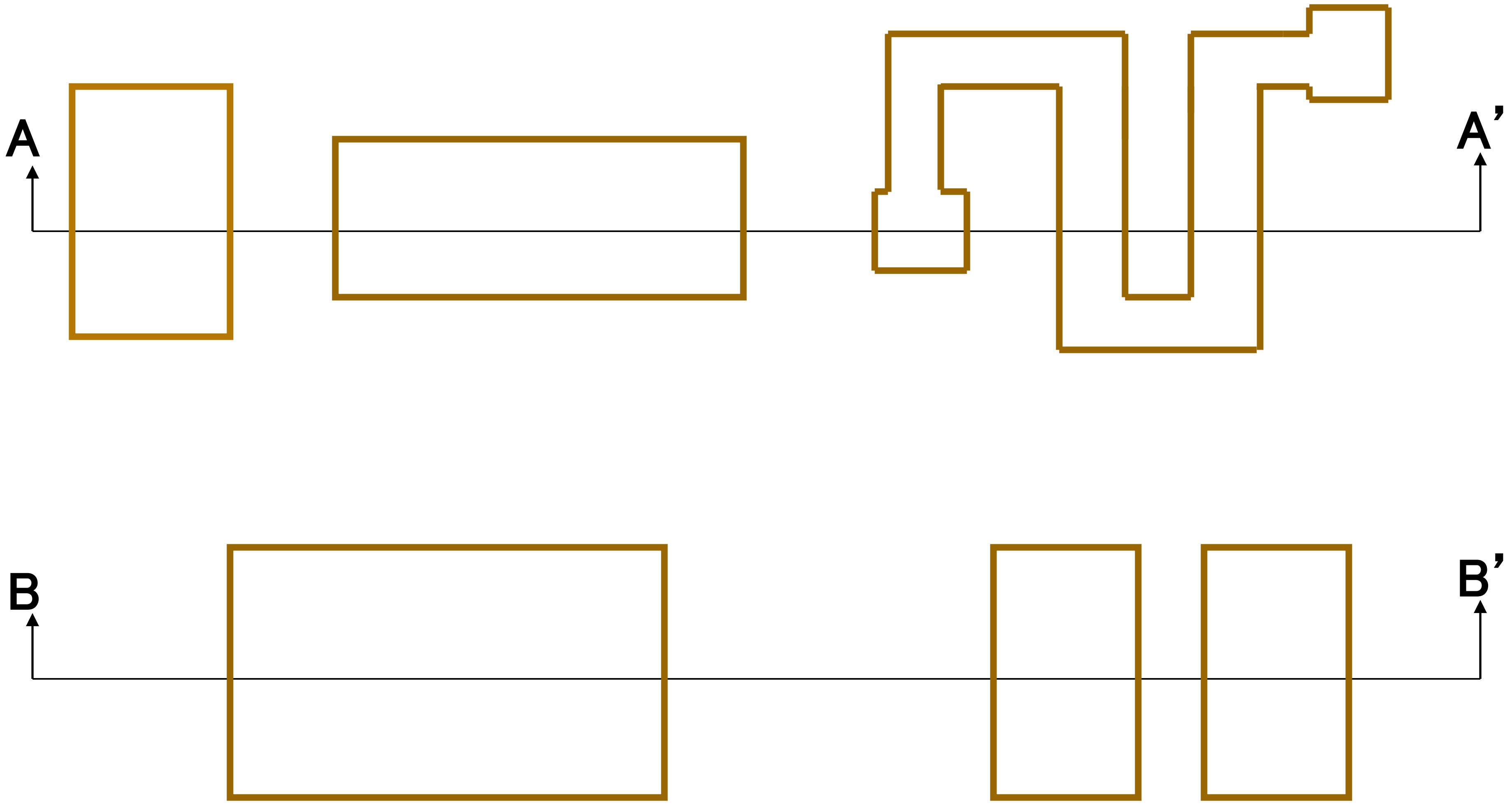


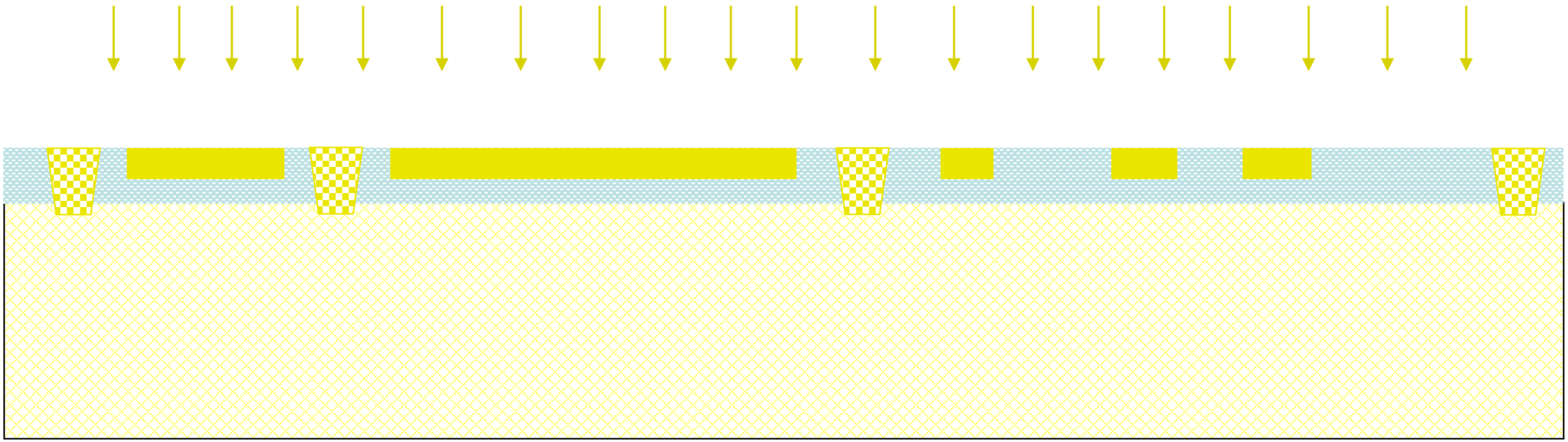
p-base diffusion

Mask 3: p-base diffusion

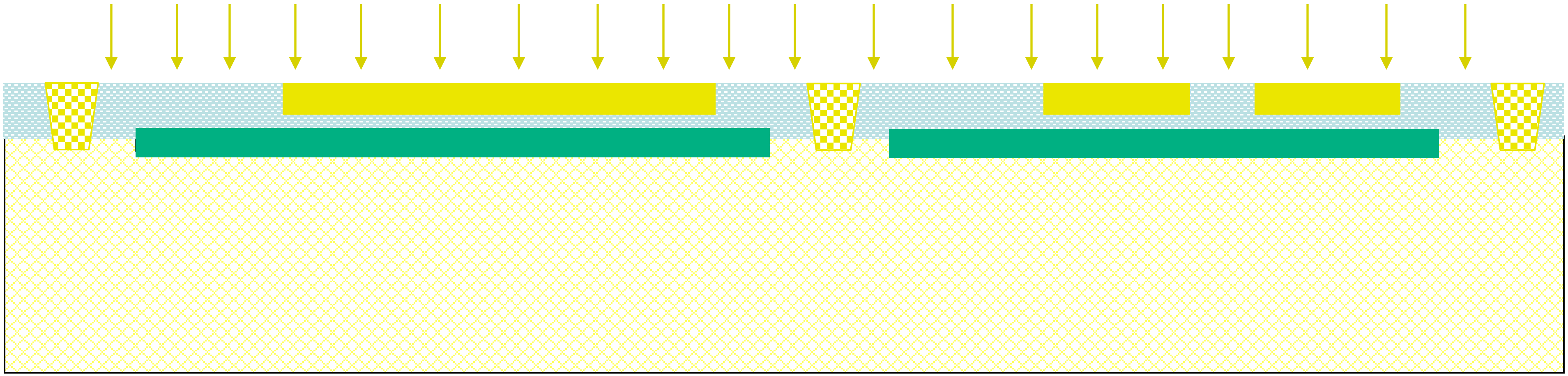


p-base Diffusion

- Photoresist present but not shown
- Deposition and diffusion combined in slides

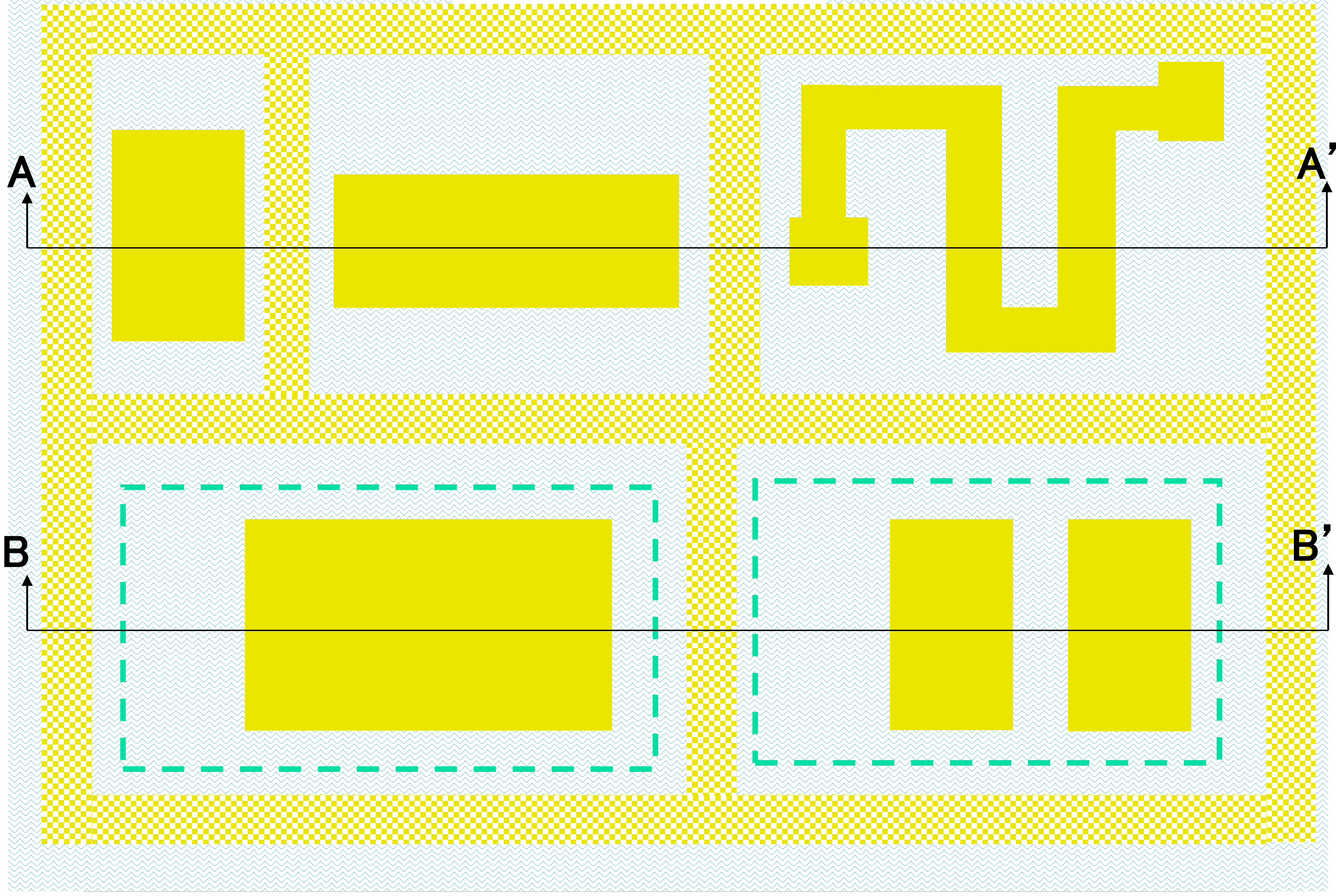


A-A’ Section



B-B’ Section

p-base Diffusion



Mask Numbering and Mappings

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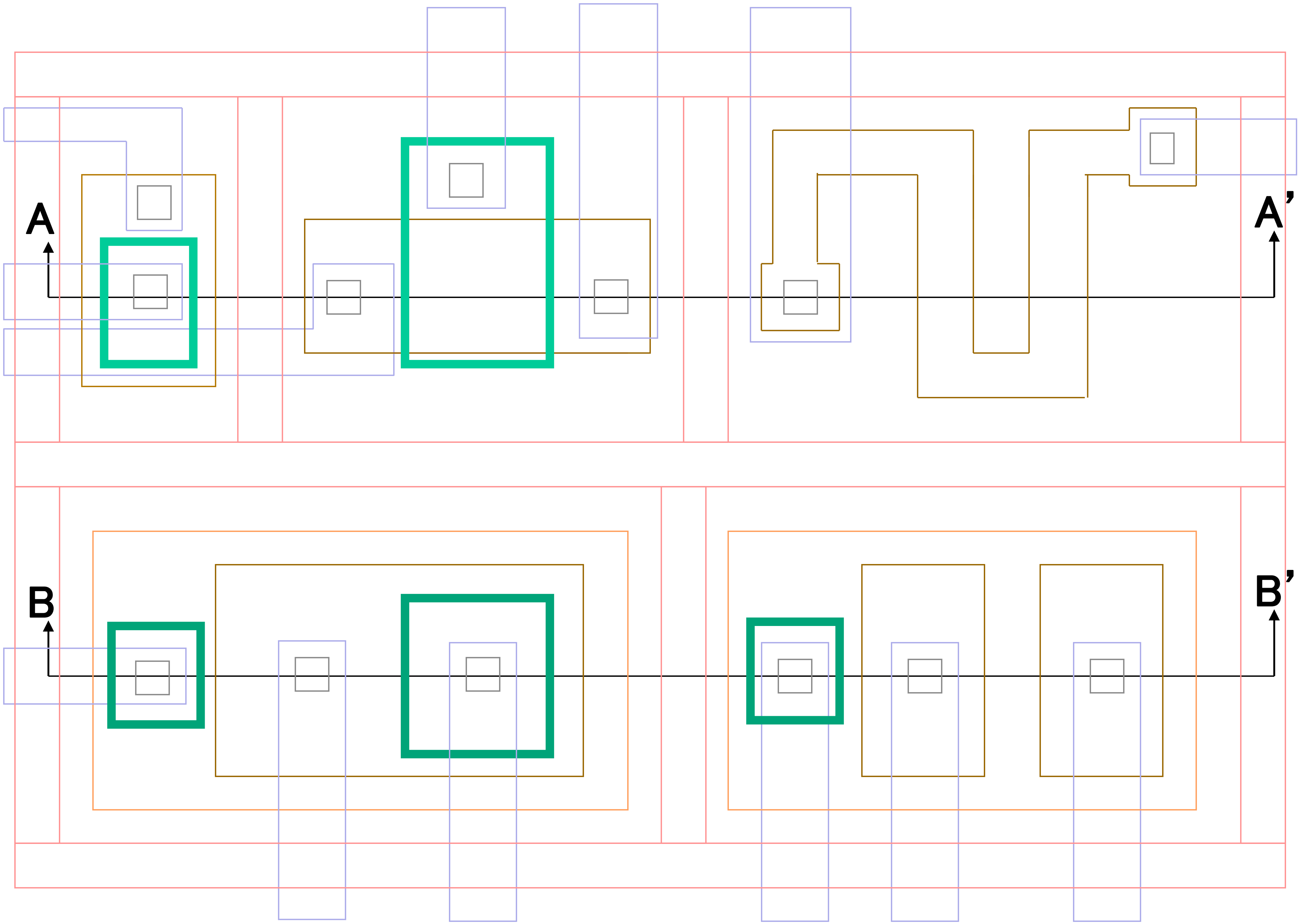
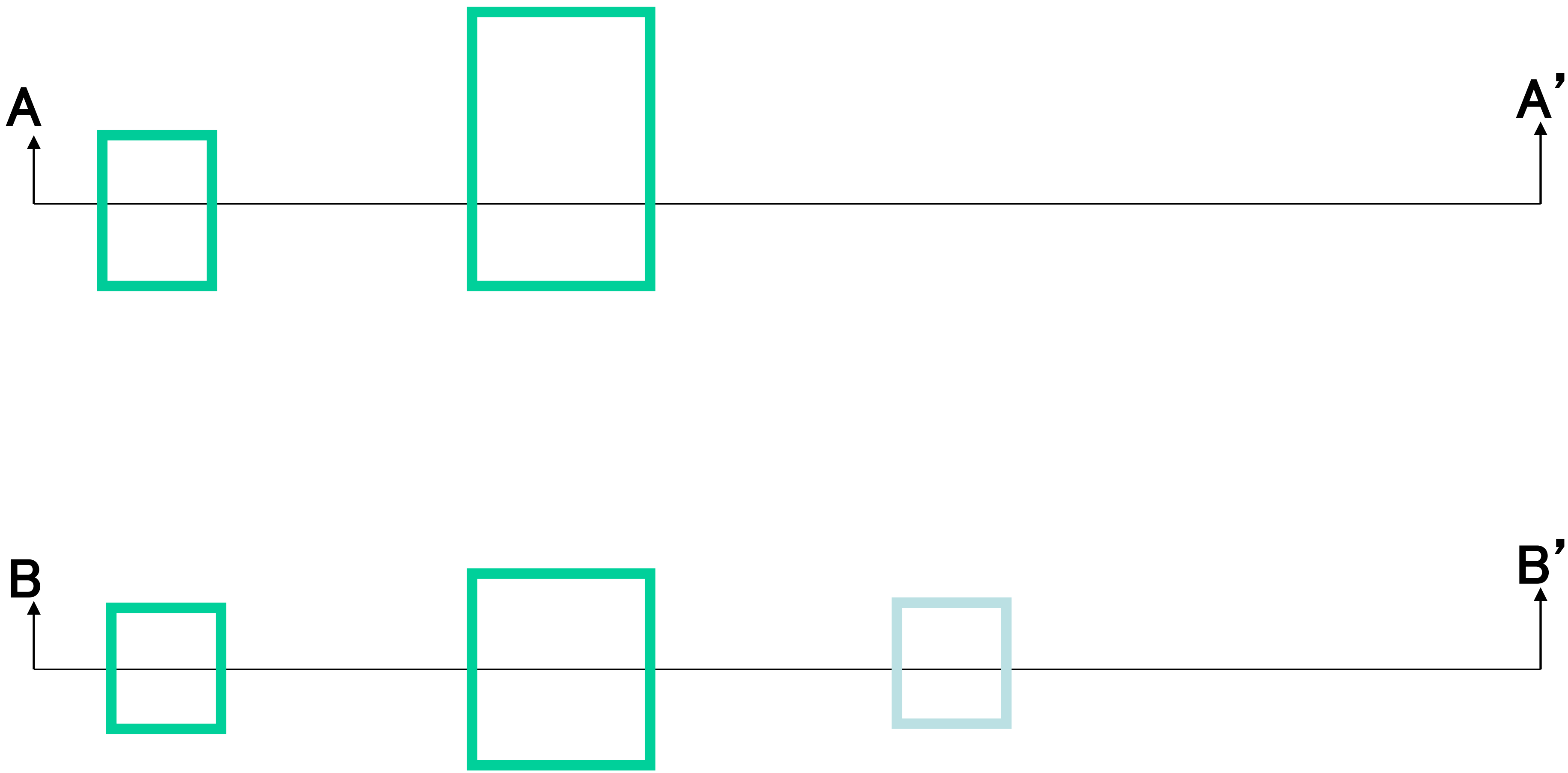
- passivation opening for contacts not shown
- isolation diffusion intentionally not shown to scale



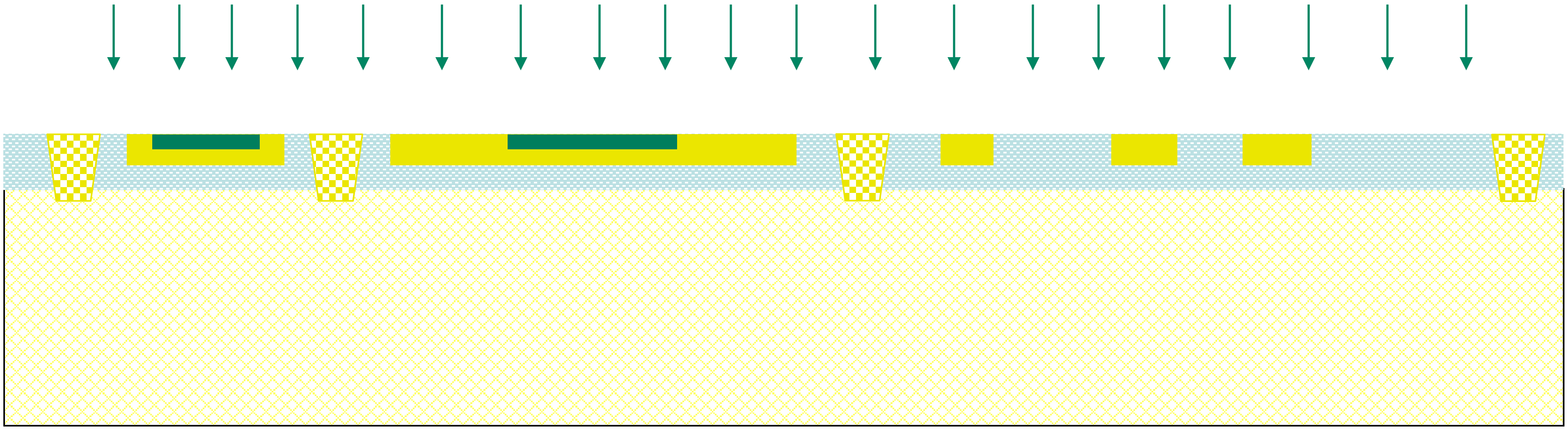
n+ emitter diffusion

Mask 4: n^+ emitter diffusion

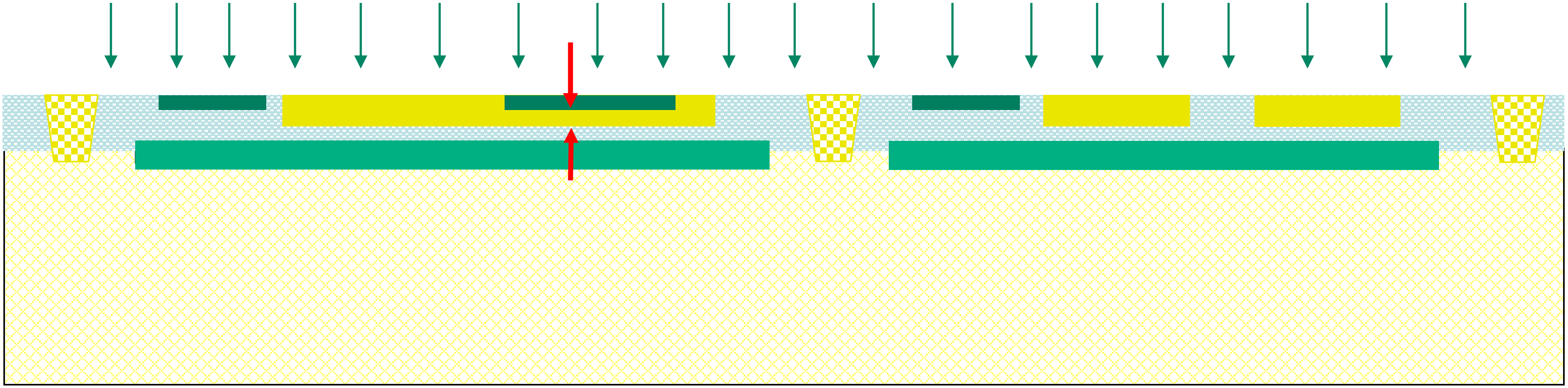


n^+ emitter Diffusion

- Photoresist present but not shown
- Deposition and diffusion combined in slides

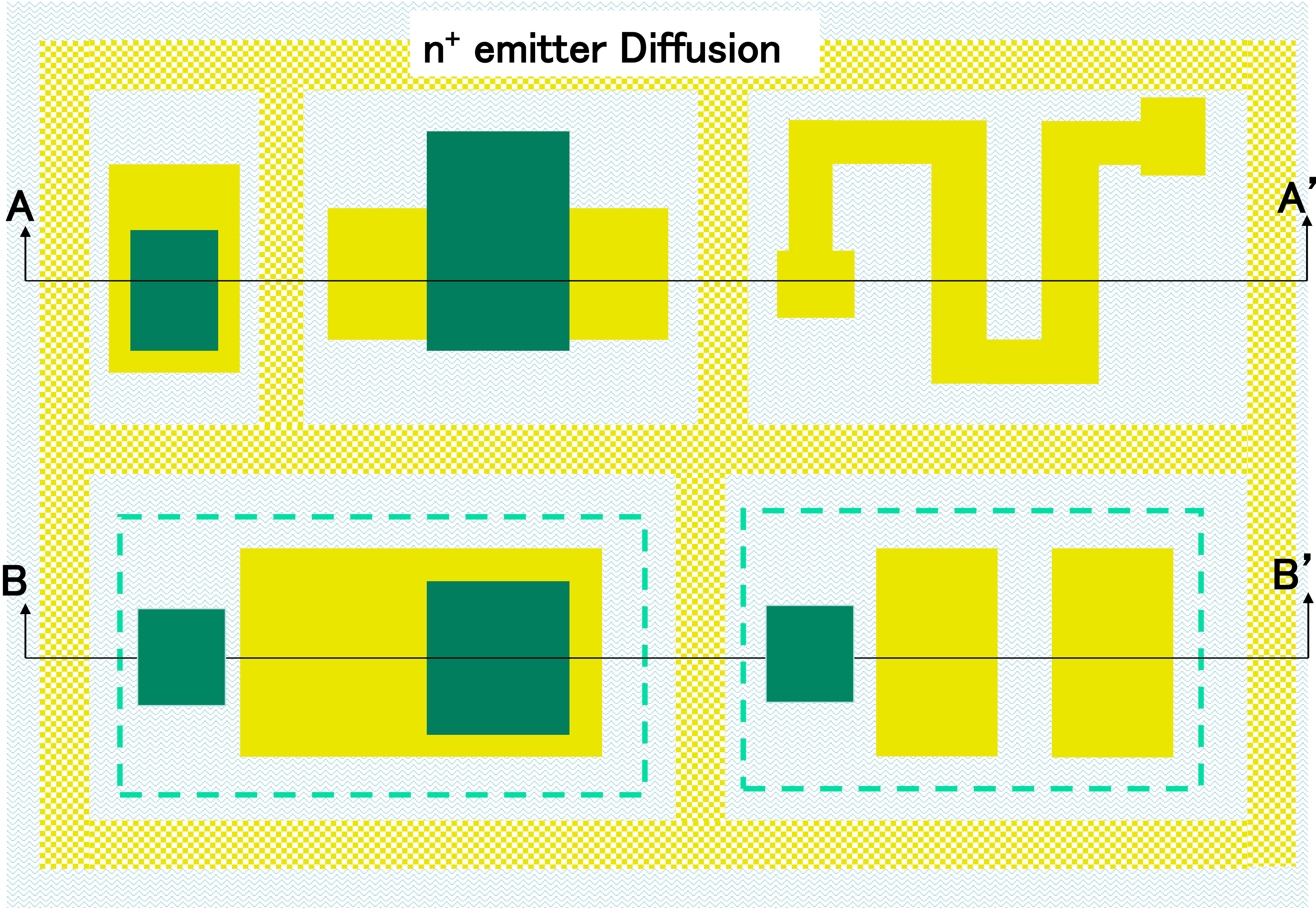


A–A’ Section

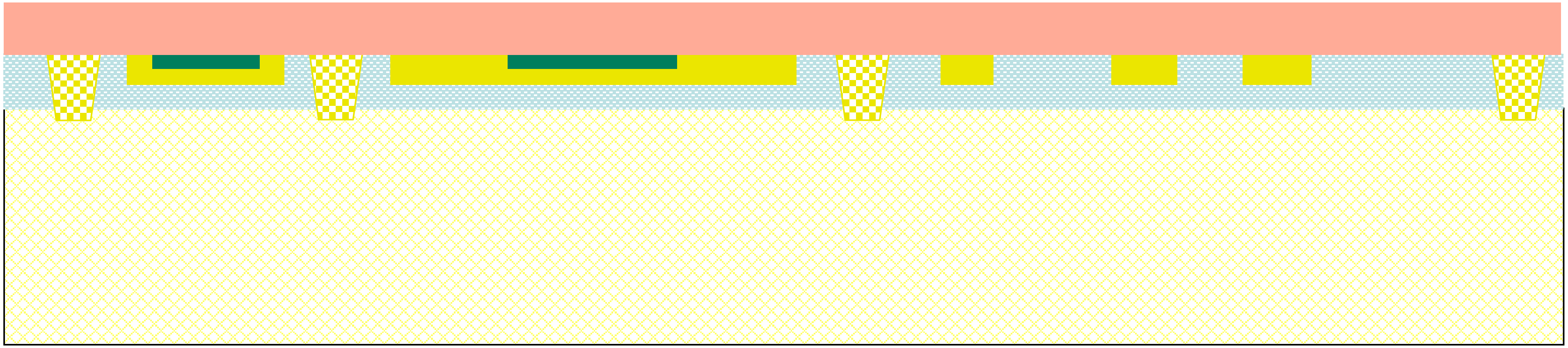


B–B’ Section

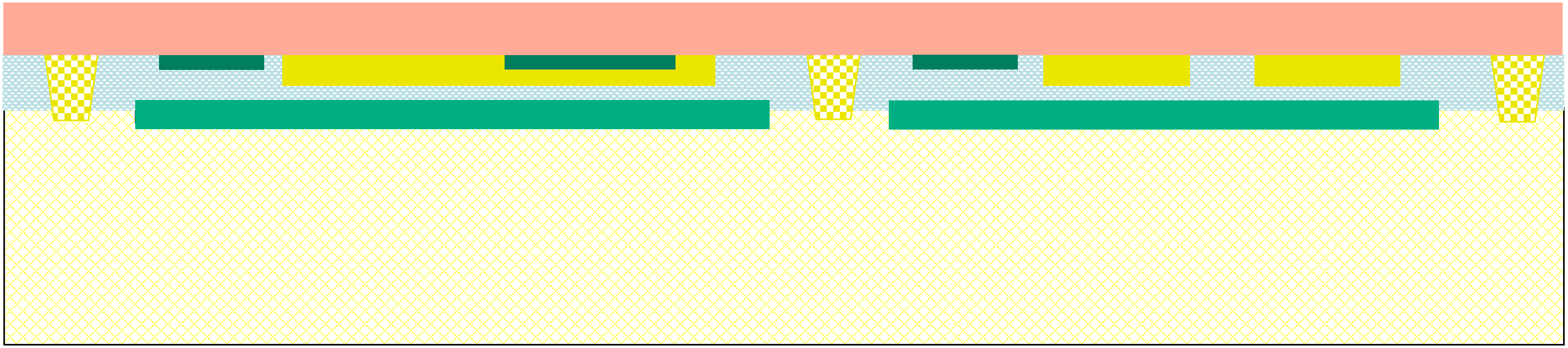
Emitter diffusion typically leaves only thin base area underneath


n+ emitter Diffusion
A
A'
B
B'

Oxidation

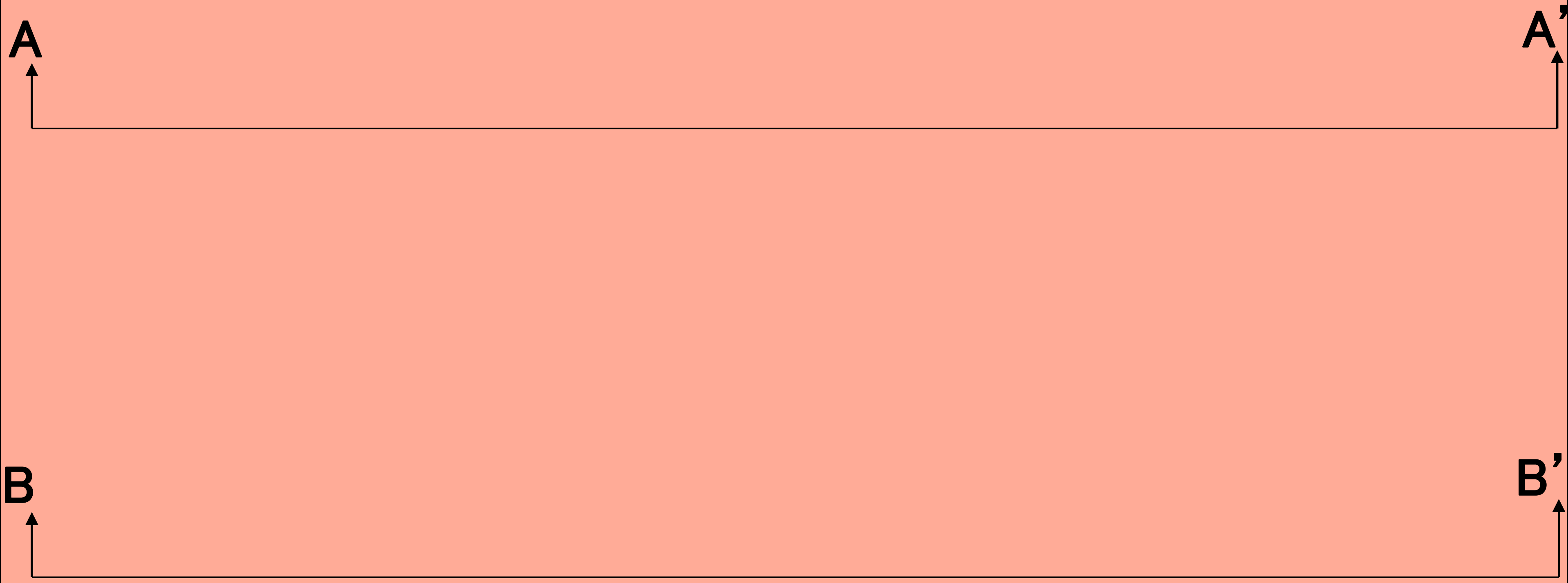


A-A' Section



B-B' Section

Oxidation

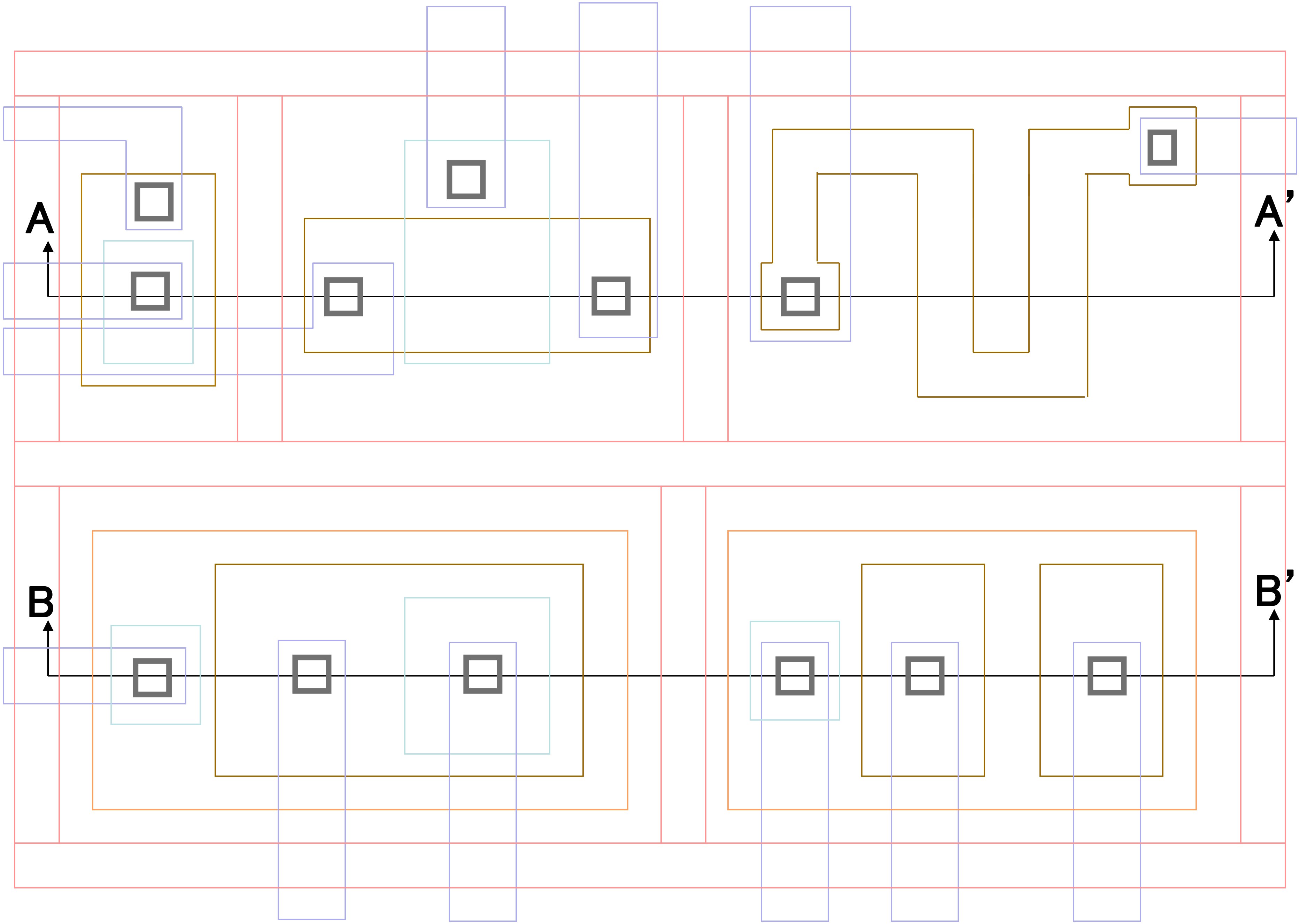


Mask Numbering and Mappings

Mask 1	n^+ buried collector
Mask 2	isolation diffusion (p^+)
Mask 3	p-base diffusion
Mask 4	n^+ emitter
Mask 5	contact
Mask 6	metal
Mask 7	passivation opening

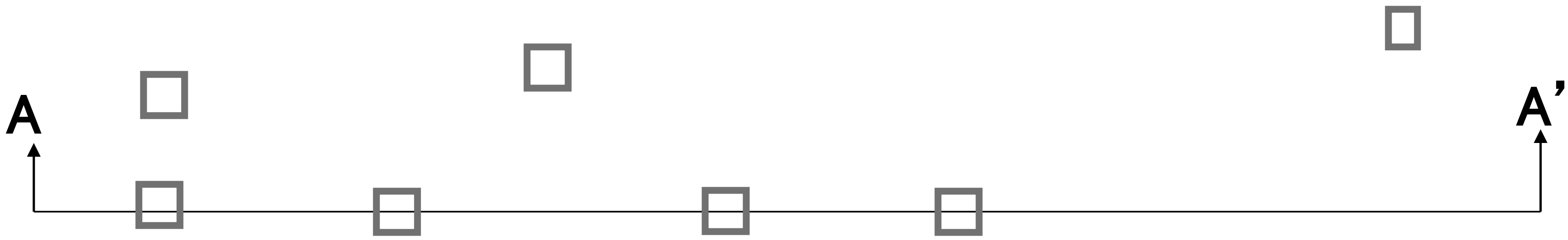
Notes:

- passivation opening for contacts not shown
- isolation diffusion intentionally not shown to scale



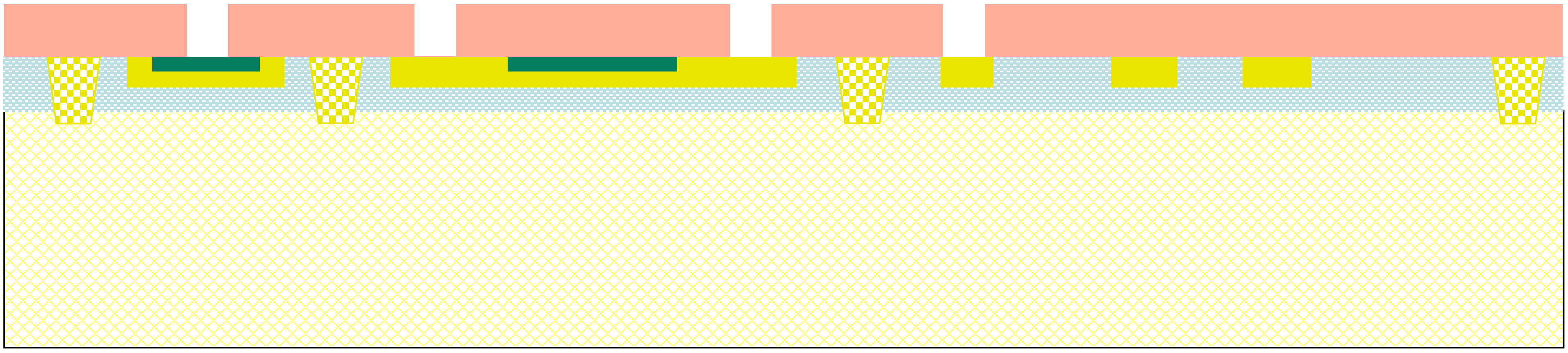
contacts

Mask 5: contacts

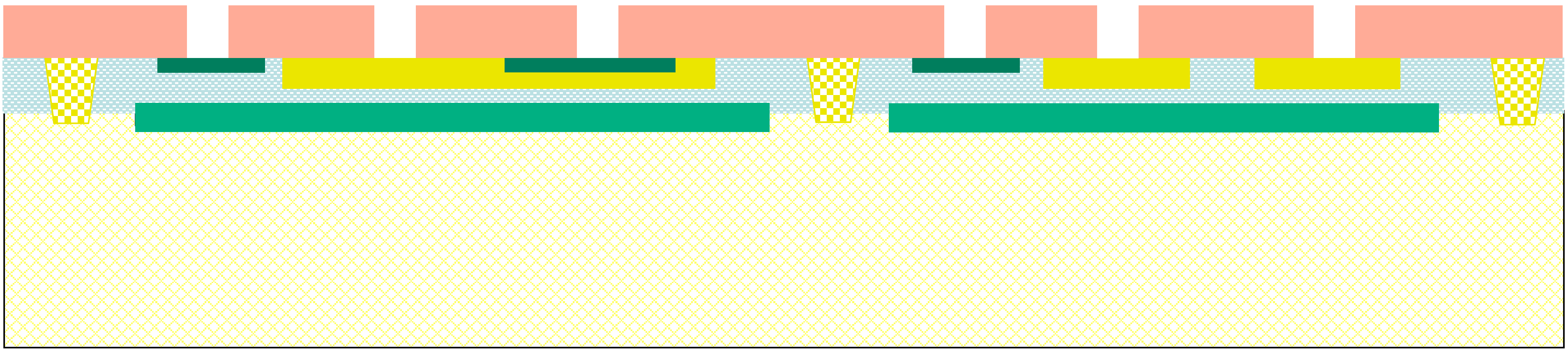


Contact Openings

- Photoresist present but not shown
- Deposition and diffusion combined in slides

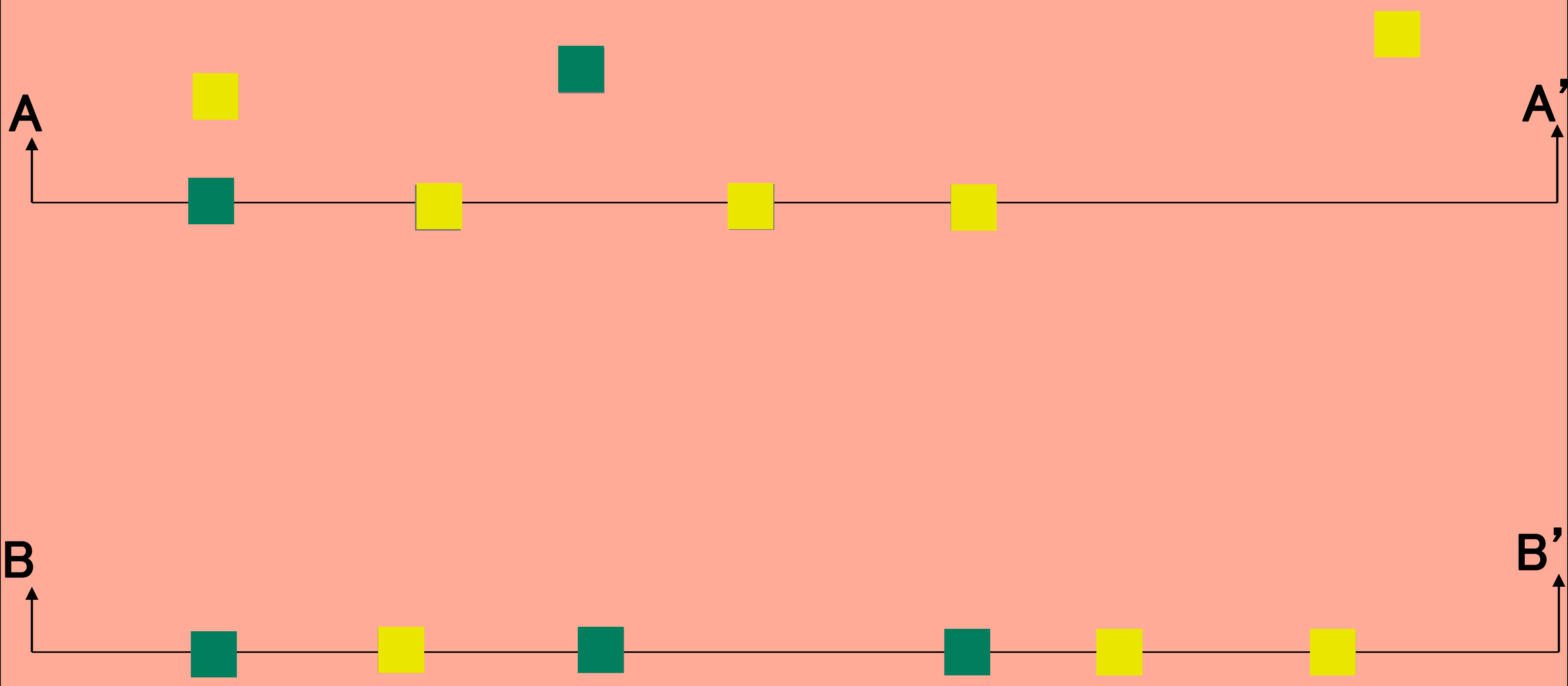


A–A’ Section



B–B’ Section

Contact Openings

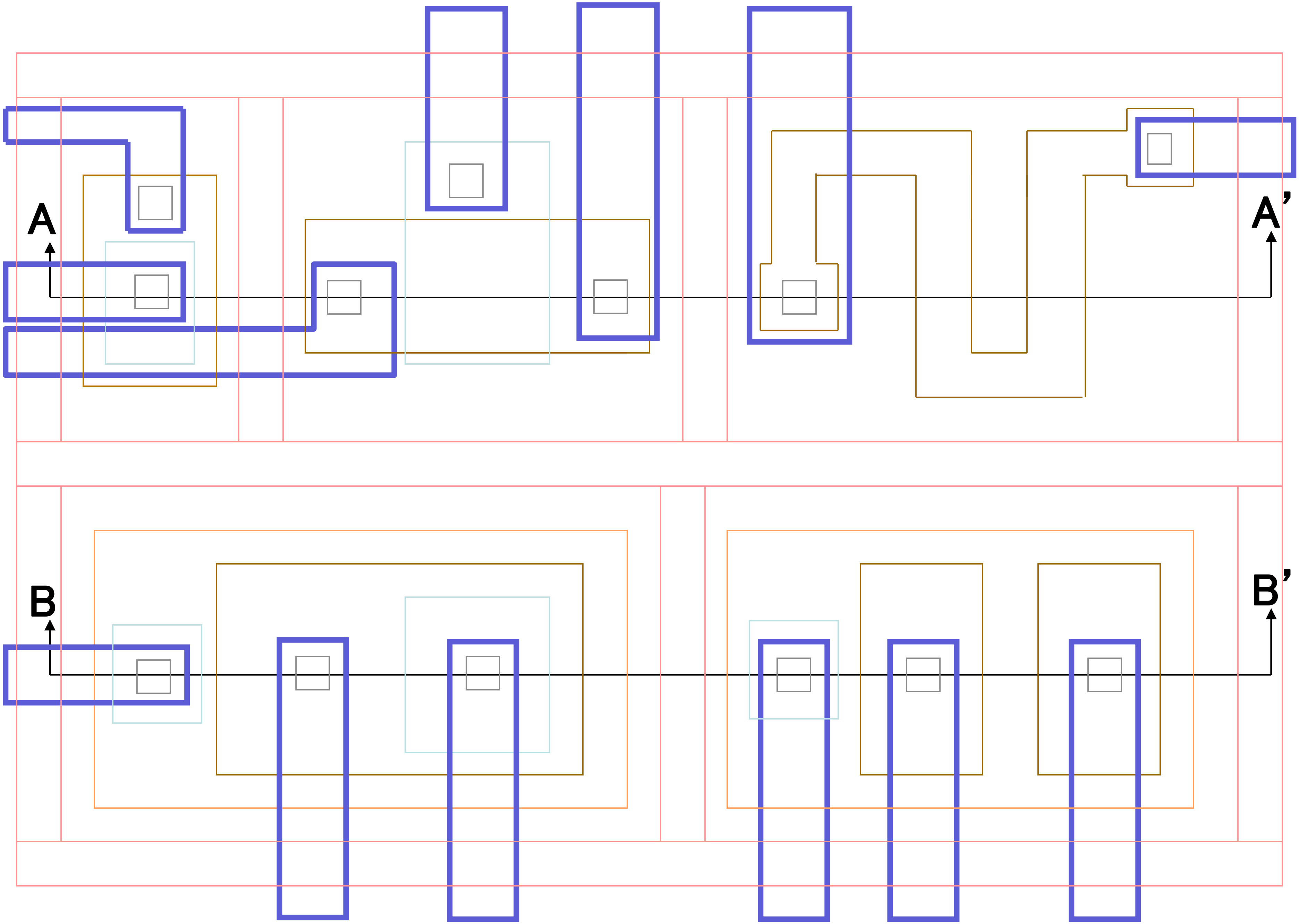


Mask Numbering and Mappings

Mask 1	n^+ buried collector
Mask 2	isolation diffusion (p^+)
Mask 3	p-base diffusion
Mask 4	n^+ emitter
Mask 5	contact
Mask 6	metal
Mask 7	passivation opening

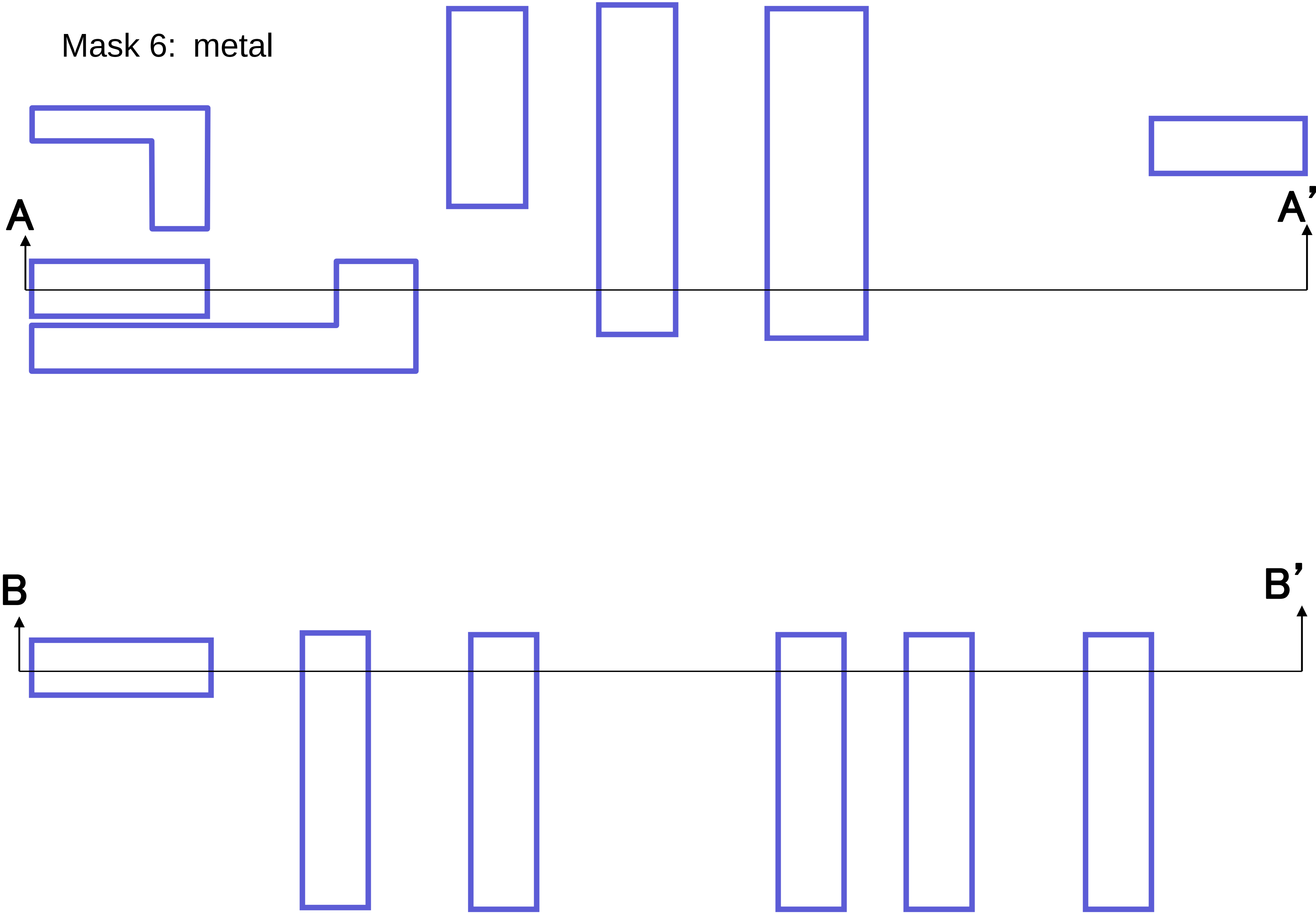
Notes:

- passivation opening for contacts not shown
- isolation diffusion intentionally not shown to scale



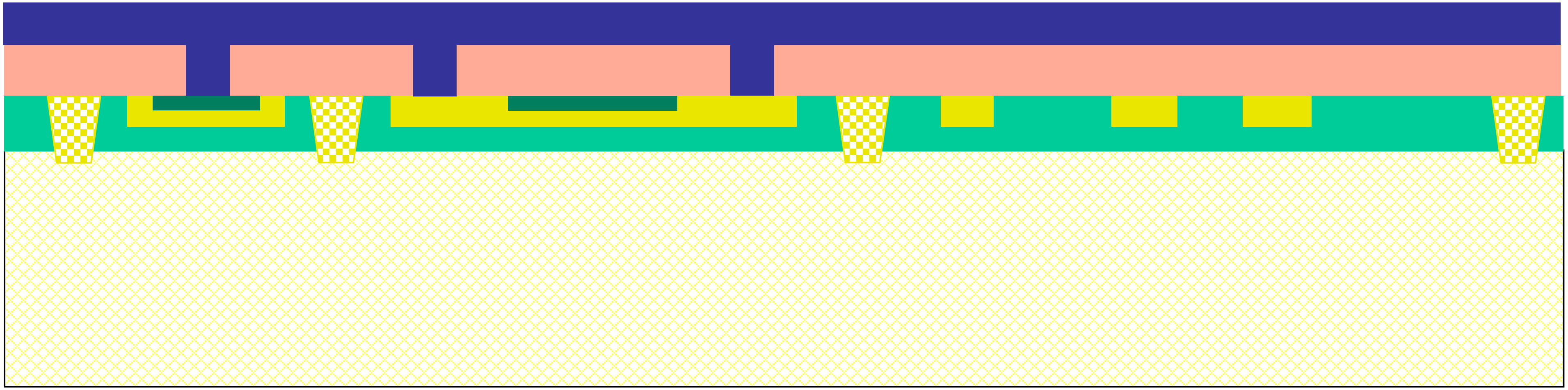
metal

Mask 6: metal

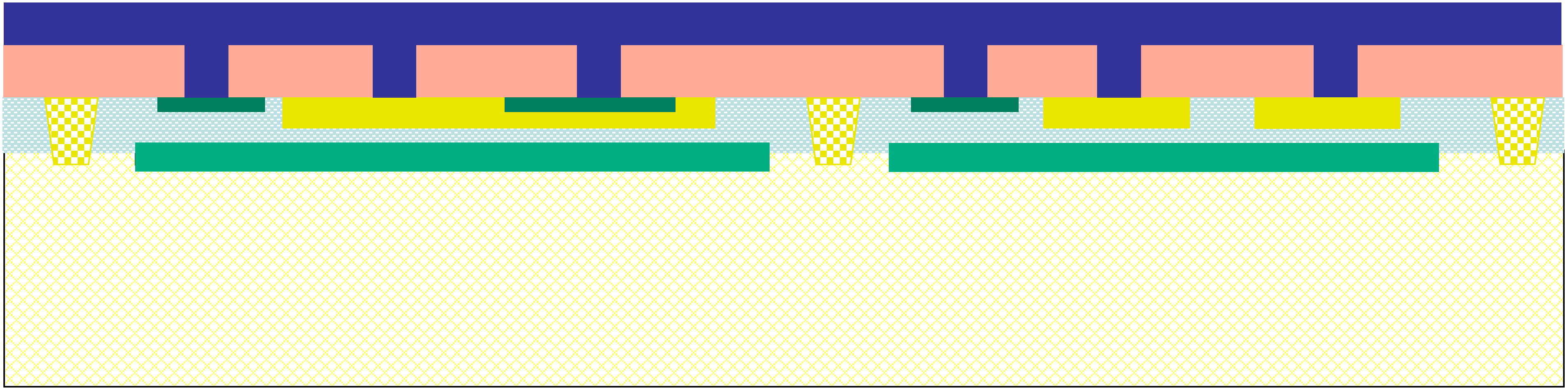


Metalization

- Photoresist present but not shown

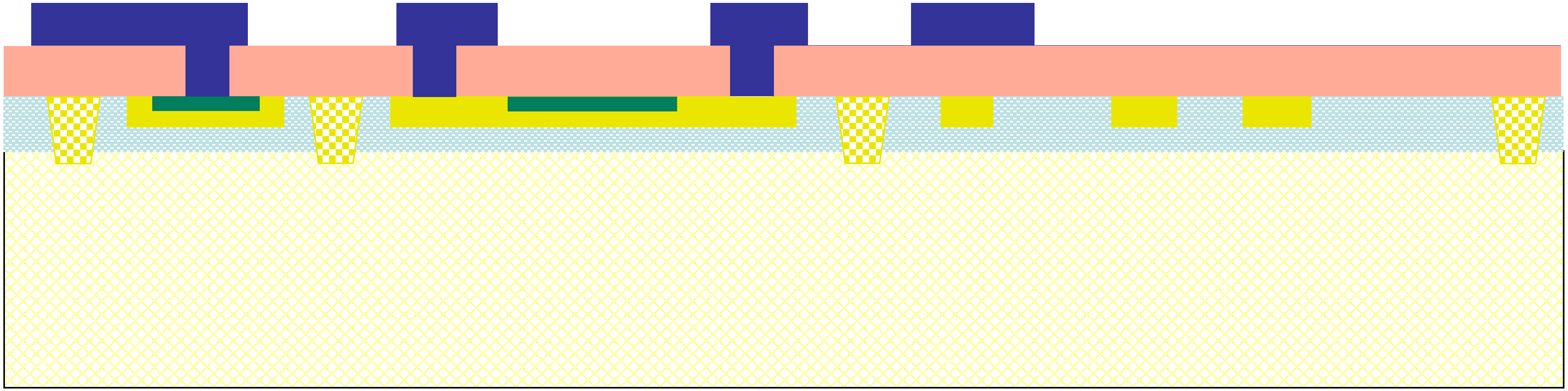


A-A' Section

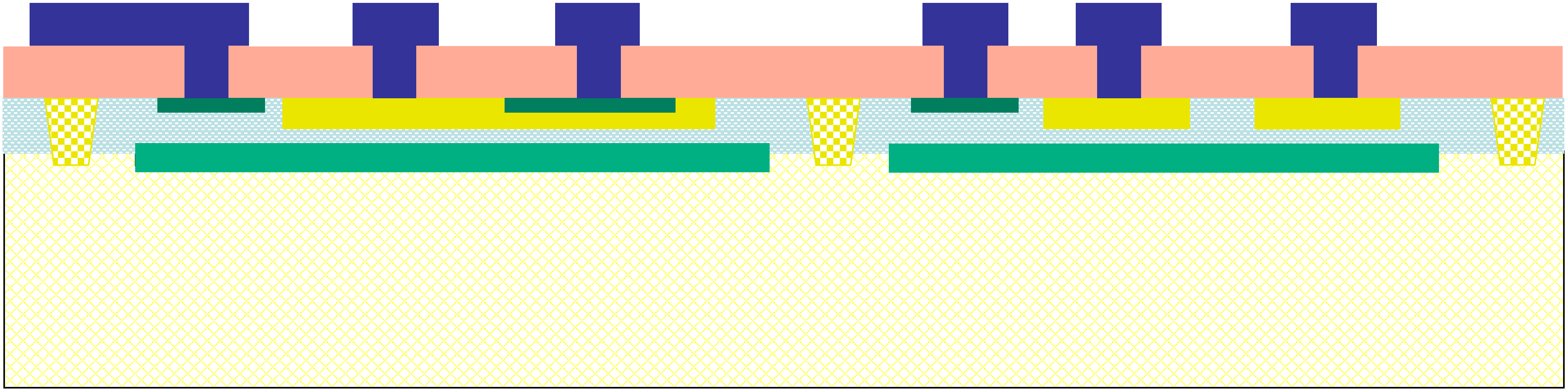


B-B' Section

Pattern Metal

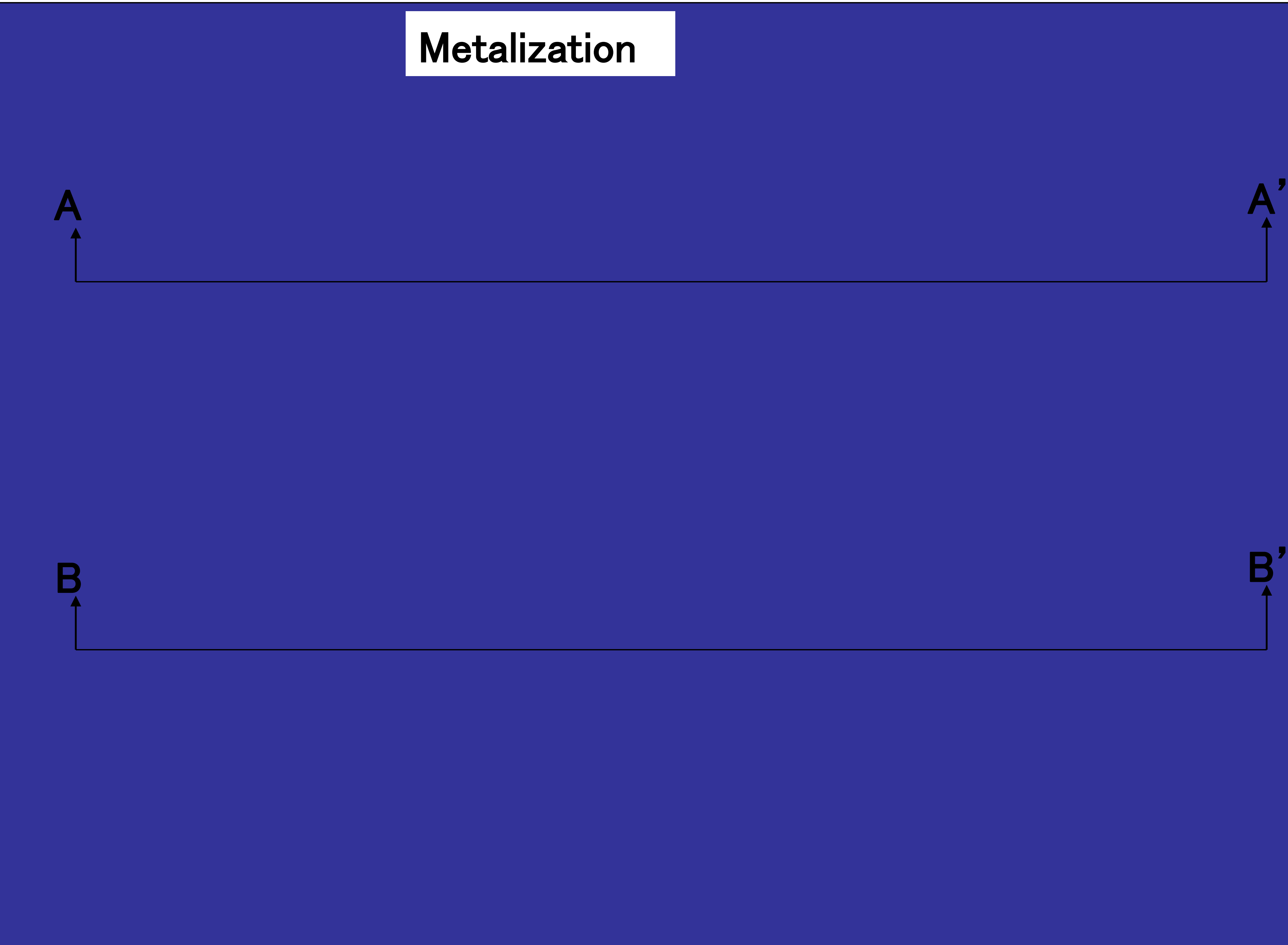


A-A’ Section

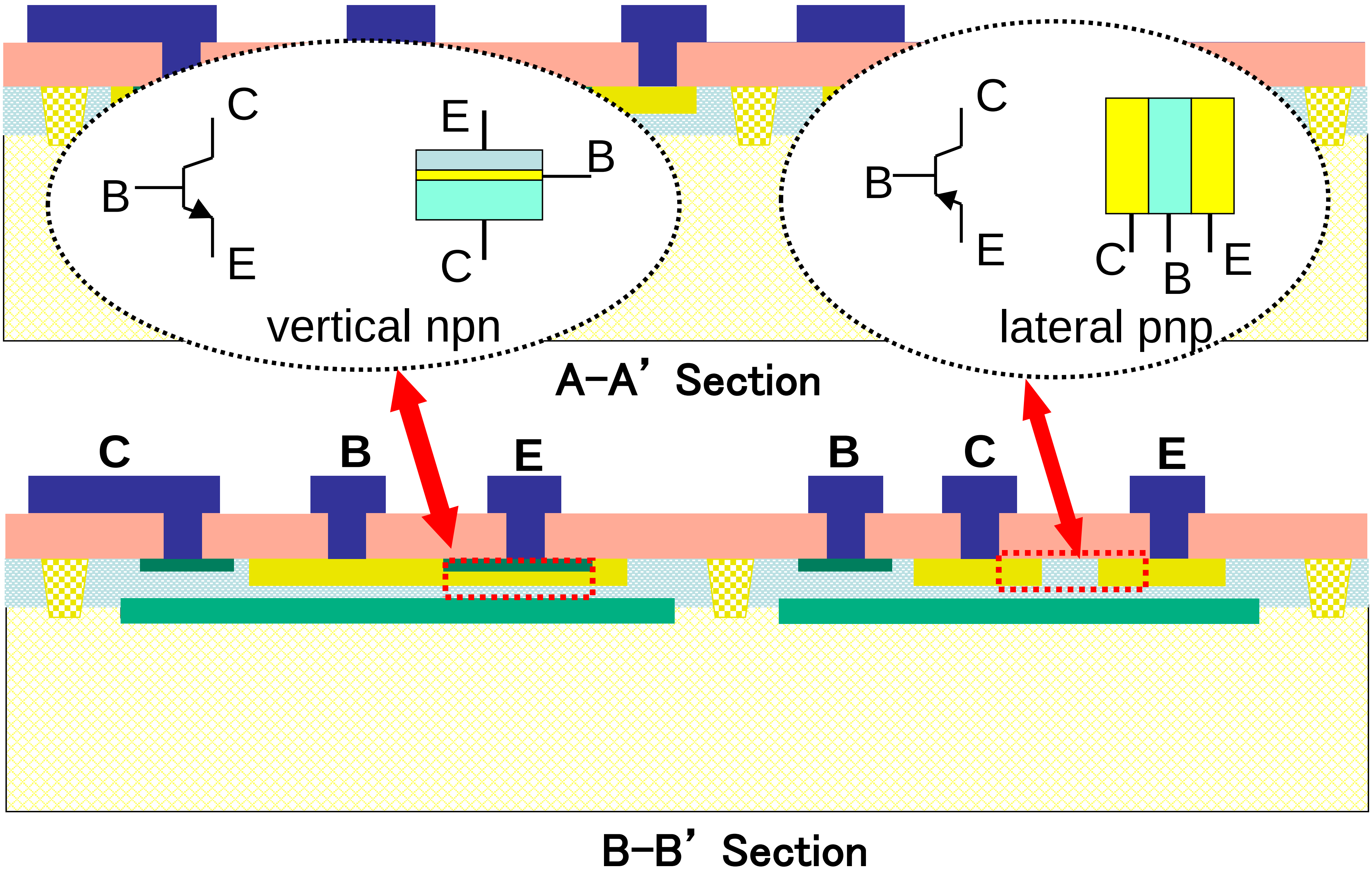


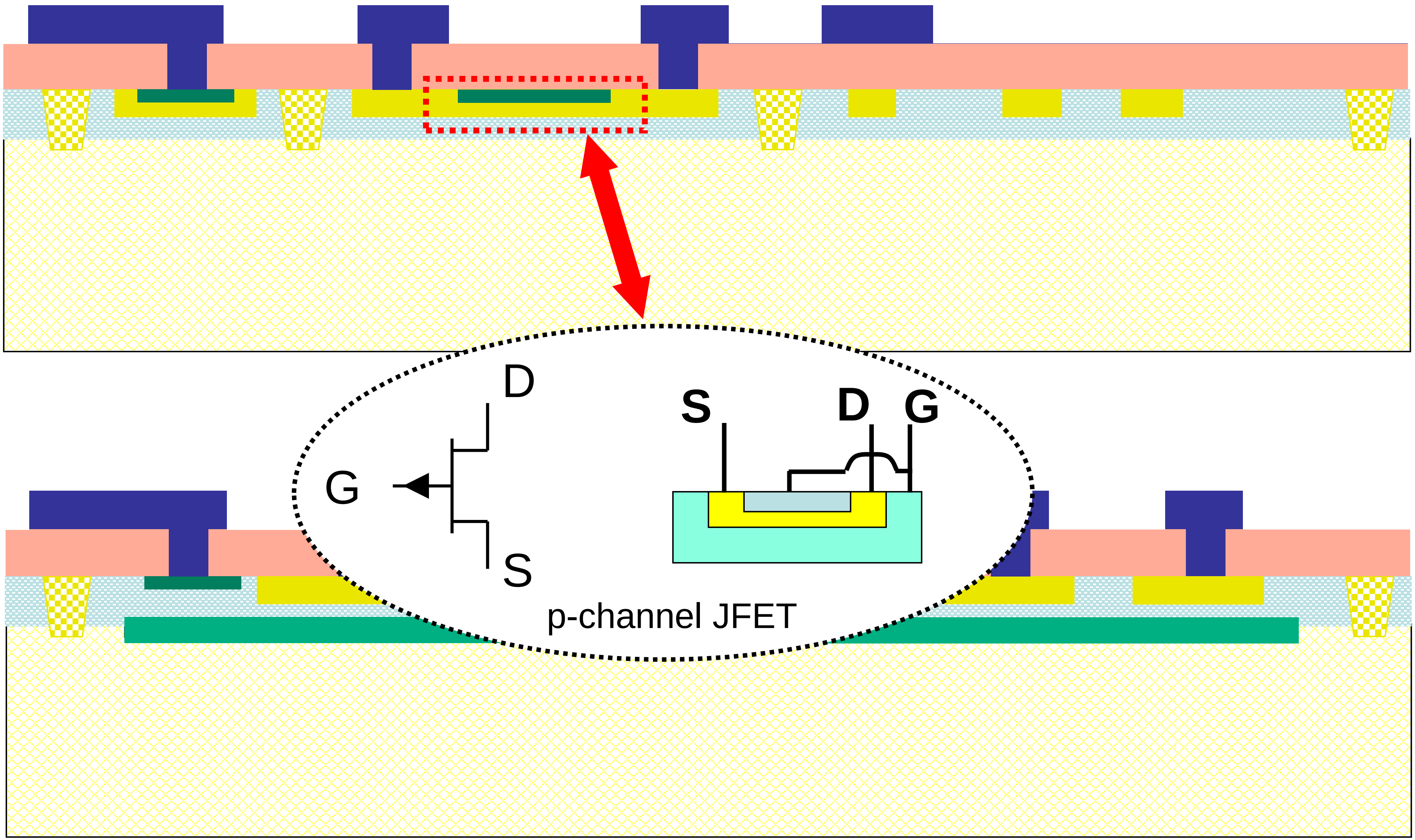
B-B’ Section

Metalization

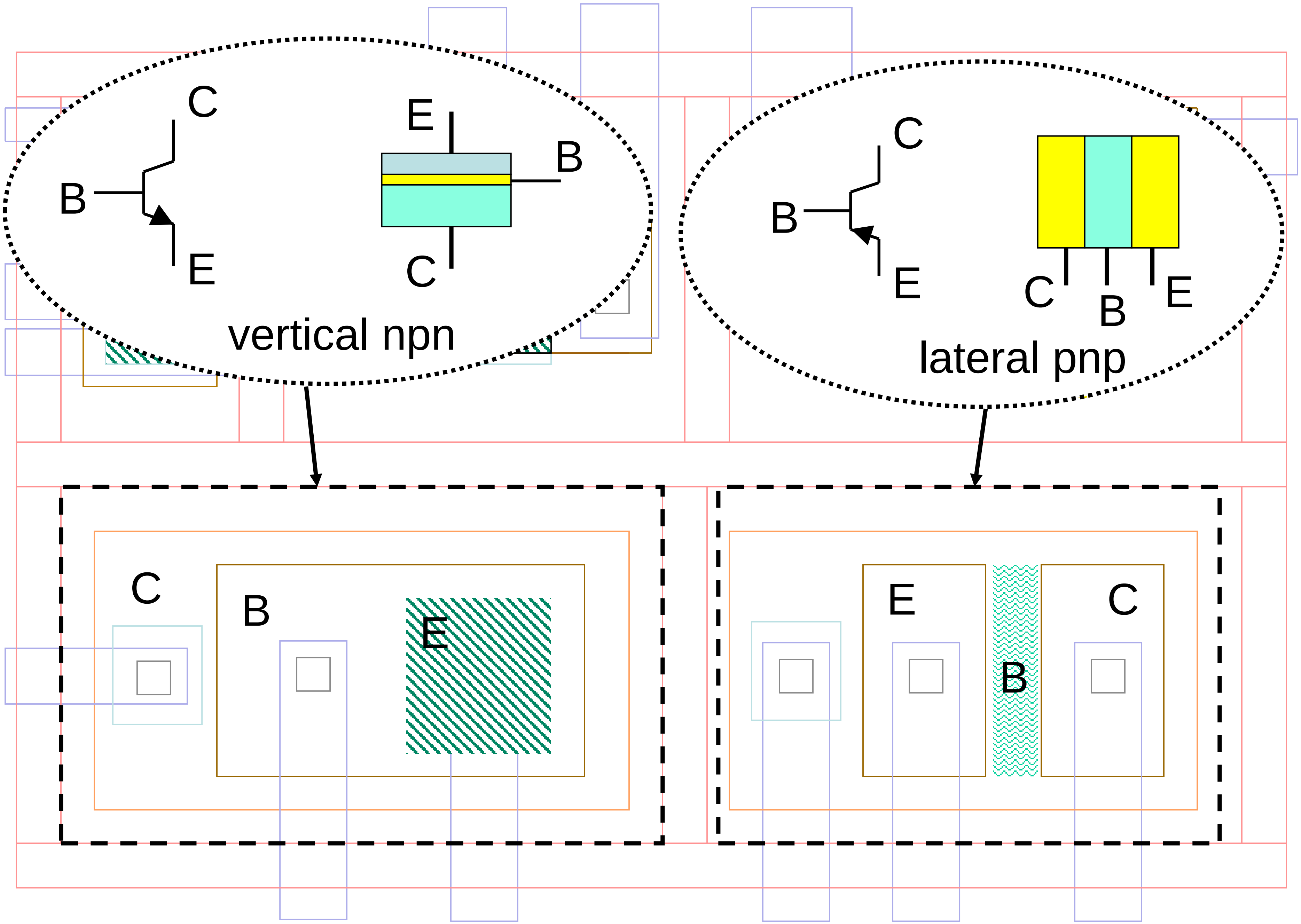


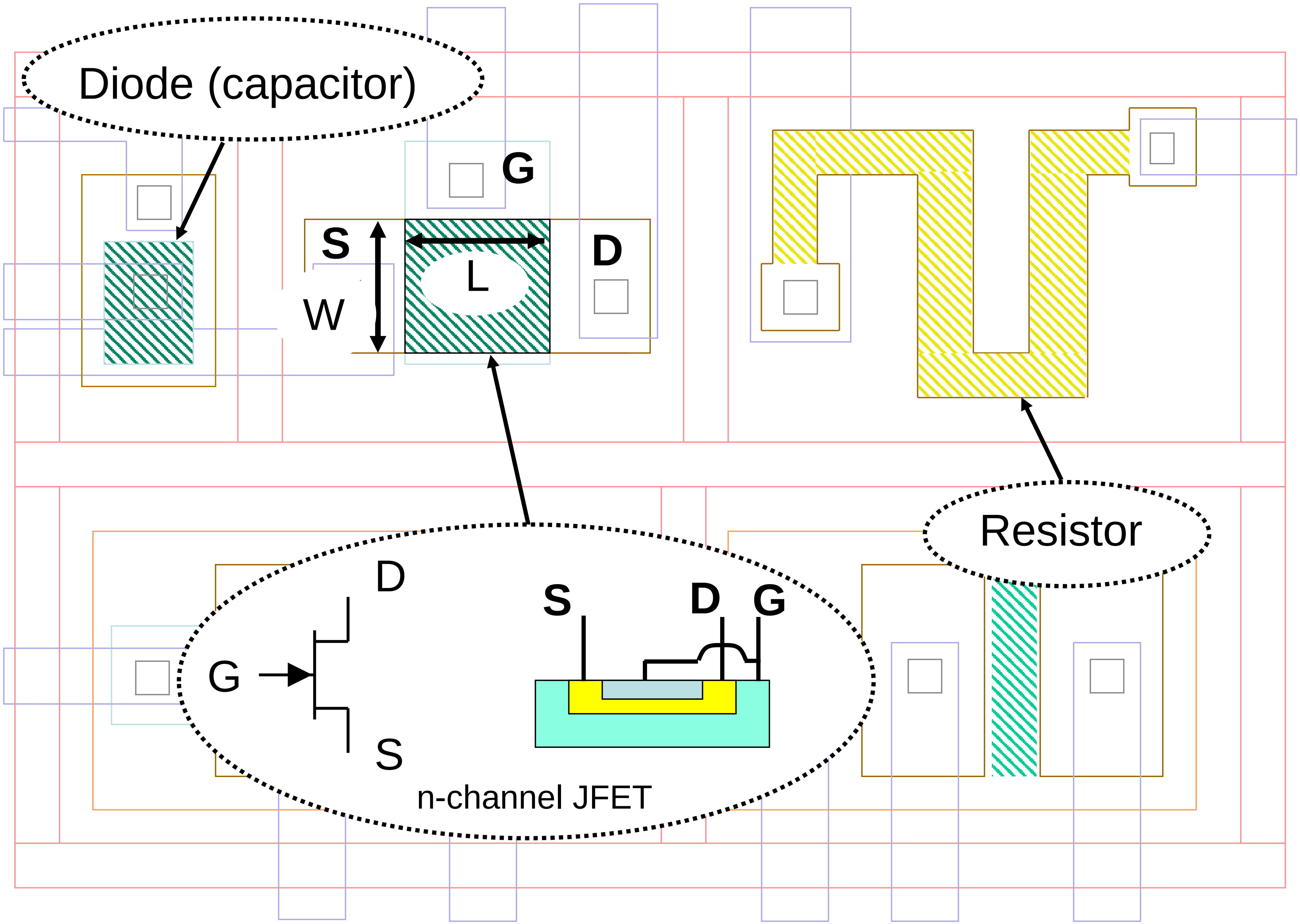

Pattern Metal
A
A'
B
B'


C
B
E
E
B
C
vertical npn
C
B
E
C
B
E
lateral pnp
A–A' Section
C
B
E
B
C
E
B–B' Section



B−B’ Section


C
B
E
E
B
C
vertical npn
C
B
E
C
B
E
lateral pnp
C
B
E
E
C
B



Diode (capacitor)
G
S
D
L
W
Resistor
D
G
S
S
D
G
n-channel JFET

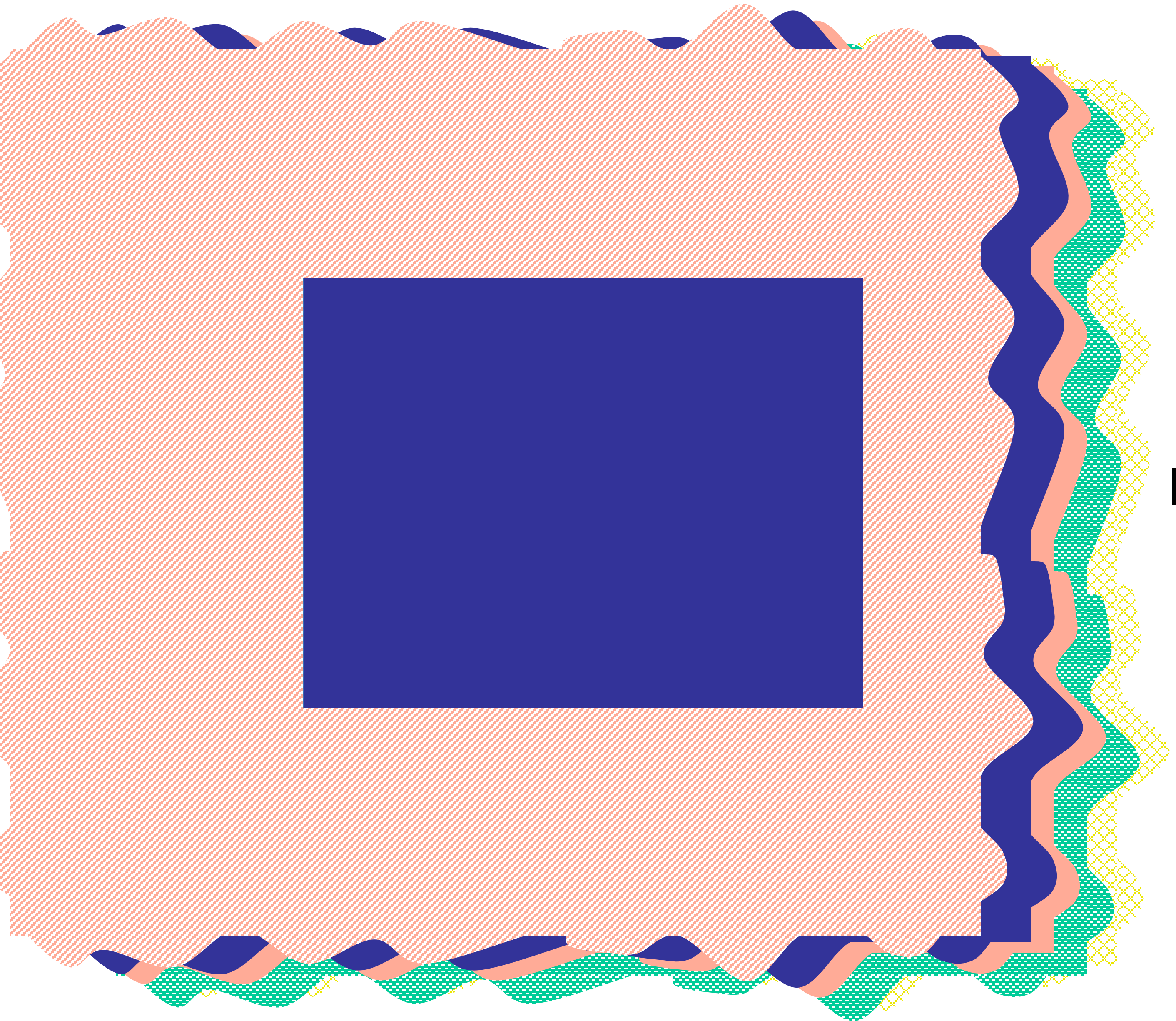
Mask Numbering and Mappings

Mask 1	n^+ buried collector
Mask 2	isolation diffusion (p^+)
Mask 3	p-base diffusion
Mask 4	n^+ emitter
Mask 5	contact
Mask 6	metal
Mask 7	passivation opening

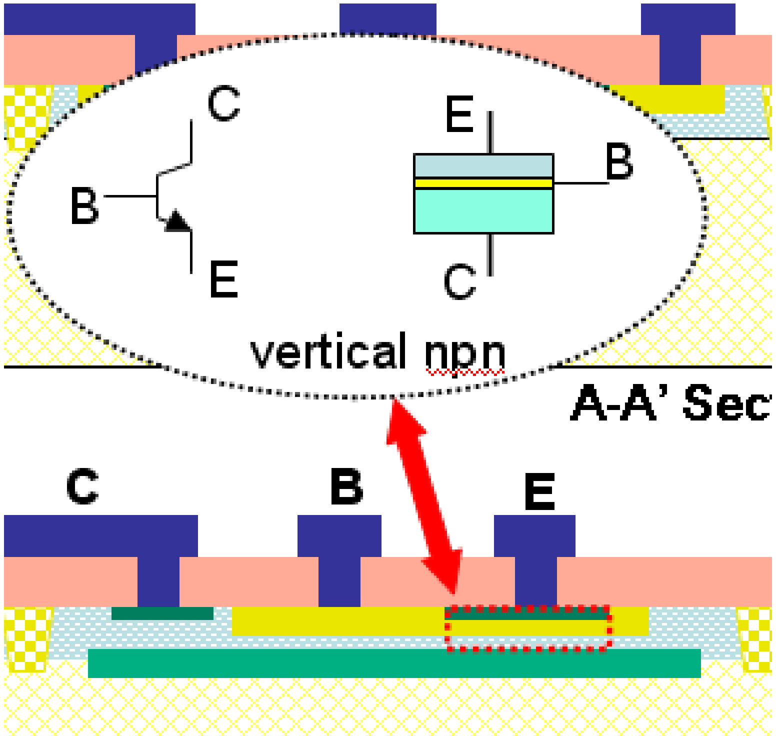
Notes:

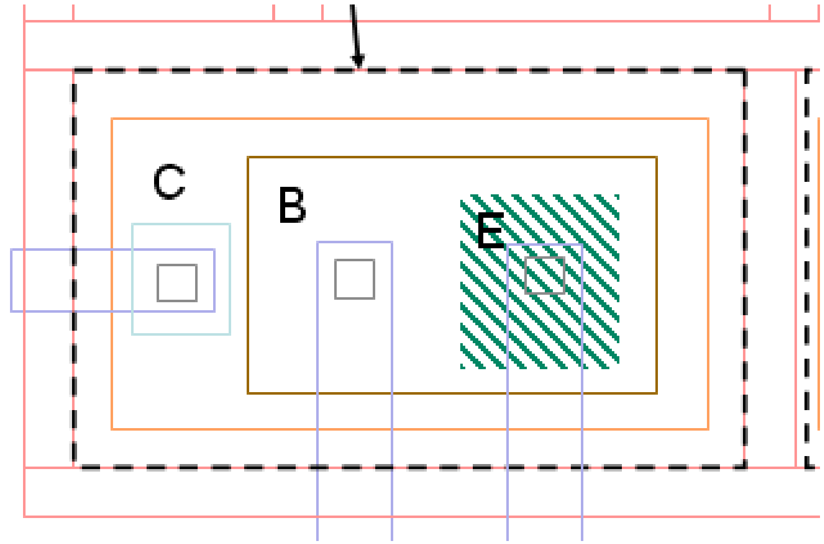
- passivation opening for contacts not shown
- isolation diffusion intentionally not shown to scale

Pad and Pad Opening



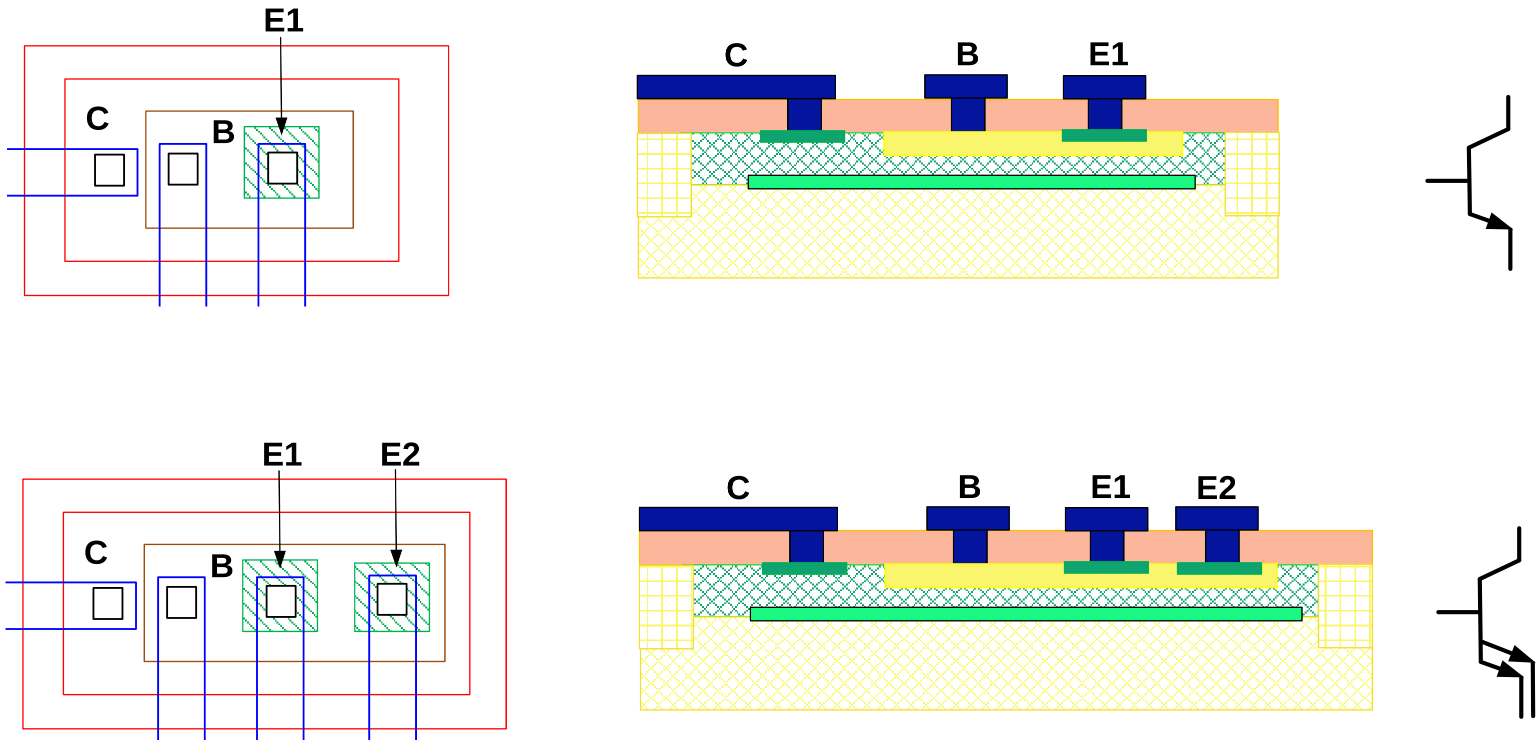
The vertical npn transistor





- Emitter area only geometric parameter that appears in basic device model !
- B and C areas large to get top contact to these regions
- Transistor much larger than emitter
- Multiple-emitter devices often used (TTL Logic) and don't significantly increase area
- Multiple B and C contacts often used (and multiple E contacts as well if A_E large)

The vertical npn transistor



Single-emitter and Double-Emitter Transistor

Base and Collector are shared

Quirks in modeling the BJT

[a]Parameters are defined in Chapters 3 and 4.

[b]Some of these Gummel-Poon parameters differ considerably from those given in Table 2C.4. They have been obtained from curve fitting and should give good results with computer simulations. The parameters of Table 2C.4 should be used for hand analysis.

[c]Parameters that are strongly area-dependent are based upon an npn emitter area of 390 μ^2 and perimeter of 80 μ, a base area of 2200 μ^2 and perimeter of 200 μ, and a collector area of 10,500 μ^2 and perimeter of 425 μ. The lateral pnp has rectangular collectors and emitters spaced 10 μ apart with areas of 230 μ^2 and perimeters of 60 μ. The base area of the pnp is 7400 μ^2 and the base perimeter is 345 μ.

[d]CJS is set to zero for the lateral transistor because it is essentially nonexistent. The parasitic capacitance from base to substrate, which totals 1.0 pF for this device, must be added externally to the BJT.

- In contrast to the MOSFET where process parameters are independent of geometry, the bipolar transistor model is for a specific transistor !
- Area emitter factor is used to model other devices
- Often multiple specific device models are given and these devices are used directly
- Often designer can not arbitrarily set A_E but rather must use parallel combinations of specific devices and layouts

MOS and Bipolar Area Comparisions

How does the area required to realize a MOSFET compare to that required to realize a BJT?

Will consider a minimum-sized device in both processes

TABLE 2C.2
Design rules for a typical bipolar process ($\lambda = 2.5\ \mu$)
(See Table 2C.3 in color plates for graphical interpretation)

	Dimension
1. n^+ buried collector diffusion (Yellow, Mask #1)	
1.1 Width	3λ
1.2 Overlap of p-base diffusion (for vertical npn)	2λ
1.3 Overlap of n^+ emitter diffusion (for collector contact of vertical npn)	2λ
1.4 Overlap of p-base diffusion (for collector and emitter of lateral pnp)	2λ
1.5 Overlap of n^+ emitter diffusion (for base contact of lateral pnp)	2λ
2. Isolation diffusion (Orange, Mask #2)	
2.1 Width	4λ
2.2 Spacing	24λ
2.3 Distance to n^+ buried collector	14λ
3. p-base diffusion (Brown, Mask #3)	
3.1 Width	3λ
3.2 Spacing	5λ
3.3 Distance to isolation diffusion	14λ
3.4 Width (resistor)	3λ
3.5 Spacing (as resistor)	3λ
4. n^+ emitter diffusion (Green, Mask #4)	
4.1 Width	3λ
4.2 Spacing	3λ
4.3 p-base diffusion overlap of n^+ emitter diffusion (emitter in base)	2λ
4.4 Spacing to isolation diffusion (for collector contact)	12λ
4.5 Spacing to p-base diffusion (for base contact of lateral pnp)	6λ
4.6 Spacing to p-base diffusion (for collector contact of vertical npn)	6λ

5. Contact (Black, Mask #5)
    - 5.1 Size (exactly) — $4\lambda \times 4\lambda$
    - 5.2 Spacing — 2λ
    - 5.3 Metal overlap of contact — λ
    - 5.4 n^+ emitter diffusion overlap of contact — 2λ
    - 5.5 p-base diffusion overlap of contact — 2λ
    - 5.6 p-base to n^+ emitter — 3λ
    - 5.7 Spacing to isolation diffusion — 4λ

6. Metalization (Blue, Mask #6)
    - 6.1 Width — 2λ
    - 6.2 Spacing — 2λ
    - 6.3 Bonding pad size — $100\ \mu \times 100\ \mu$
    - 6.4 Probe pad size — $75\ \mu \times 75\ \mu$
    - 6.5 Bonding pad separation — $50\ \mu$
    - 6.6 Bonding to probe pad — $30\ \mu$
    - 6.7 Probe pad separation — $30\ \mu$
    - 6.8 Pad to circuitry — $40\ \mu$
    - 6.9 Maximum current density — $0.8\ mA/\mu$ width

7. Passivation (Purple, Mask #7)
    - 7.1 Minimum bonding pad opening — $90\ \mu \times 90\ \mu$
    - 7.2 Minimum probe pad opening — $65\ \mu \times 65\ \mu$

Consider Initially the Emitter in the BJT
surrounded by a base region

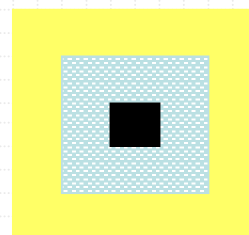


TABLE 2C.2

Design rules for a typical bipolar process ($\lambda = 2.5\ \mu$)
(See Table 2C.3 in color plates for graphical interpretation)

	Dimension
1. n^+ buried collector diffusion (Yellow, Mask #1)	
1.1 Width	3λ
1.2 Overlap of p-base diffusion (for vertical npn)	2λ
1.3 Overlap of n^+ emitter diffusion (for collector contact of vertical npn)	2λ
1.4 Overlap of p-base diffusion (for collector and emitter of lateral pnp)	2λ
1.5 Overlap of n^+ emitter diffusion (for base contact of lateral pnp)	2λ
2. Isolation diffusion (Orange, Mask #2)	
2.1 Width	4λ
2.2 Spacing	24λ
2.3 Distance to n^+ buried collector	14λ
3. p-base diffusion (Brown, Mask #3)	
3.1 Width	3λ
3.2 Spacing	5λ
3.3 Distance to isolation diffusion	14λ
3.4 Width (resistor)	3λ
3.5 Spacing (as resistor)	3λ
4. n^+ emitter diffusion (Green, Mask #4)	
4.1 Width	3λ
4.2 Spacing	3λ
4.3 p-base diffusion overlap of n^+ emitter diffusion (emitter in base)	2λ
4.4 Spacing to isolation diffusion (for collector contact)	12λ
4.5 Spacing to p-base diffusion (for base contact of lateral pnp)	6λ
4.6 Spacing to p-base diffusion (for collector contact of vertical npn)	6λ

5. Contact (Black, Mask #5)

5.1 Size (exactly)	$\boxed{4\lambda \times 4\lambda}$
5.2 Spacing	2λ
5.3 Metal overlap of contact	λ
5.4 n^+ emitter diffusion overlap of contact	2λ
5.5 p-base diffusion overlap of contact	2λ
5.6 p-base to n^+ emitter	3λ
5.7 Spacing to isolation diffusion	4λ

6. Metalization (Blue, Mask #6)

6.1 Width	2λ
6.2 Spacing	2λ
6.3 Bonding pad size	$100\ \mu \times 100\ \mu$
6.4 Probe pad size	$75\ \mu \times 75\ \mu$
6.5 Bonding pad separation	$50\ \mu$
6.6 Bonding to probe pad	$30\ \mu$
6.7 Probe pad separation	$30\ \mu$
6.8 Pad to circuitry	$40\ \mu$
6.9 Maximum current density	0.8 mA/μ width

7. Passivation (Purple, Mask #7)

7.1 Minimum bonding pad opening	$90\ \mu \times 90\ \mu$
7.2 Minimum probe pad opening	$65\ \mu \times 65\ \mu$

From design rules (left to right) 4.3, 5.1, 5.4, 5.6, 5.5

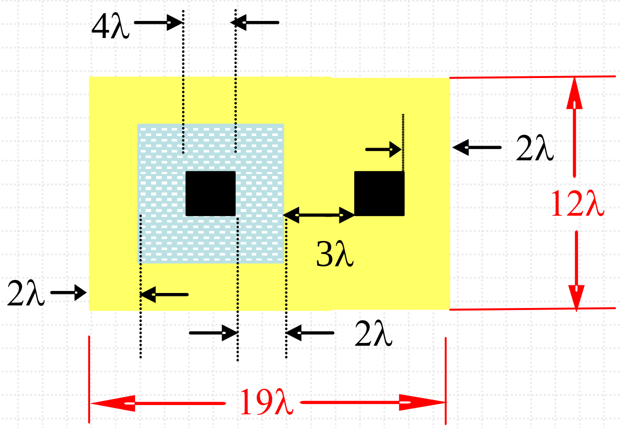


TABLE 2C.2
Design rules for a typical bipolar process ($\lambda = 2.5\ \mu$)
(See Table 2C.3 in color plates for graphical interpretation)

	Dimension
1. n^+ buried collector diffusion (Yellow, Mask #1)	
1.1 Width	3λ
1.2 Overlap of p-base diffusion (for vertical npn)	2λ
1.3 Overlap of n^+ emitter diffusion (for collector contact of vertical npn)	2λ
1.4 Overlap of p-base diffusion (for collector and emitter of lateral pnp)	2λ
1.5 Overlap of n^+ emitter diffusion (for base contact of lateral pnp)	2λ
2. Isolation diffusion (Orange, Mask #2)	
2.1 Width	4λ
2.2 Spacing	24λ
2.3 Distance to n^+ buried collector	14λ
3. p-base diffusion (Brown, Mask #3)	
3.1 Width	3λ
3.2 Spacing	5λ
3.3 Distance to isolation diffusion	14λ
3.4 Width (resistor)	3λ
3.5 Spacing (as resistor)	3λ
4. n^+ emitter diffusion (Green, Mask #4)	
4.1 Width	3λ
4.2 Spacing	3λ
4.3 p-base diffusion overlap of n^+ emitter diffusion (emitter in base)	2λ
4.4 Spacing to isolation diffusion (for collector contact)	12λ
4.5 Spacing to p-base diffusion (for base contact of lateral pnp)	6λ
4.6 Spacing to p-base diffusion (for collector contact of vertical npn)	6λ

Add n+ buried for collector

From design rule 1.2

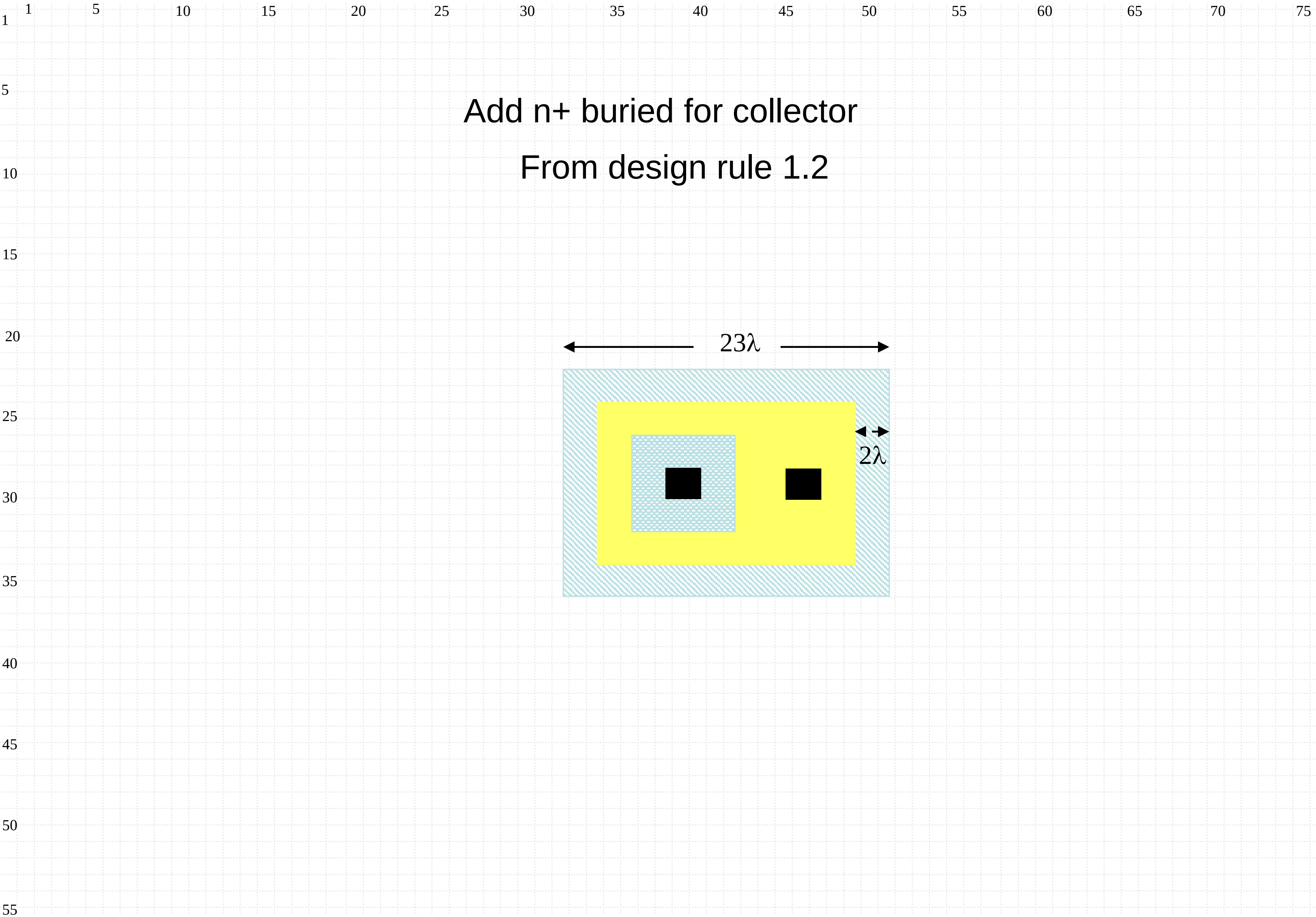
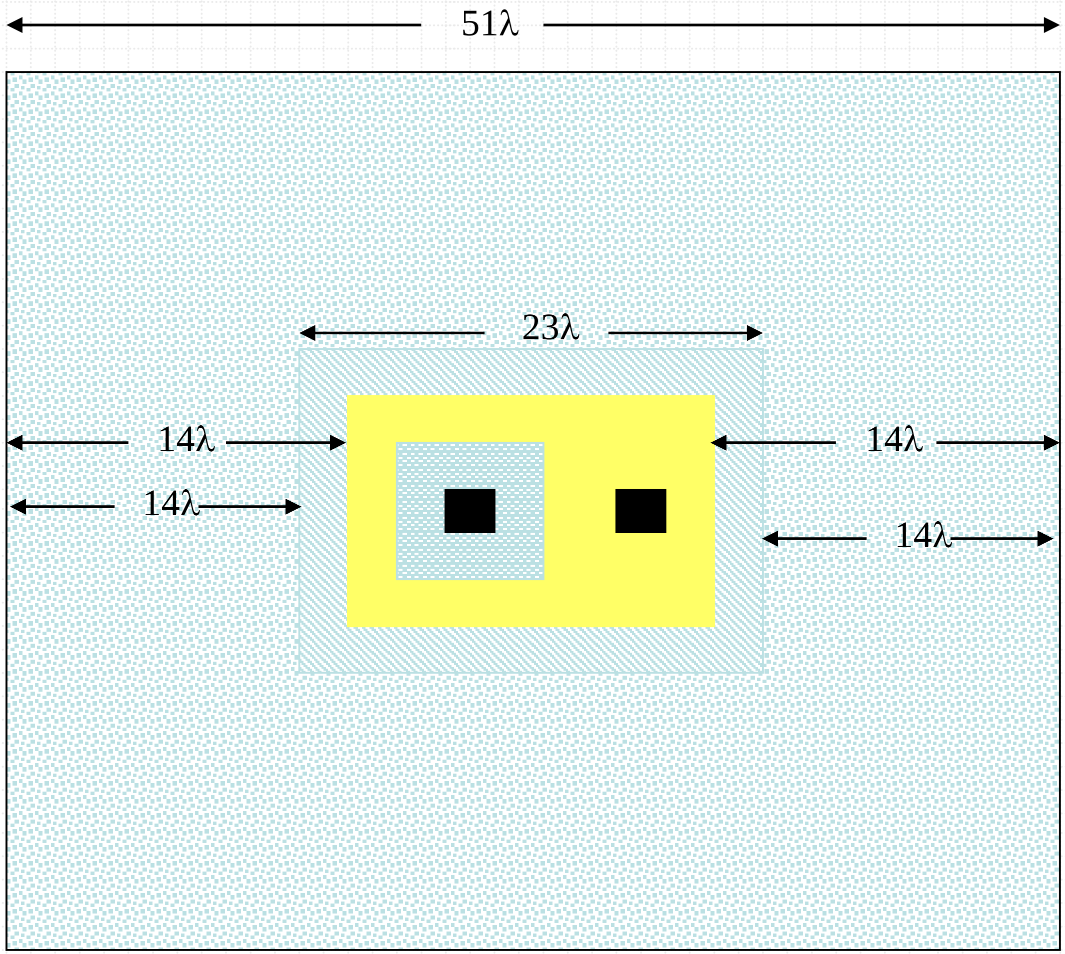


TABLE 2C.2
Design rules for a typical bipolar process ($\lambda = 2.5\ \mu$)
(See Table 2C.3 in color plates for graphical interpretation)

	Dimension
1. n^+ buried collector diffusion (Yellow, Mask #1)	
1.1 Width	3λ
1.2 Overlap of p-base diffusion (for vertical npn)	2λ
1.3 Overlap of n^+ emitter diffusion (for collector contact of vertical npn)	2λ
1.4 Overlap of p-base diffusion (for collector and emitter of lateral pnp)	2λ
1.5 Overlap of n^+ emitter diffusion (for base contact of lateral pnp)	2λ
2. Isolation diffusion (Orange, Mask #2)	
2.1 Width	4λ
2.2 Spacing	24λ
2.3 Distance to n^+ buried collector	14λ
3. p-base diffusion (Brown, Mask #3)	
3.1 Width	3λ
3.2 Spacing	5λ
3.3 Distance to isolation diffusion	14λ
3.4 Width (resistor)	3λ
3.5 Spacing (as resistor)	3λ
4. n^+ emitter diffusion (Green, Mask #4)	
4.1 Width	3λ
4.2 Spacing	3λ
4.3 p-base diffusion overlap of n^+ emitter diffusion (emitter in base)	2λ
4.4 Spacing to isolation diffusion (for collector contact)	12λ
4.5 Spacing to p-base diffusion (for base contact of lateral pnp)	6λ
4.6 Spacing to p-base diffusion (for collector contact of vertical npn)	6λ

Add n-epi region
from design rules 2.3 and 3.3



5. Contact (Black, Mask #5)

5.1 Size (exactly)	$4\lambda \times 4\lambda$
5.2 Spacing	2λ
5.3 Metal overlap of contact	λ
5.4 n^+ emitter diffusion overlap of contact	2λ
5.5 p-base diffusion overlap of contact	2λ
5.6 p-base to n^+ emitter	3λ
5.7 Spacing to isolation diffusion	4λ

6. Metalization (Blue, Mask #6)

6.1 Width	2λ
6.2 Spacing	2λ
6.3 Bonding pad size	$100\ \mu \times 100\ \mu$
6.4 Probe pad size	$75\ \mu \times 75\ \mu$
6.5 Bonding pad separation	$50\ \mu$
6.6 Bonding to probe pad	$30\ \mu$
6.7 Probe pad separation	$30\ \mu$
6.8 Pad to circuitry	$40\ \mu$
6.9 Maximum current density	0.8 mA/μ width

7. Passivation (Purple, Mask #7)

7.1 Minimum bonding pad opening	$90\ \mu \times 90\ \mu$
7.2 Minimum probe pad opening	$65\ \mu \times 65\ \mu$

Add contact to n-epi region from design rules 2.3 and 3.3

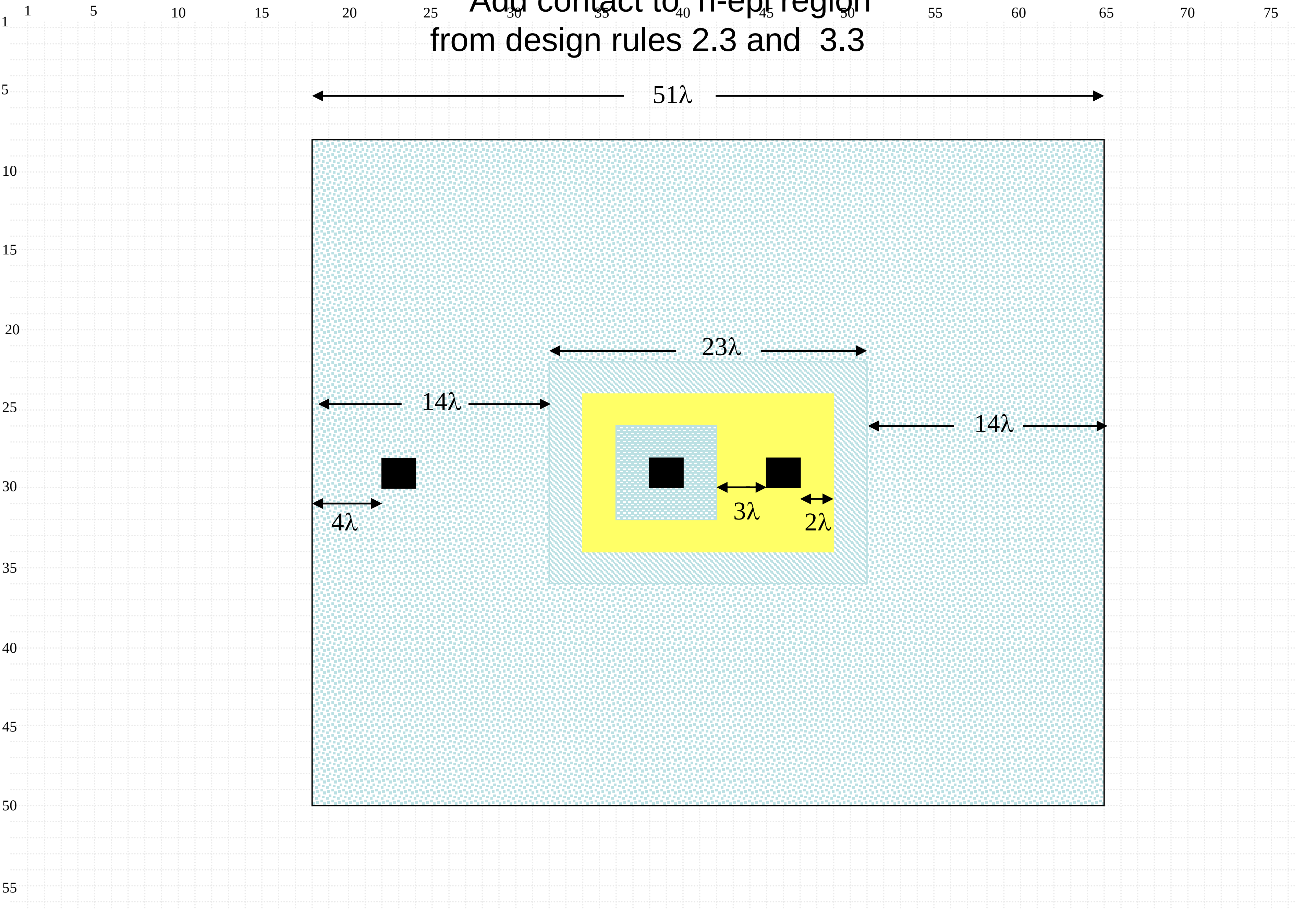


TABLE 2C.2
Design rules for a typical bipolar process ($\lambda = 2.5\ \mu$)
(See Table 2C.3 in color plates for graphical interpretation)

	Dimension
1. n^+ buried collector diffusion (Yellow, Mask #1)	
1.1 Width	3λ
1.2 Overlap of p-base diffusion (for vertical npn)	2λ
1.3 Overlap of n^+ emitter diffusion (for collector contact of vertical npn)	2λ
1.4 Overlap of p-base diffusion (for collector and emitter of lateral pnp)	2λ
1.5 Overlap of n^+ emitter diffusion (for base contact of lateral pnp)	2λ
2. Isolation diffusion (Orange, Mask #2)	
2.1 Width	4λ
2.2 Spacing	24λ
2.3 Distance to n^+ buried collector	14λ
3. p-base diffusion (Brown, Mask #3)	
3.1 Width	3λ
3.2 Spacing	5λ
3.3 Distance to isolation diffusion	14λ
3.4 Width (resistor)	3λ
3.5 Spacing (as resistor)	3λ
4. n^+ emitter diffusion (Green, Mask #4)	
4.1 Width	3λ
4.2 Spacing	3λ
4.3 p-base diffusion overlap of n^+ emitter diffusion (emitter in base)	2λ
4.4 Spacing to isolation diffusion (for collector contact)	12λ
4.5 Spacing to p-base diffusion (for base contact of lateral pnp)	6λ
4.6 Spacing to p-base diffusion (for collector contact of vertical npn)	6λ

5. Contact (Black, Mask #5)

5.1 Size (exactly)	$4\lambda \times 4\lambda$
5.2 Spacing	2λ
5.3 Metal overlap of contact	λ
5.4 n^+ emitter diffusion overlap of contact	2λ
5.5 p-base diffusion overlap of contact	2λ
5.6 p-base to n^+ emitter	3λ
5.7 Spacing to isolation diffusion	4λ

6. Metalization (Blue, Mask #6)

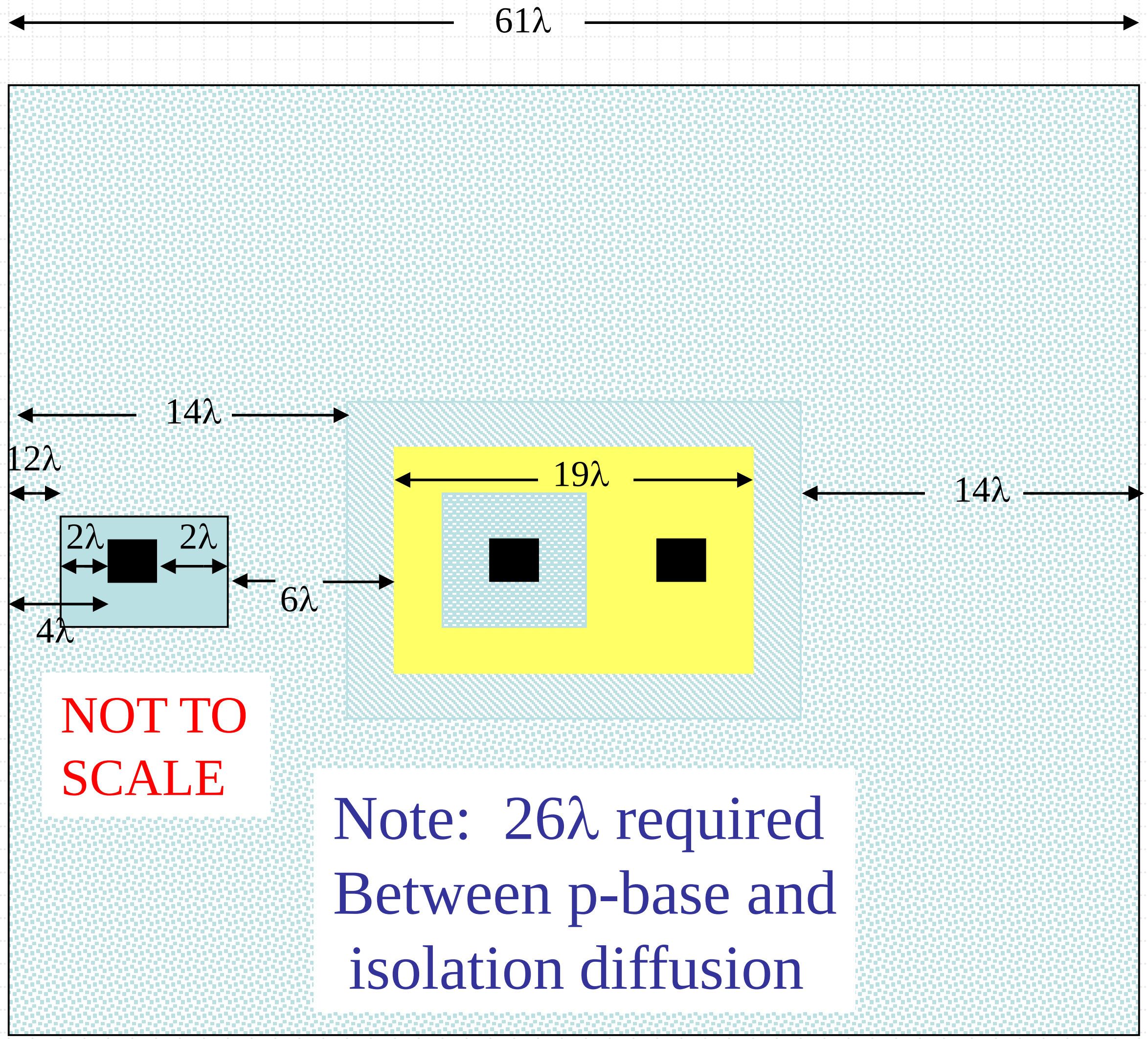
6.1 Width	2λ
6.2 Spacing	2λ
6.3 Bonding pad size	$100\ \mu \times 100\ \mu$
6.4 Probe pad size	$75\ \mu \times 75\ \mu$
6.5 Bonding pad separation	$50\ \mu$
6.6 Bonding to probe pad	$30\ \mu$
6.7 Probe pad separation	$30\ \mu$
6.8 Pad to circuitry	$40\ \mu$
6.9 Maximum current density	0.8 mA/μ width

7. Passivation (Purple, Mask #7)

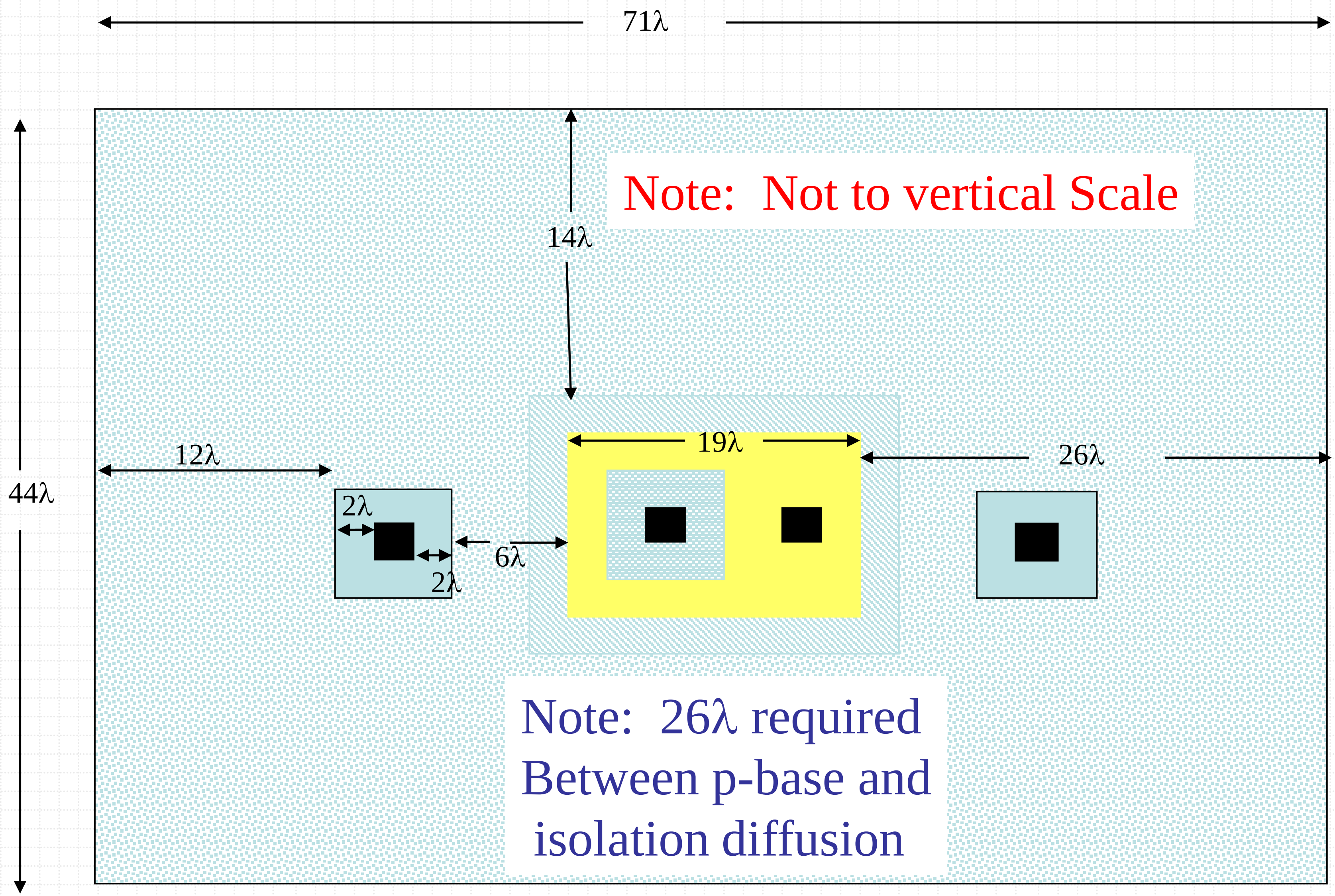
7.1 Minimum bonding pad opening	$90\ \mu \times 90\ \mu$
7.2 Minimum probe pad opening	$65\ \mu \times 65\ \mu$

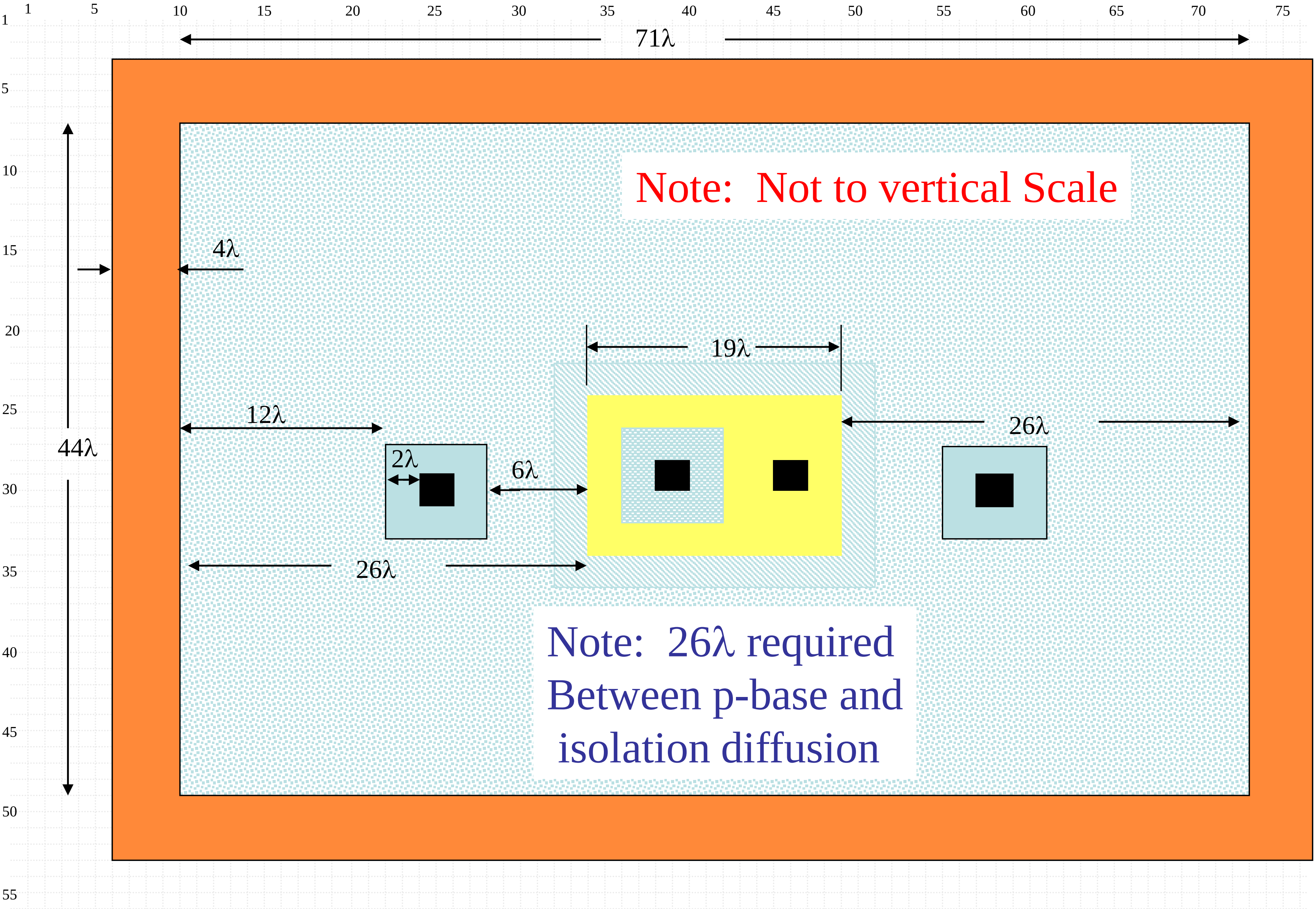
But, there are some rather strict rules relating to the epi contact

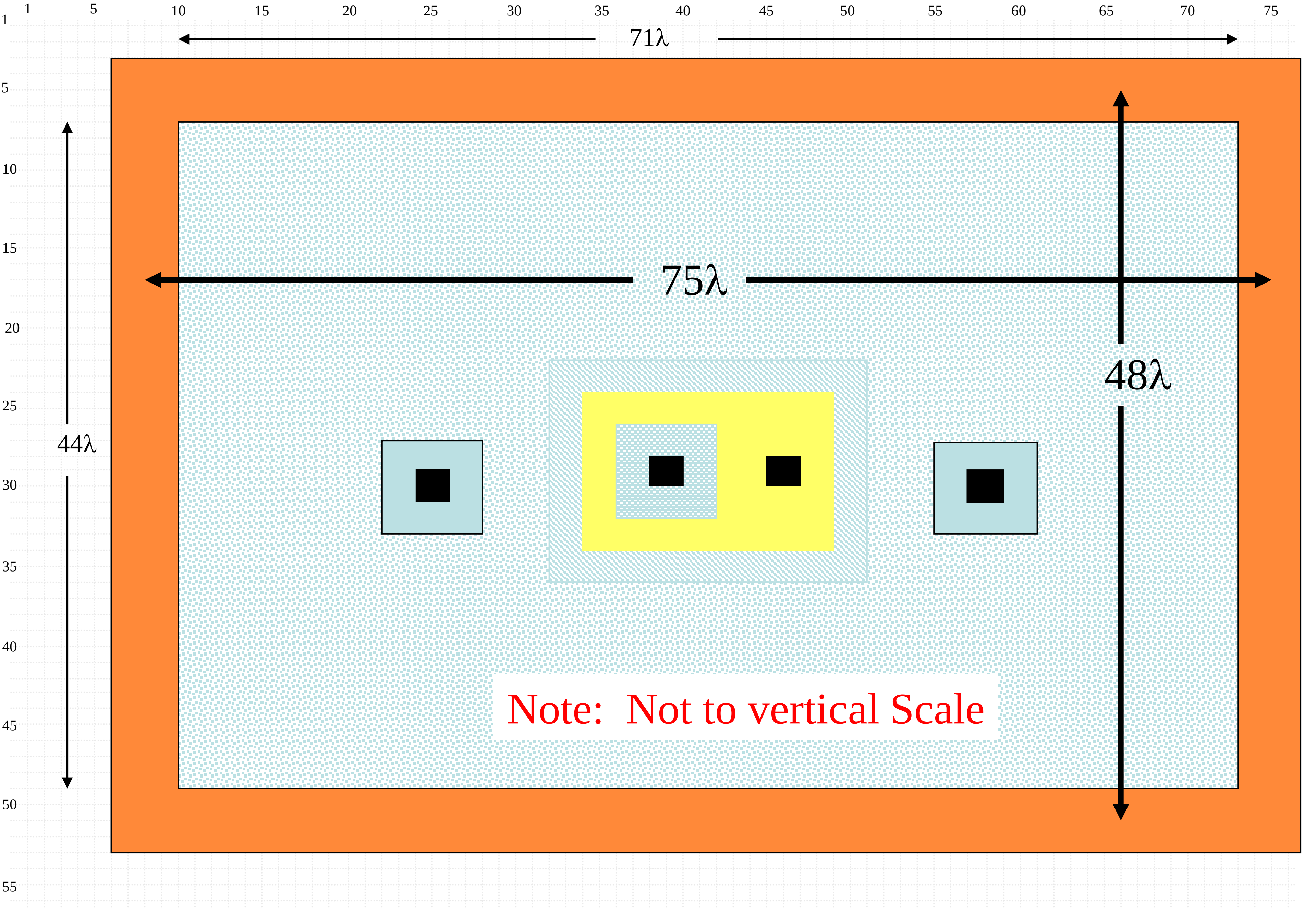
from (left to right) rules 4.4, 5.4, 4.6



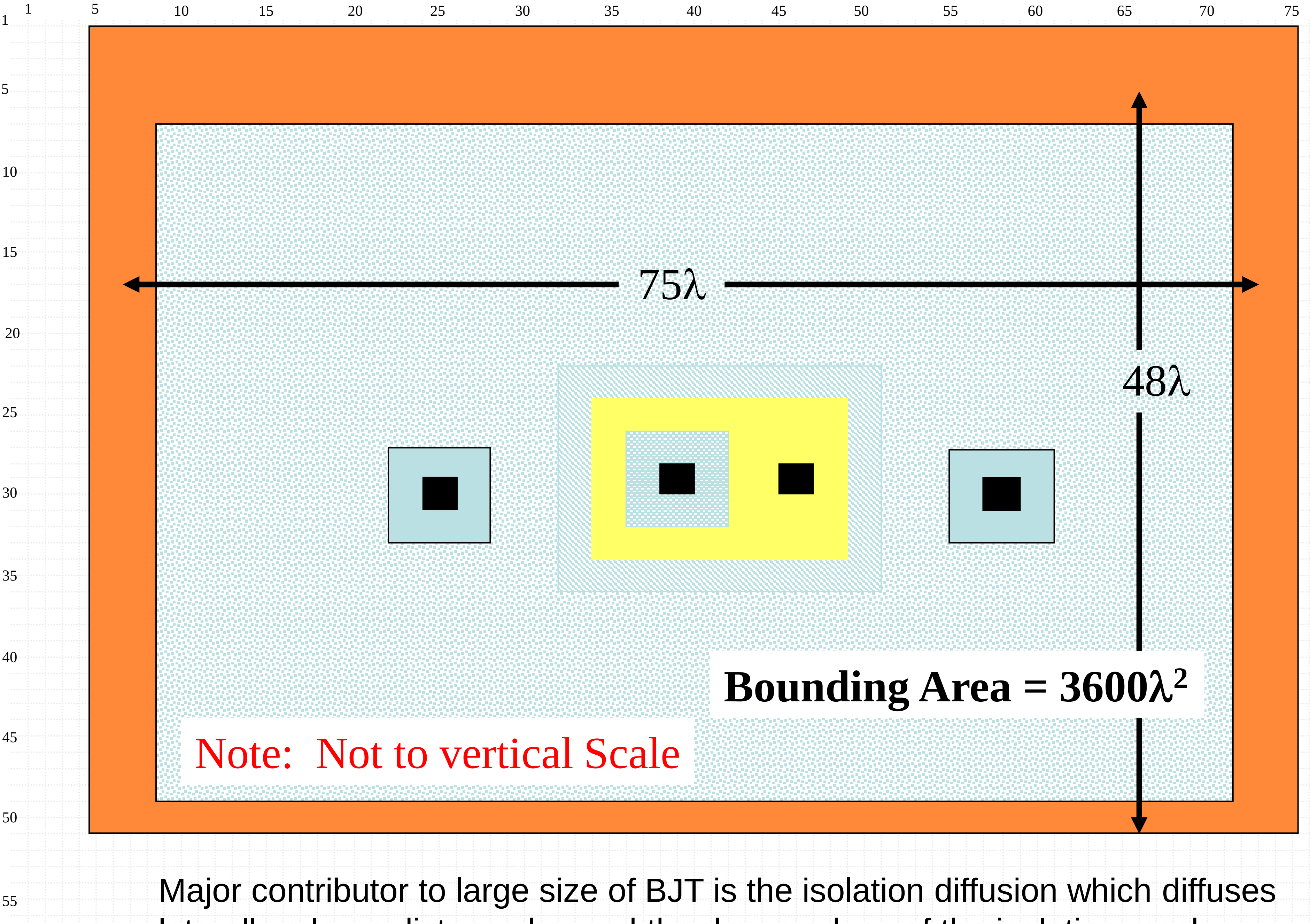
Consider a structure with a collector contact on both sides of epi




71λ
Note: Not to vertical Scale
4λ
19λ
12λ
26λ
44λ
2λ
6λ
26λ
Note: 26λ required
Between p-base and
isolation diffusion

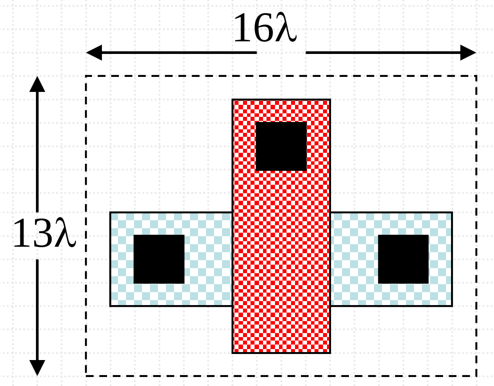


71λ
75λ
48λ
44λ
Note: Not to vertical Scale



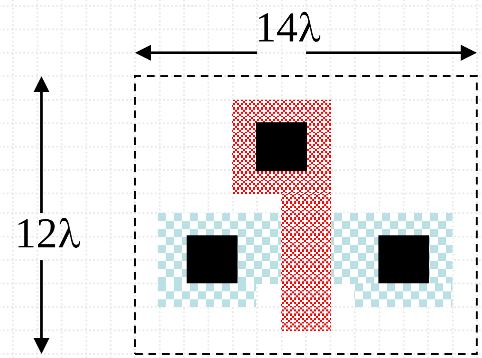
Major contributor to large size of BJT is the isolation diffusion which diffuses laterally a large distance beyond the drawn edges of the isolation mask

Comparison with Area for n-channel MOSFET in Bulk CMOS



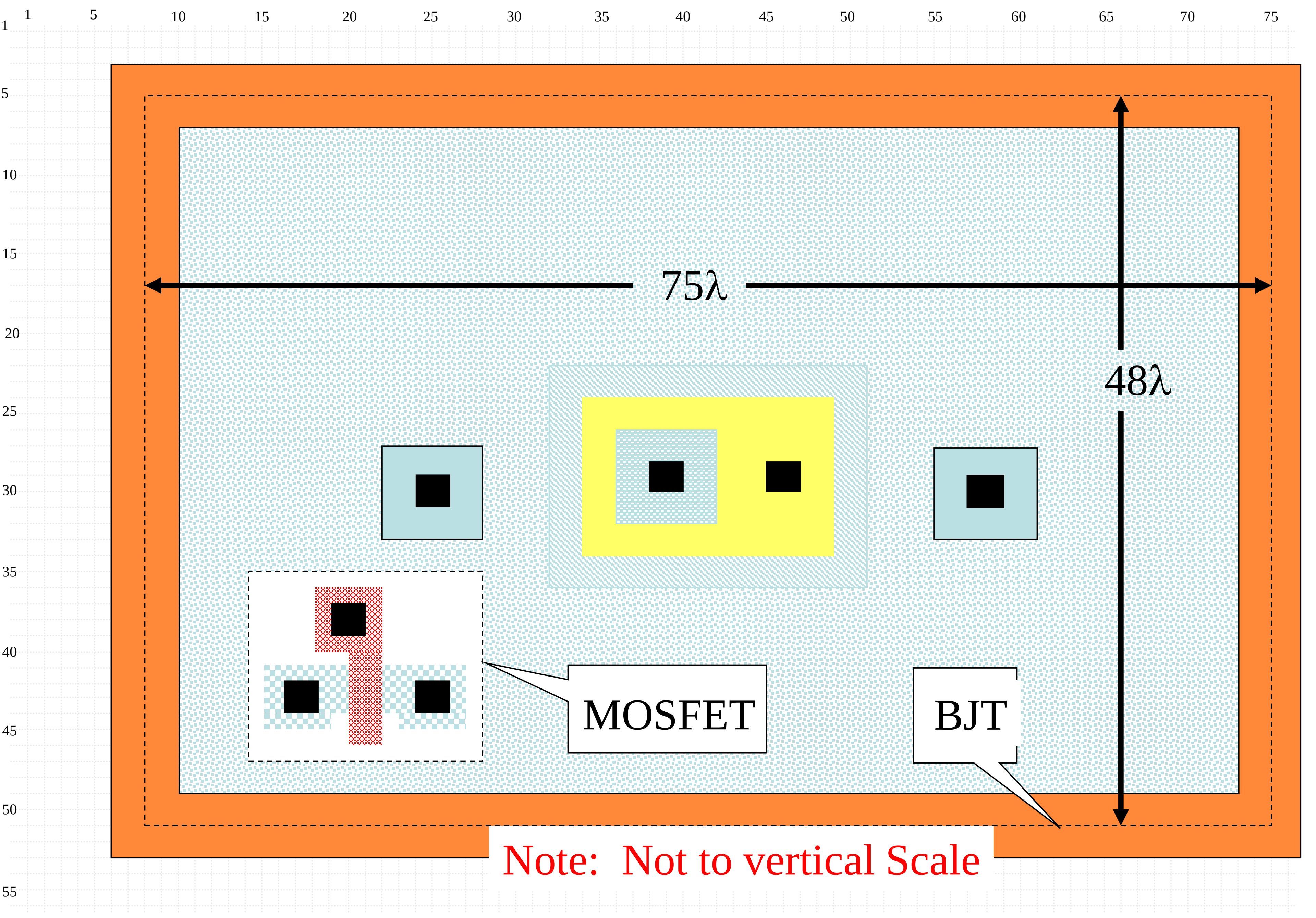
Bounding Area = $208\lambda^2$

Minimum-Sized MOSFET



Bounding Area = $168\lambda^2$

Active Area = $6\lambda^2$


75λ
48λ
MOSFET
BJT
Note: Not to vertical Scale

Area Comparison between BJT and MOSFET

- BJT Area = 3600 λ^2
- n-channel MOSFET Area = 168 λ^2
- Area Ratio = 21:1

End of Lecture 21