EE 330
Lecture 18

CMOS Process Flow
Bipolar Devices

How many models of the MOSFET do we have?

Switch-level model (2)

Square-law model

Square-law model (with λ and bulk additions)

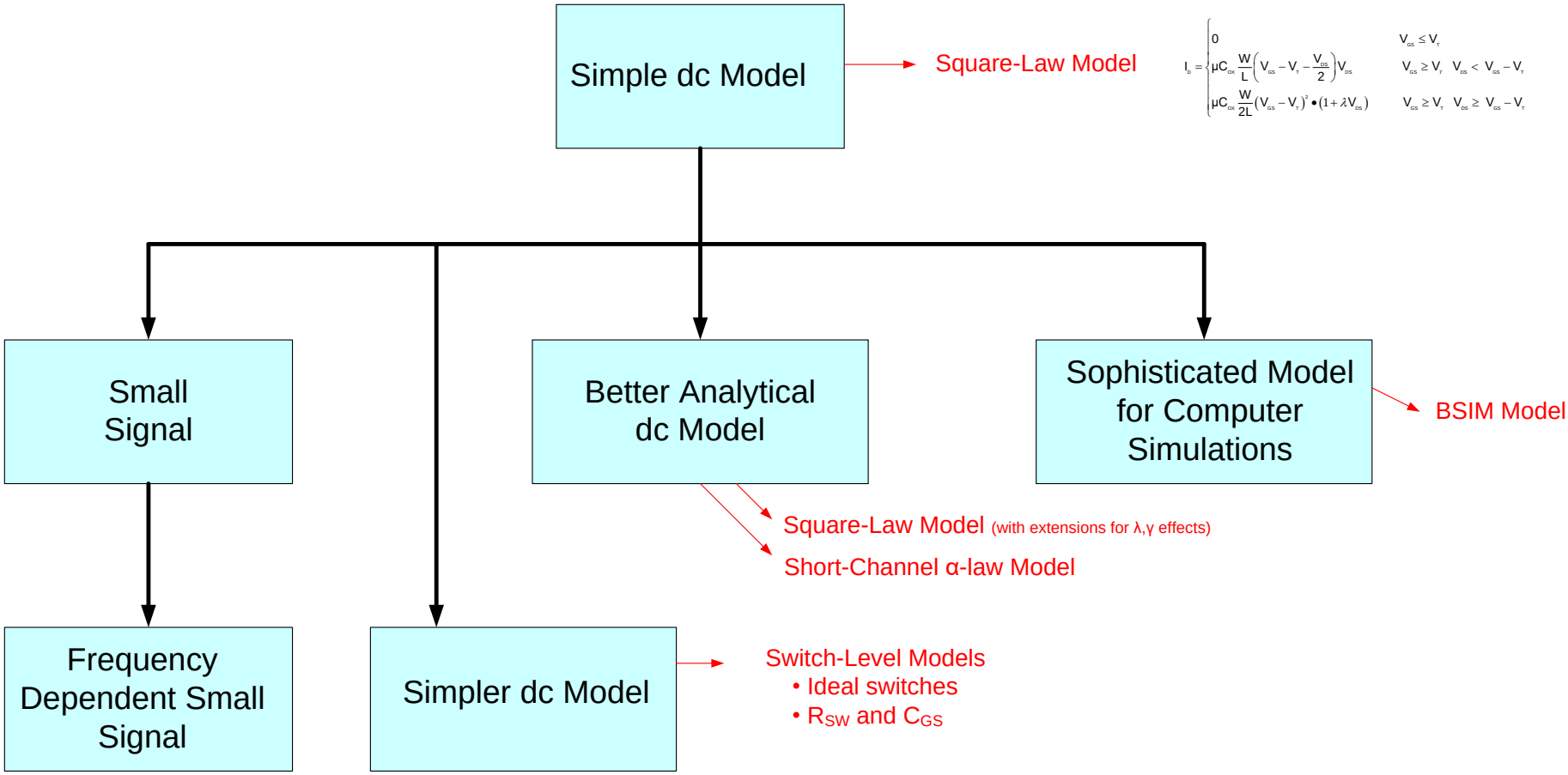
α-law model (with λ and bulk additions)

BSIM model

BSIM model (with binning extensions)

BSIM model (with binning extensions and process corners)

Model Status



Basic Devices and Device Models

- Resistor
- Diode
- Capacitor
- MOSFET
- BJT

Lets pick up a discussion of
Technology Files before moving to BJT

Technology Files

- Design Rules
- Process Flow (Fabrication Technology)
- Model Parameters

TABLE 2B.1
Process scenario of major process steps in typical n-well CMOS process[a]

1.	Clean wafer	
2.	GROW THIN OXIDE	
3.	Apply photoresist	
4.	PATTERN **n-well**	(MASK #1)
5.	Develop photoresist	
6.	Deposit and diffus n-type impurities	
7.	Strip photoresist	
8.	Strip thin oxide	
9.	Grow thin oxide	
10.	Apply layer of Si_3N_4	
11.	Apply photoresist	
12.	PATTERN Si_3N_4 (active area definition)	(MASK #2)
13.	Develop photoresist	
14.	Etch Si_3N_4	
15.	Strip photoresist	
	Optional field threshold voltage adjust	
	A.1 Apply photoresist	
	A.2 PATTERN ANTIMOAT IN SUBSTRATE	(MASK #A1)
	A.3 Develop photoresist	
	A.4 FIELD IMPLANT p-type)	
	A.5 Strip photoresist	
16.	GROW FIELD OXIDE	
17.	Strip Si_3N_4	
18.	Strip thin oxide	
19.	GROW GATE OXIDE	
20.	POLYSILICON DEPOSITION (POLY I)	
21.	Apply photoresist	
22.	PATTERN POLYSILICON	(MASK #3)
23.	Develop photoresist	
24.	ETCH POLYSILICON	

25. Strip photoresist
Optional steps for double polysilicon process
B.1 Strip thin oxide
B.2 GROW THIN OXIDE
B.3 POLYSILICON DEPOSITION (POLY II)
B.4 Apply photoresist
B.5 PATTERN POLYSILICON (MASK #B1)
B.6 Develop photoresist
B.7 ETCH POLYSILICON
B.8 Strip photoresist
B.9 Strip thin oxide

26. Apply photoresist
27. PATTERN P-CHANNEL DRAINS AND SOURCES AND P^+ GUARD RINGS (p-well ohmic contacts) (MASK #4)
28. Develop photoresist
29. p^+ IMPLANT
30. Strip photoresist
31. Apply photoresist
32. PATTERN N-CHANNEL DRAINS AND SOURCES AND N^+ GUARD RINGS (top ohmic contact to substrate) (MASK #5)
33. Develop photoresist
34. n^+ IMPLANT
35. Strip photoresist
36. Strip thin oxide
37. Grow oxide
38. Apply photoresist
39. PATTERN CONTACT OPENINGS (MASK #6)
40. Develop photoresist
41. Etch oxide
42. Strip photoresist

43.	APPLY METAL	
44.	Apply photoresist	
45.	PATTERN METAL	(MASK #7)
46.	Develop photoresist	
47.	Etch metal	
48.	Strip photoresist	
	Optional steps for double metal process	
	C.1 Strip thin oxide	
	C.2 DEPOSIT INTERMETAL OXIDE	
	C.3 Apply photoresist	
	C.4 PATTERN VIAS	(MASK #C1)
	C.5 Develop photoresist	
	C.6 Etch oxide	
	C.7 Strip photoresist	
	C.8 APPLY METAL (Metal 2)	
	C.9 Apply photoresist	
	C.10 PATTERN METAL	(MASK #C2)
	C.11 Develop photoresist	
	C.12 Etch metal	
	C.13 Strip photoresist	
49.	APPLY PASSIVATION	
50.	Apply photoresist	
51.	PATTERN PAD OPENINGS	(MASK #8)
52.	Develop photoresist	
53.	Etch passivation	
54.	Strip photoresist	
55.	ASSEMBLE, PACKAGE AND TEST	

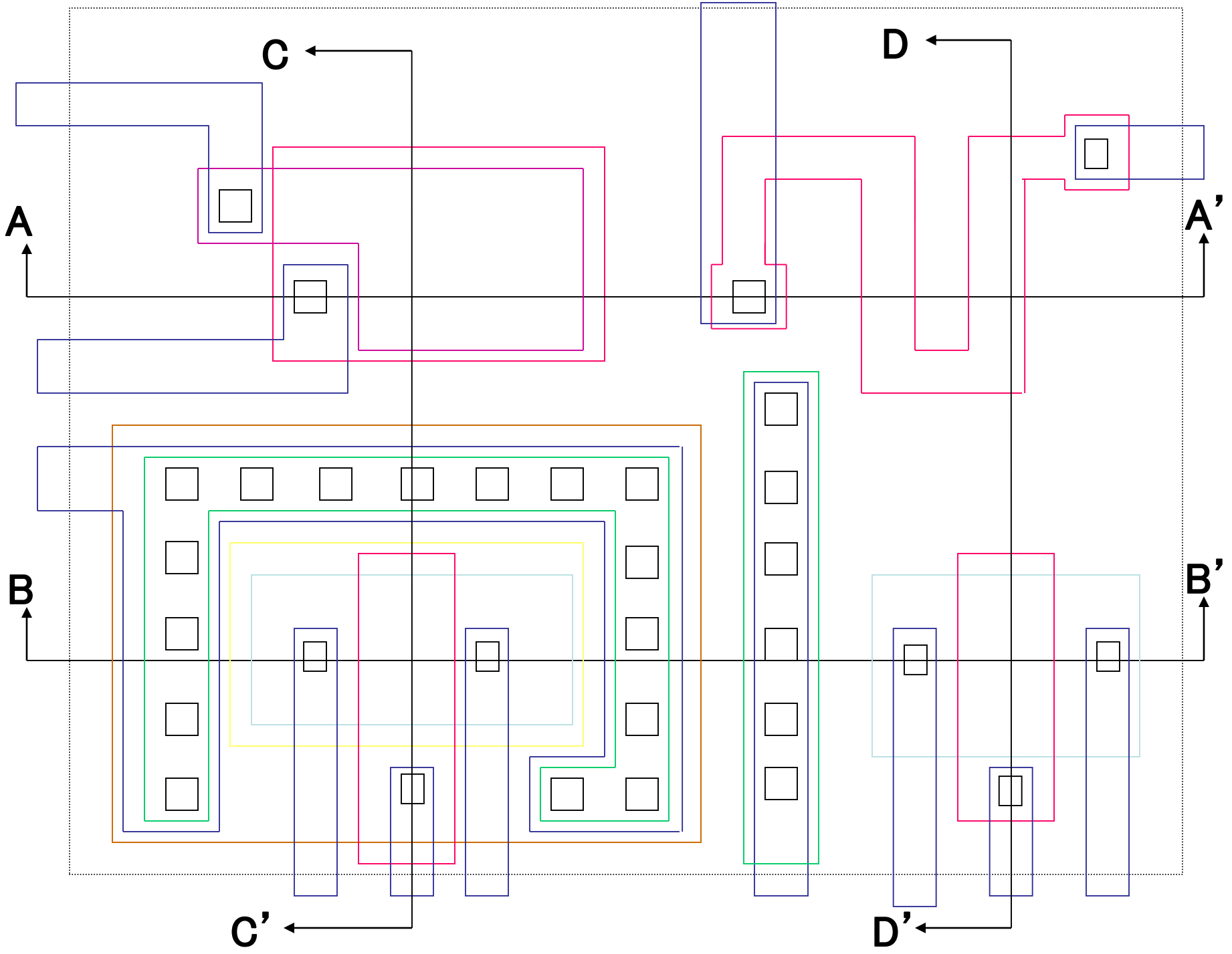
Bulk CMOS Process Description

- n-well process
- Single Metal Only Depicted
- Double Poly

- This type of process dominates what is used for high-volume “low-cost” processing of integrated circuits today
- Many process variants and specialized processes are used for lower-volume or niche applications
- Emphasis in this course will be on the electronics associated with the design of integrated electronic circuits in processes targeting high-volume low-cost products where competition based upon price differentiation may be acute
- Basic electronics concepts, however, are applicable for lower-volume or niche applicaitons

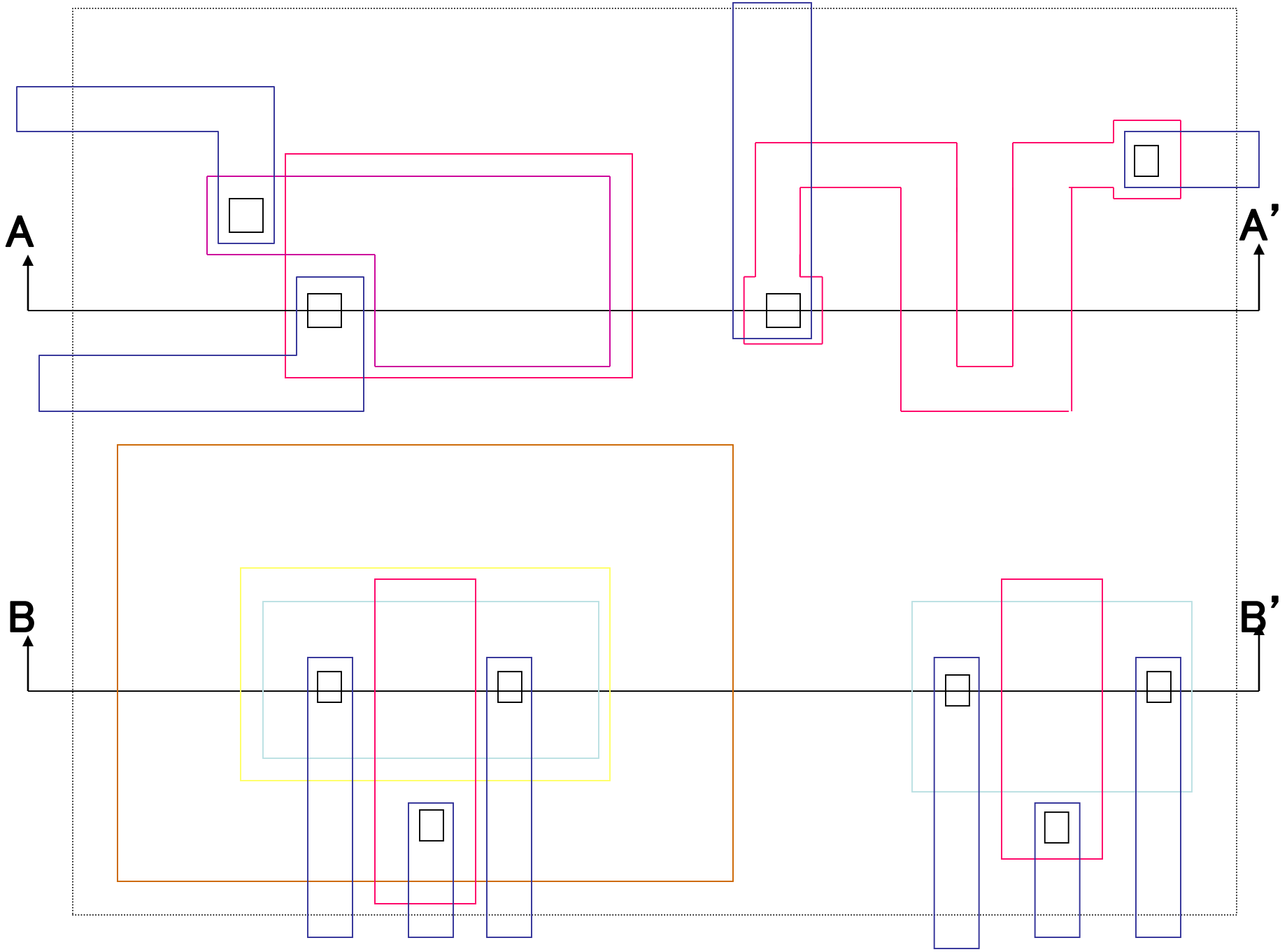
Components Shown

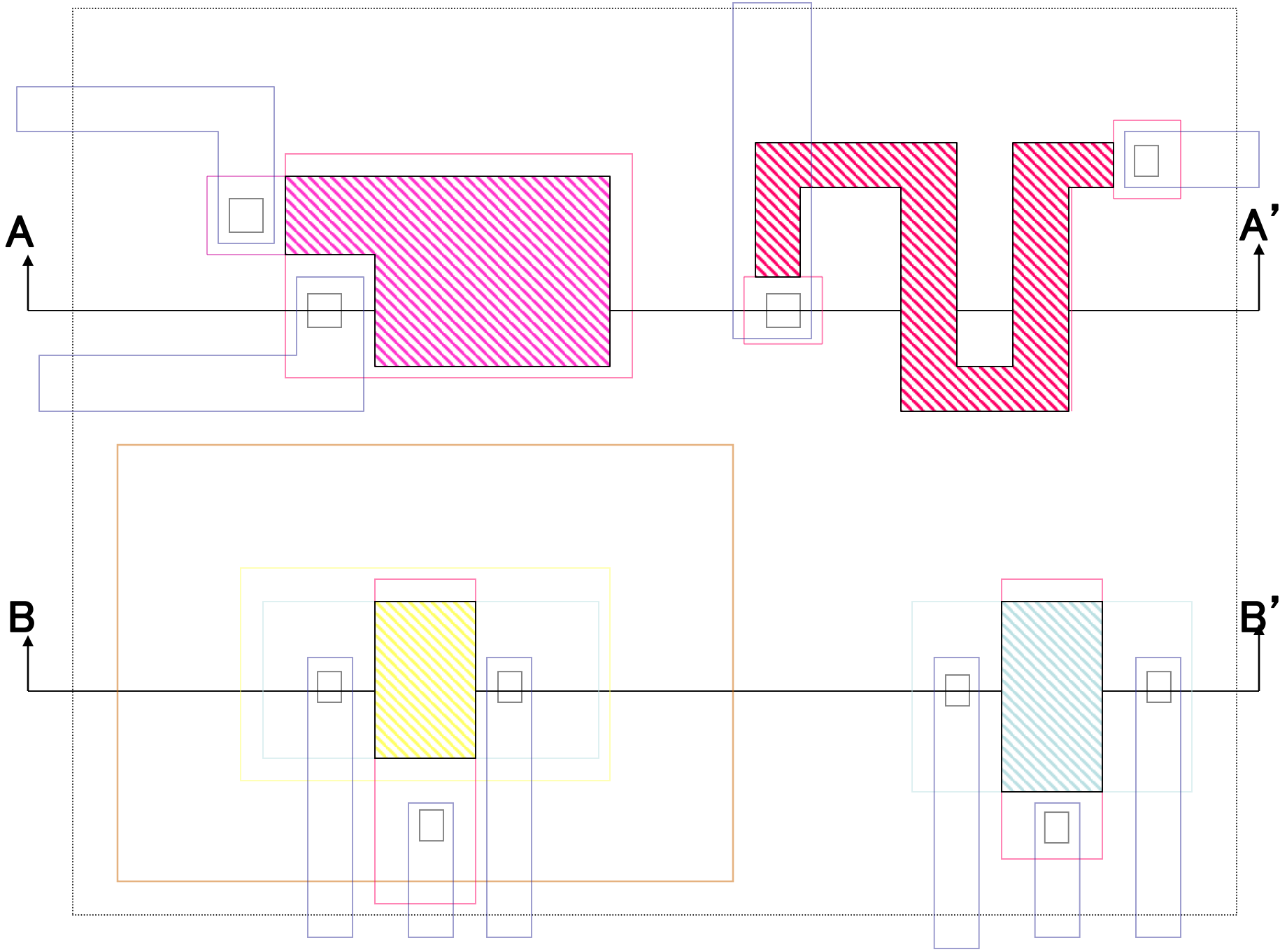
- n-channel MOSFET
- p-channel MOSFET
- Poly Resistor
- Doubly Poly Capacitor

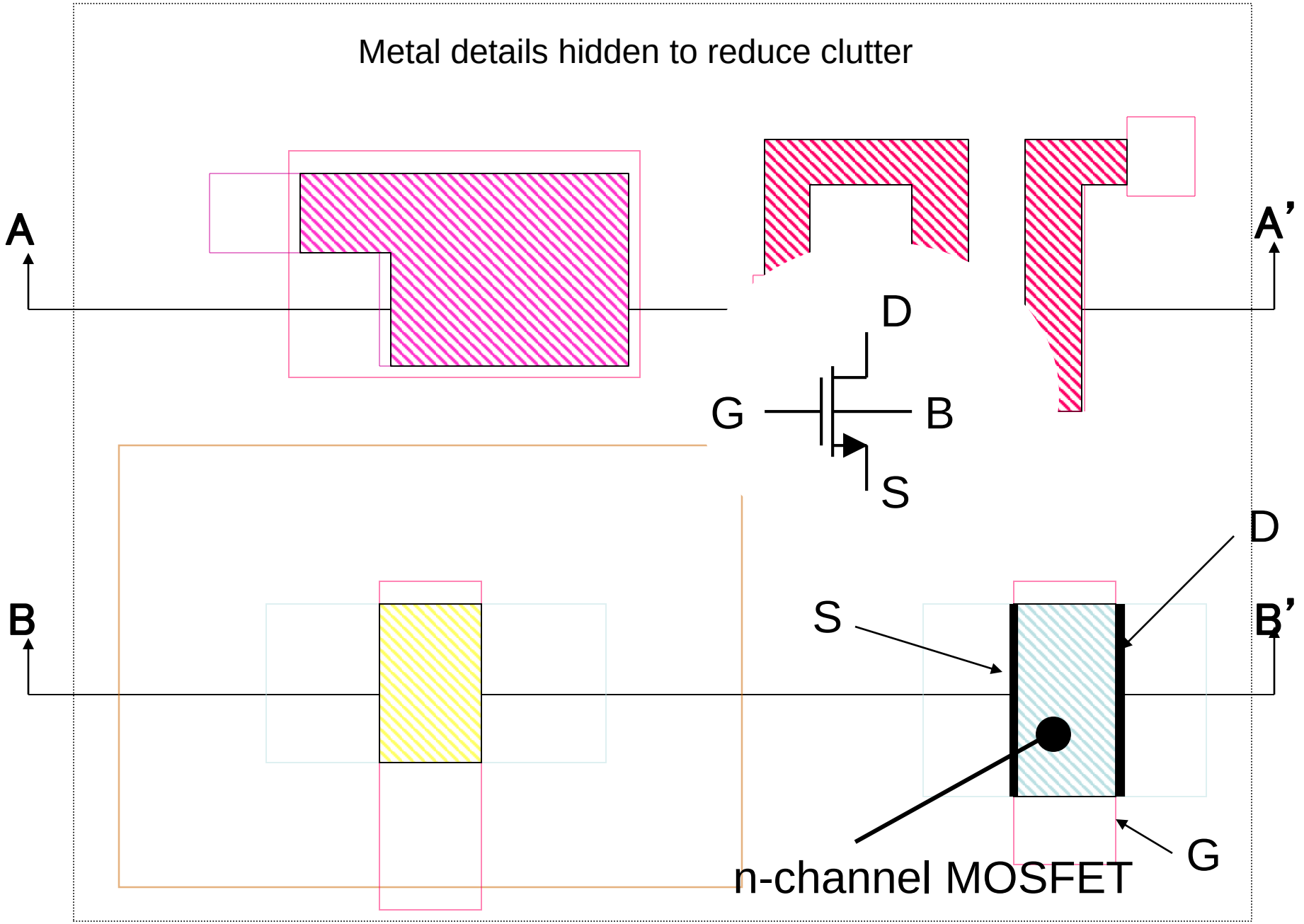

C
D
A
A’
B
B’
C’
D’

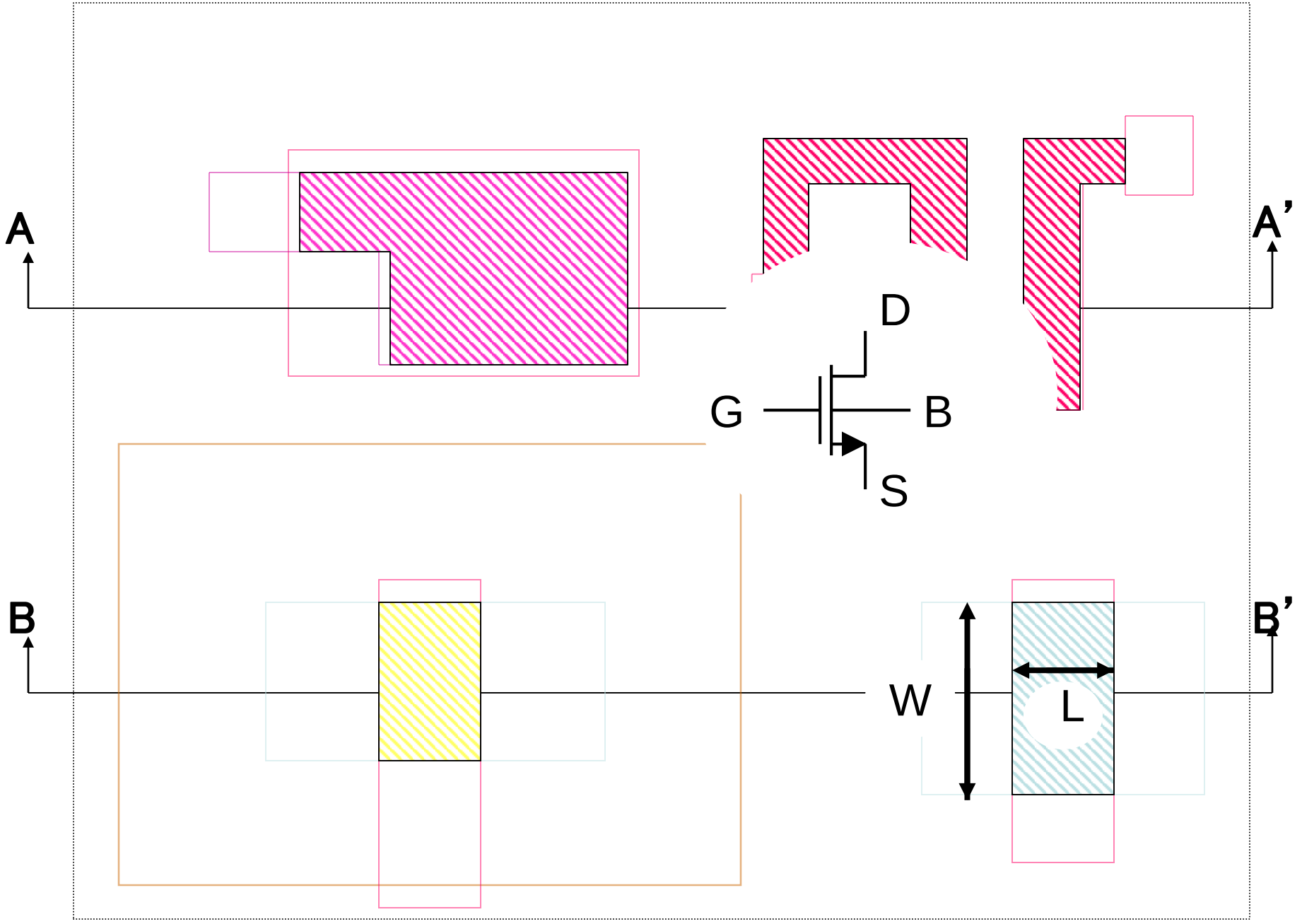
Consider Basic Components Only

Well Contacts and Guard Rings Will be Discussed Later


A
A'
B
B'


A
A'
B
B'


Metal details hidden to reduce clutter
A
A'
D
G
B
S
B
B'
S
D
G
n-channel MOSFET


A
A'
D
G
B
S
B
B'
W
L

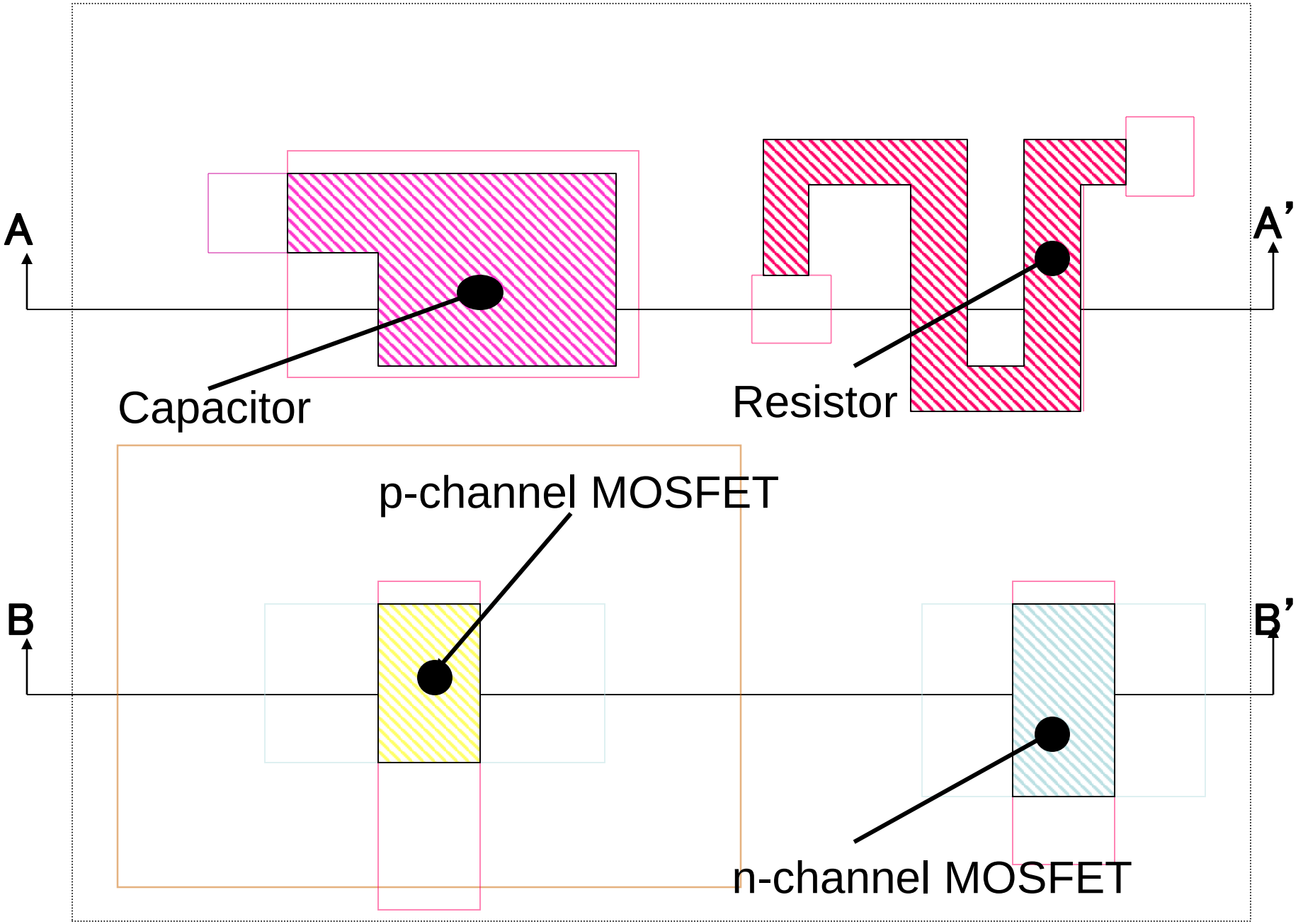
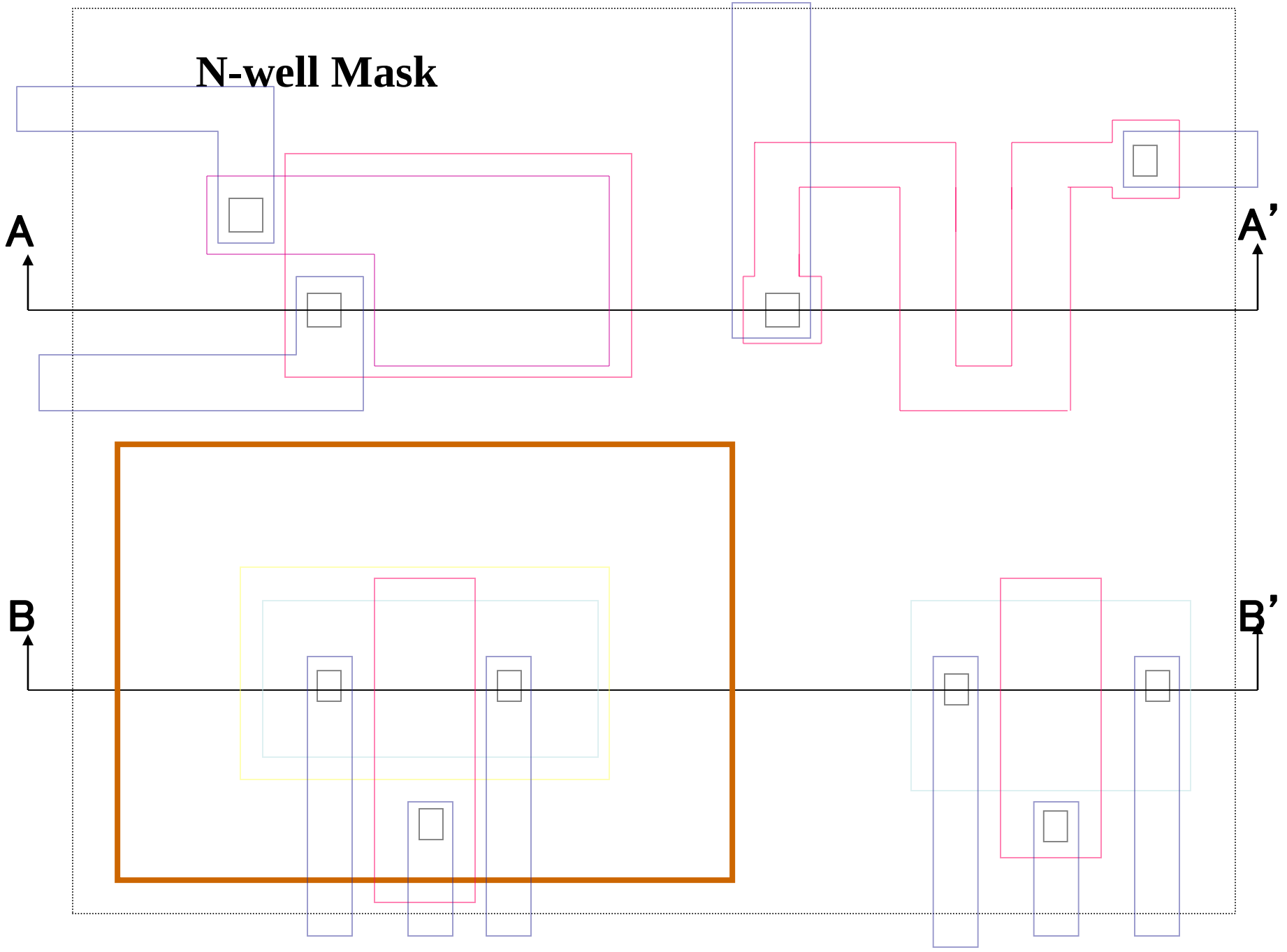

A
A'
Capacitor
Resistor
p-channel MOSFET
B
B'
n-channel MOSFET

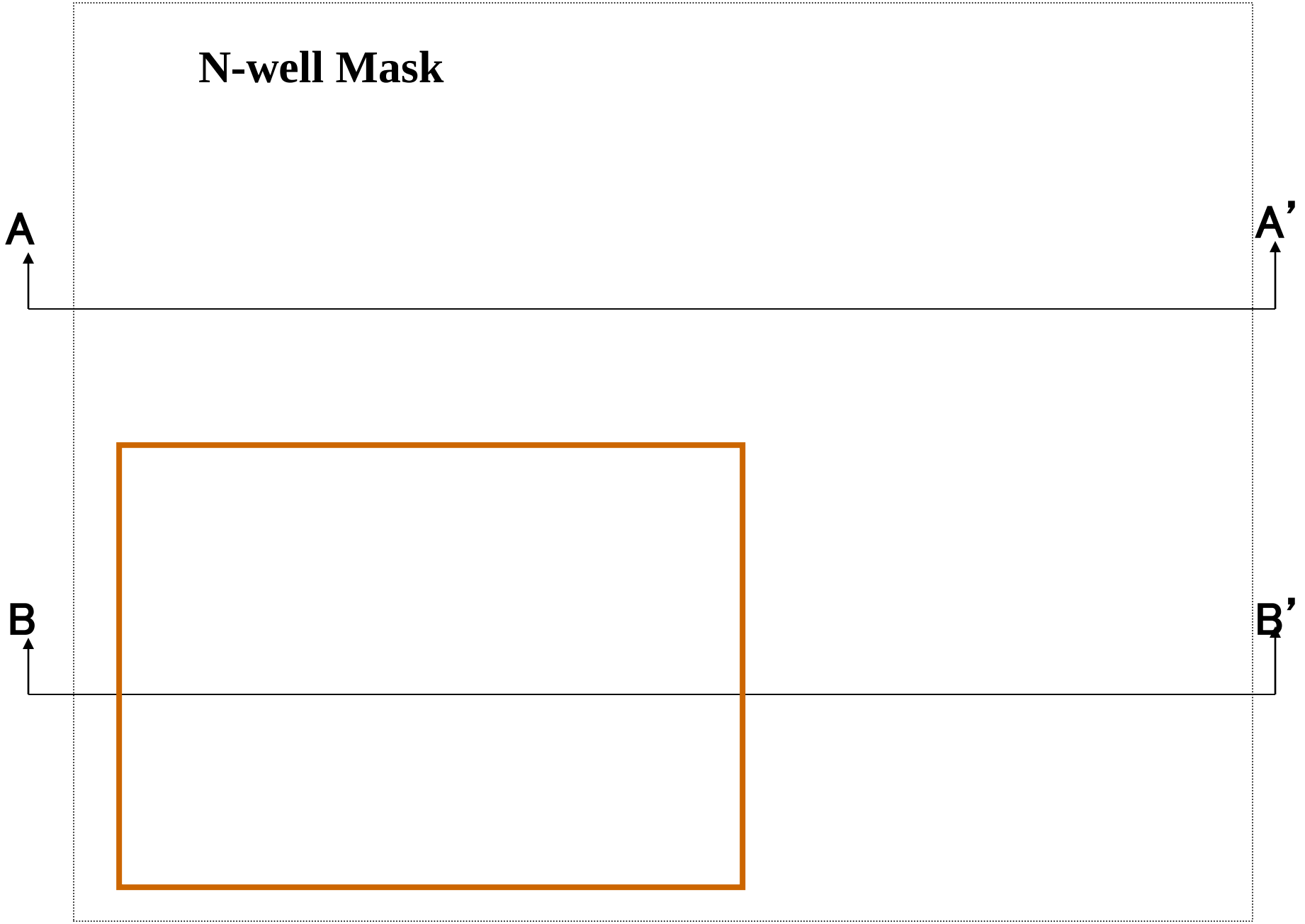
TABLE 2B.1
Process scenario of major process steps in typical n-well CMOS process[a]

1.	Clean wafer	
2.	GROW THIN OXIDE	
3.	Apply photoresist	
4.	PATTERN **n-well**	(MASK #1)
5.	Develop photoresist	
6.	Deposit and diffus n-type impurities	
7.	Strip photoresist	
8.	Strip thin oxide	
9.	Grow thin oxide	
10.	Apply layer of Si_3N_4	
11.	Apply photoresist	
12.	PATTERN Si_3N_4 (active area definition)	(MASK #2)
13.	Develop photoresist	
14.	Etch Si_3N_4	
15.	Strip photoresist	
	Optional field threshold voltage adjust	
	A.1 Apply photoresist	
	A.2 PATTERN ANTIMOAT IN SUBSTRATE	(MASK #A1)
	A.3 Develop photoresist	
	A.4 FIELD IMPLANT p-type)	
	A.5 Strip photoresist	
16.	GROW FIELD OXIDE	
17.	Strip Si_3N_4	
18.	Strip thin oxide	
19.	GROW GATE OXIDE	
20.	POLYSILICON DEPOSITION (POLY I)	
21.	Apply photoresist	
22.	PATTERN POLYSILICON	(MASK #3)
23.	Develop photoresist	
24.	ETCH POLYSILICON	

n-well mask

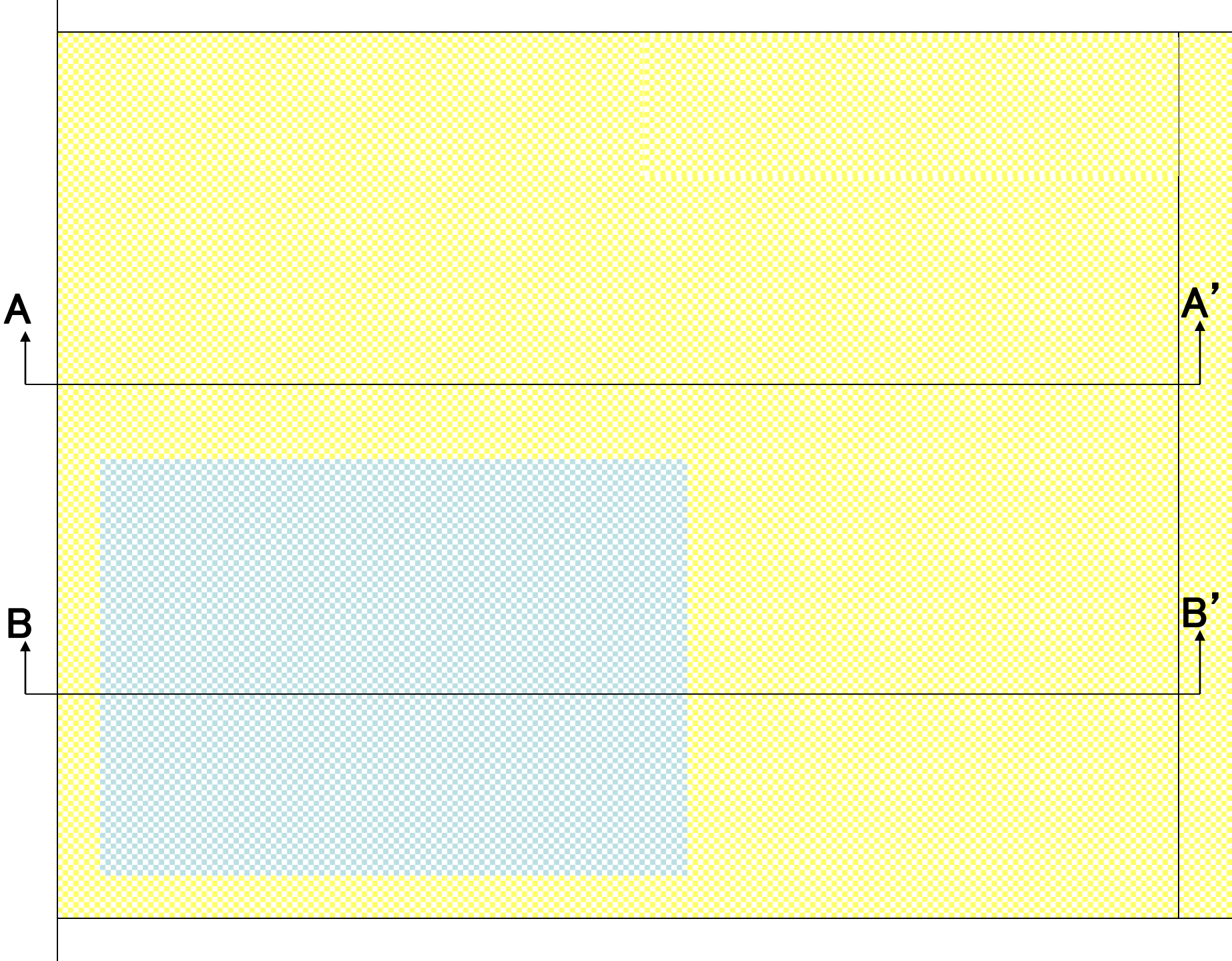

N-well Mask
A
A'
B
B'

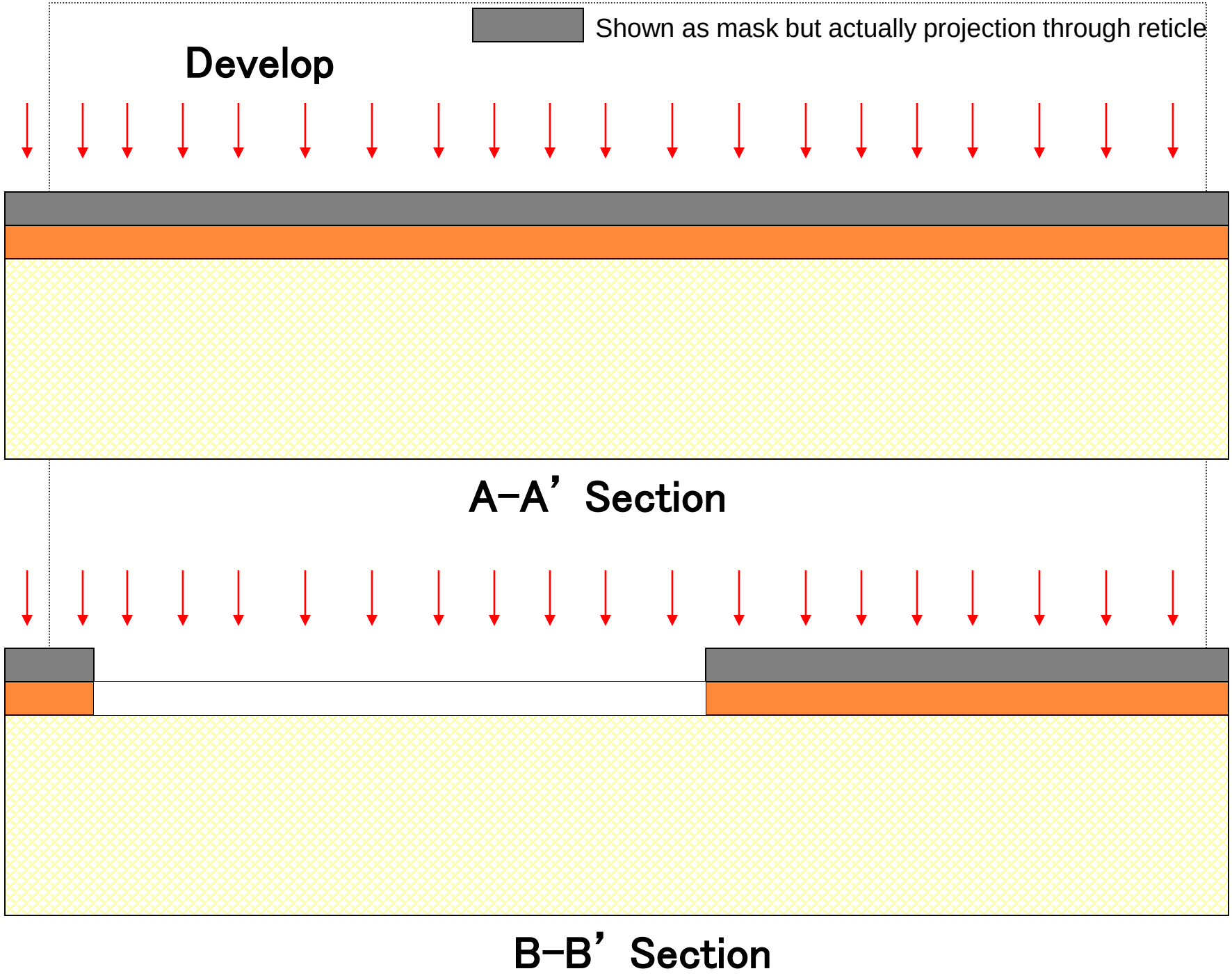
N-well Mask

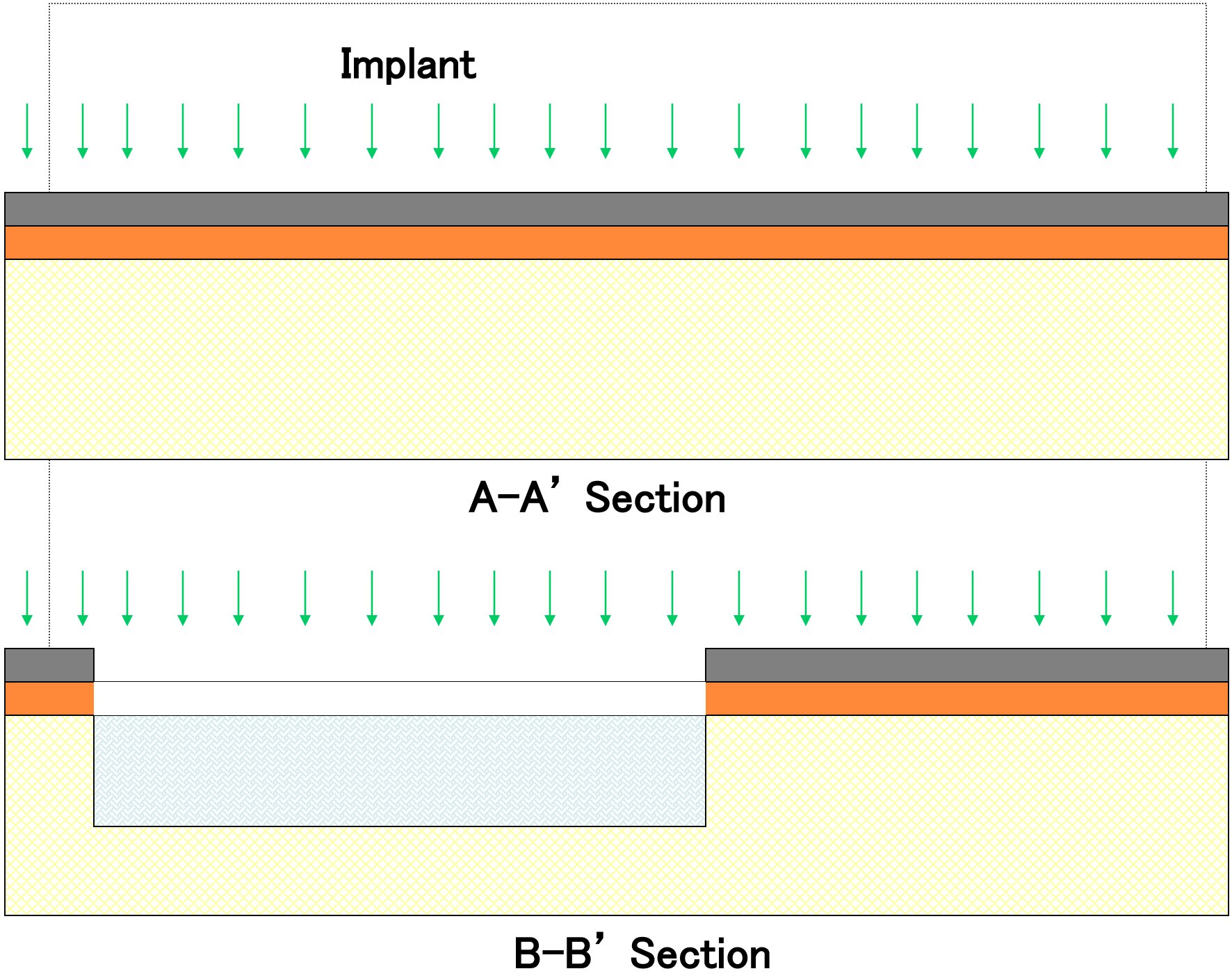


Detailed Description of First Photolithographic Steps Only

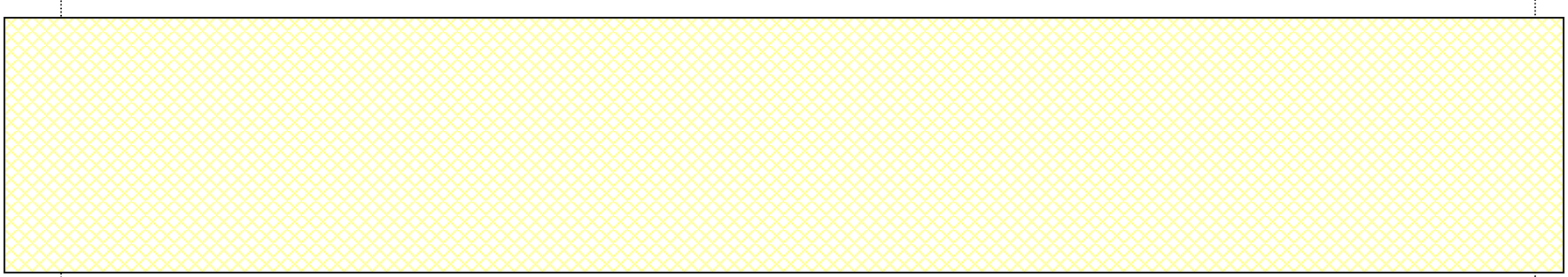
- Top View
- Cross-Section View


A
A'
B
B'

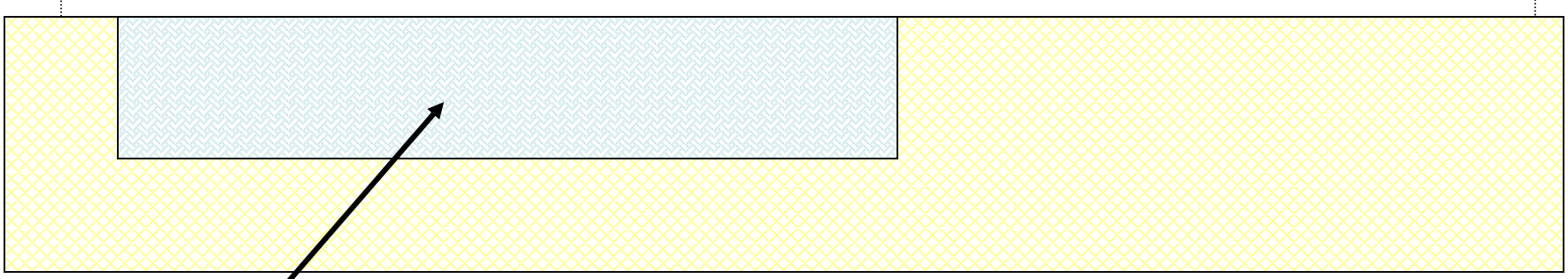

Shown as mask but actually projection through reticle
Develop
A-A' Section
B-B' Section


Implant
A-A' Section
B-B' Section

N-well Mask



A-A’ Section



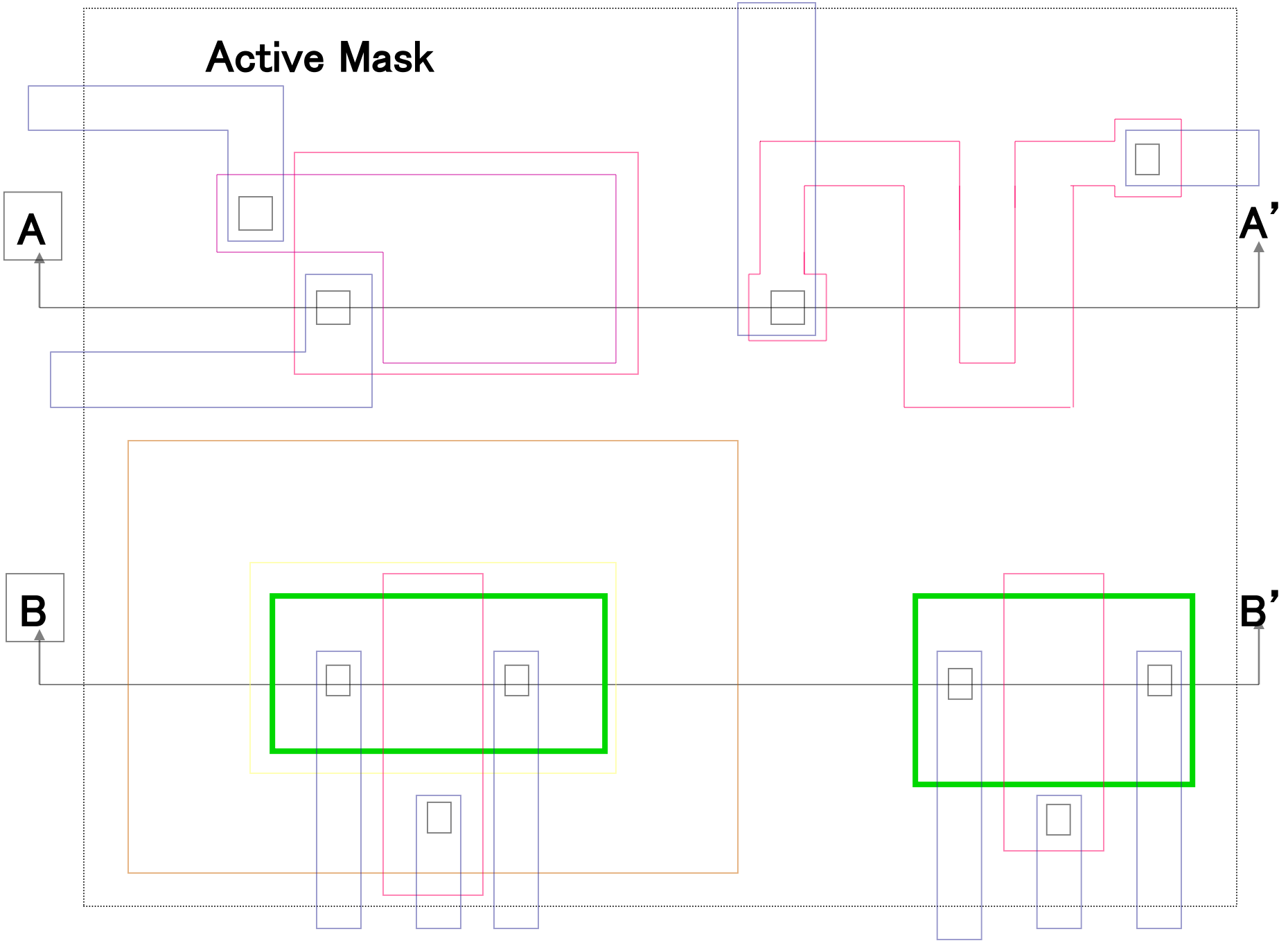
B-B’ Section

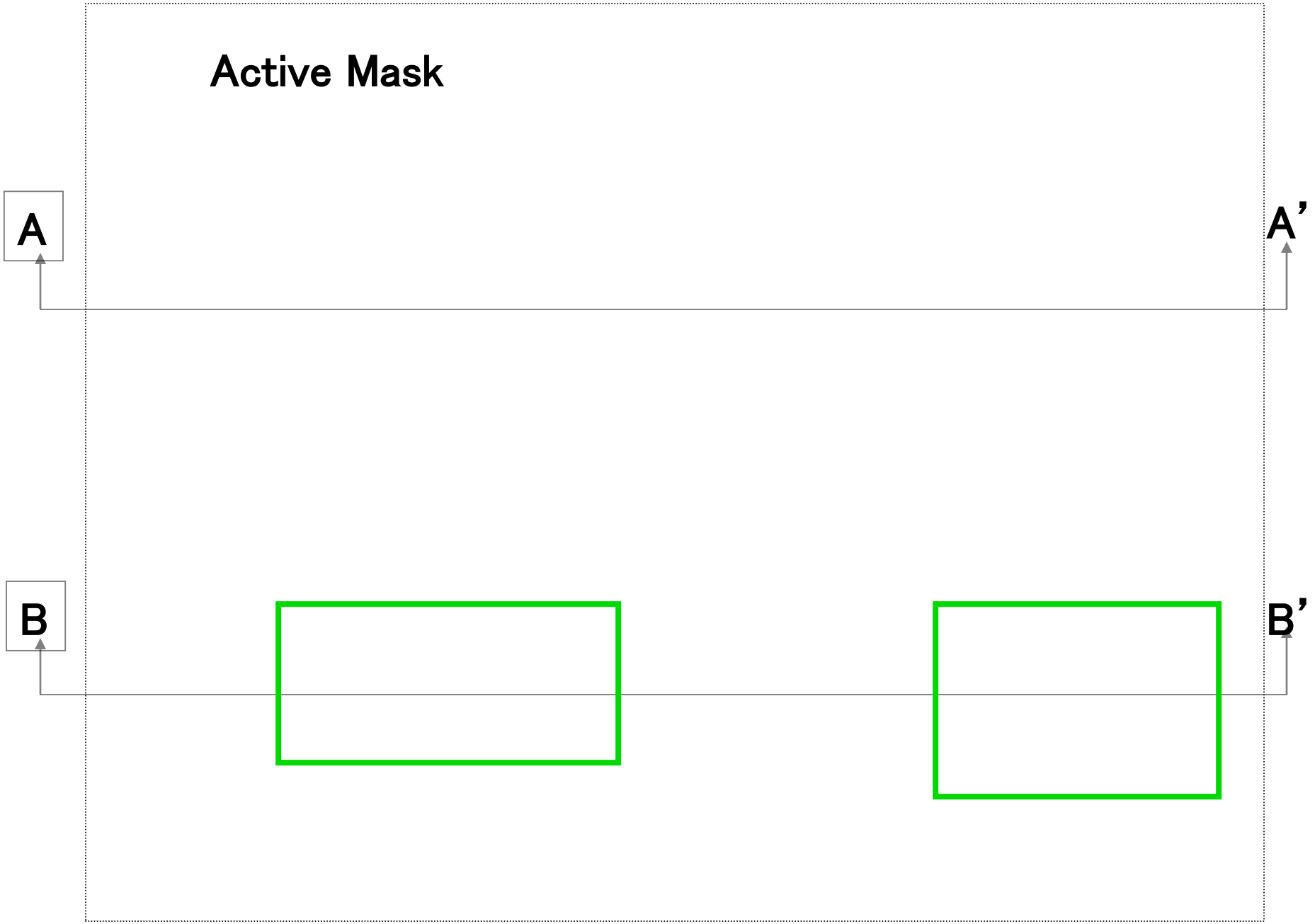
TABLE 2B.1
Process scenario of major process steps in typical n-well CMOS process[a]

1.	Clean wafer	
2.	GROW THIN OXIDE	
3.	Apply photoresist	
4.	PATTERN **n-well**	(MASK #1)
5.	Develop photoresist	
6.	Deposit and diffus n-type impurities	
7.	Strip photoresist	
8.	Strip thin oxide	
9.	Grow thin oxide	
10.	Apply layer of Si_3N_4	
11.	Apply photoresist	
12.	PATTERN Si_3N_4 (active area definition)	(MASK #2)
13.	Develop photoresist	
14.	Etch Si_3N_4	
15.	Strip photoresist	
	Optional field threshold voltage adjust	
	A.1 Apply photoresist	
	A.2 PATTERN ANTIMOAT IN SUBSTRATE	(MASK #A1)
	A.3 Develop photoresist	
	A.4 FIELD IMPLANT p-type)	
	A.5 Strip photoresist	
16.	GROW FIELD OXIDE	
17.	Strip Si_3N_4	
18.	Strip thin oxide	
19.	GROW GATE OXIDE	
20.	POLYSILICON DEPOSITION (POLY I)	
21.	Apply photoresist	
22.	PATTERN POLYSILICON	(MASK #3)
23.	Develop photoresist	
24.	ETCH POLYSILICON	

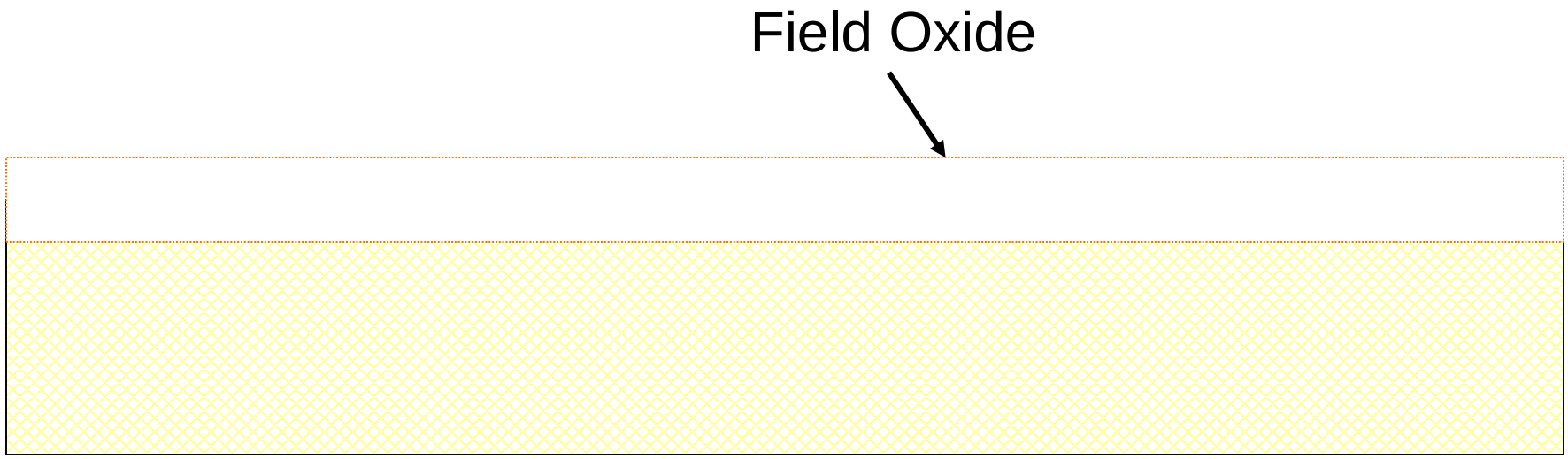
n-well mask

active mask

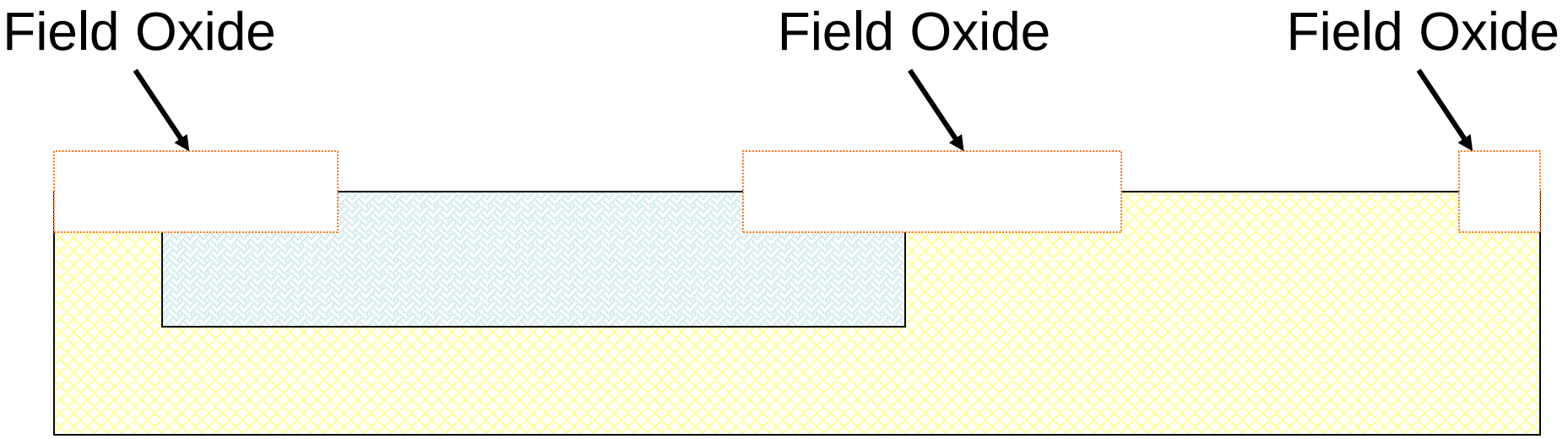

Active Mask
A
A'
B
B'


Active Mask
A
A'
B
B'

Active Mask



A-A' Section



B-B' Section

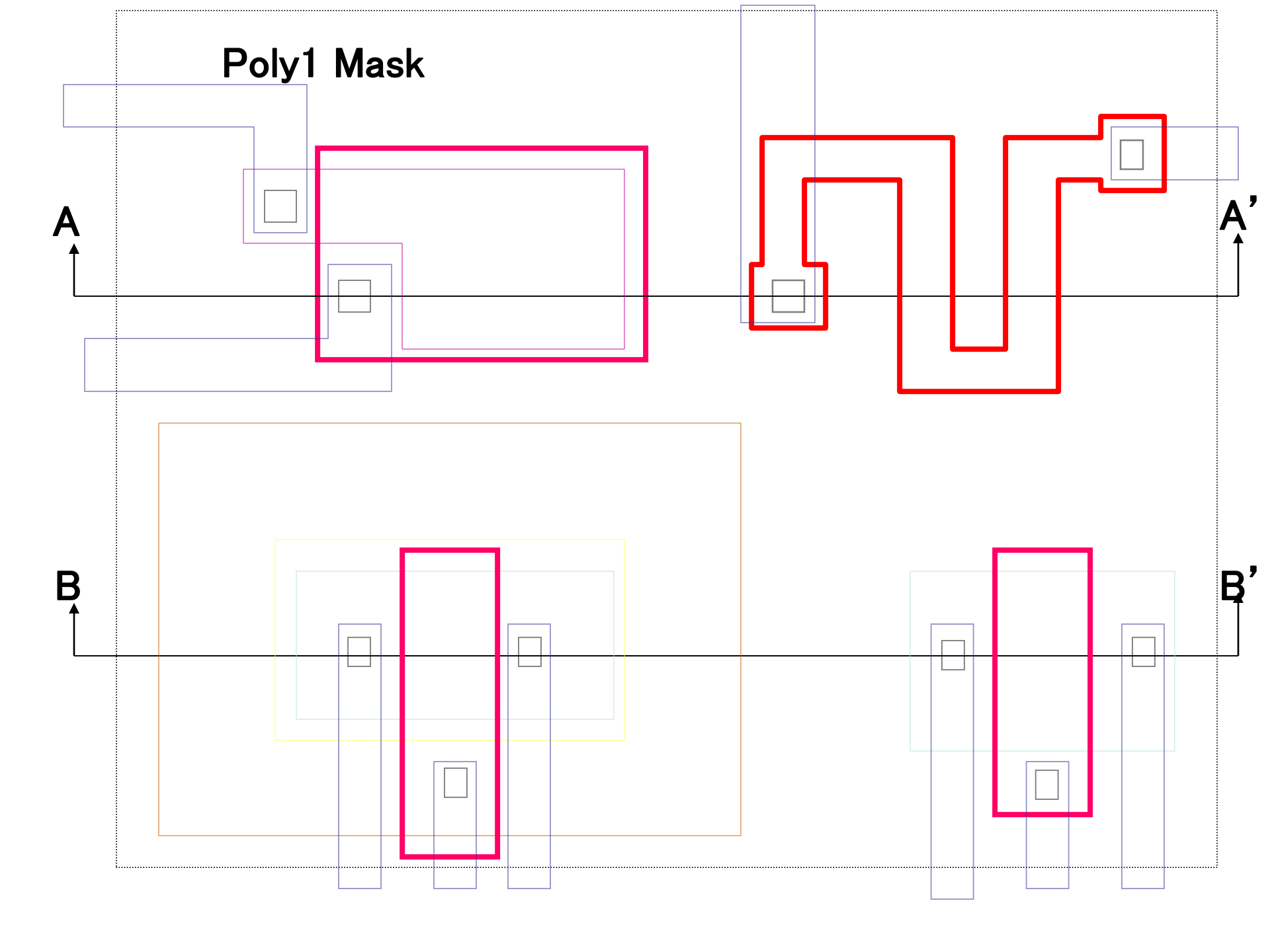
TABLE 2B.1
Process scenario of major process steps in typical n-well CMOS process[a]

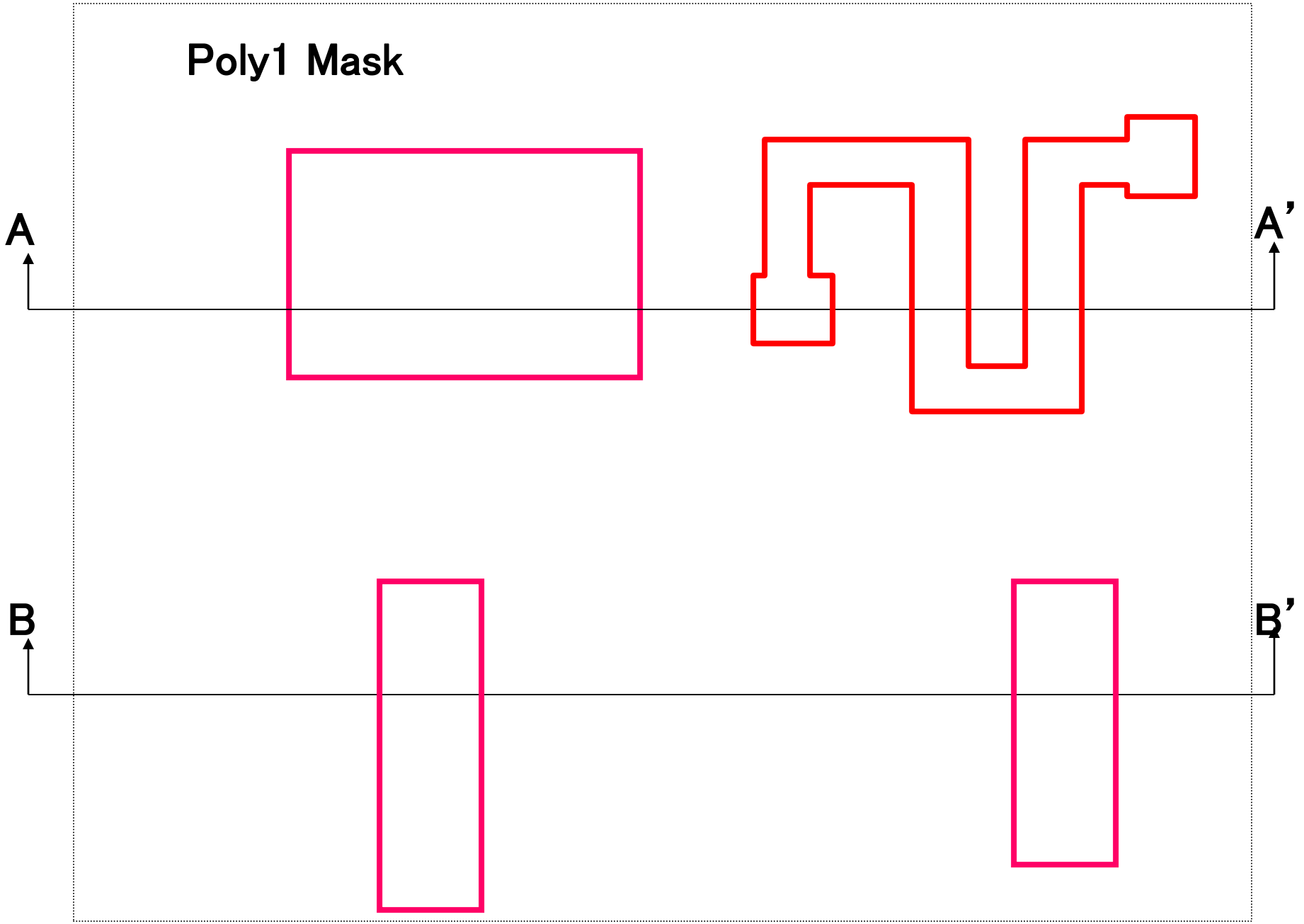
1.	Clean wafer	
2.	GROW THIN OXIDE	
3.	Apply photoresist	
4.	PATTERN **n-well**	(MASK #1)
5.	Develop photoresist	
6.	Deposit and diffus n-type impurities	
7.	Strip photoresist	
8.	Strip thin oxide	
9.	Grow thin oxide	
10.	Apply layer of Si_3N_4	
11.	Apply photoresist	
12.	PATTERN Si_3N_4 (active area definition)	(MASK #2)
13.	Develop photoresist	
14.	Etch Si_3N_4	
15.	Strip photoresist	
	Optional field threshold voltage adjust	
	A.1 Apply photoresist	
	A.2 PATTERN ANTIMOAT IN SUBSTRATE	(MASK #A1)
	A.3 Develop photoresist	
	A.4 FIELD IMPLANT p-type)	
	A.5 Strip photoresist	
16.	GROW FIELD OXIDE	
17.	Strip Si_3N_4	
18.	Strip thin oxide	
19.	GROW GATE OXIDE	
20.	POLYSILICON DEPOSITION (POLY I)	
21.	Apply photoresist	
22.	PATTERN POLYSILICON	(MASK #3)
23.	Develop photoresist	
24.	ETCH POLYSILICON	

n-well mask

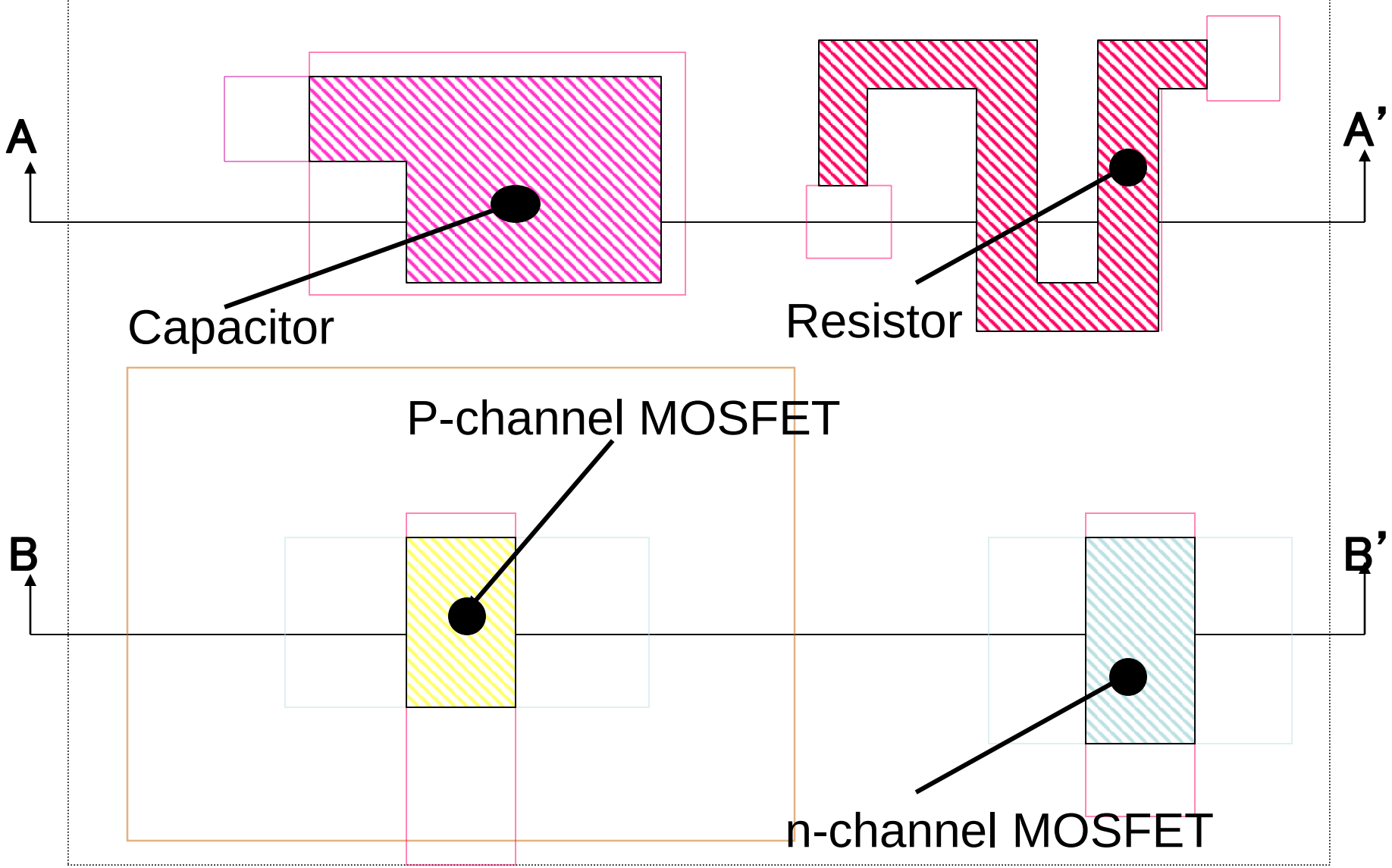
active mask

Poly I mask

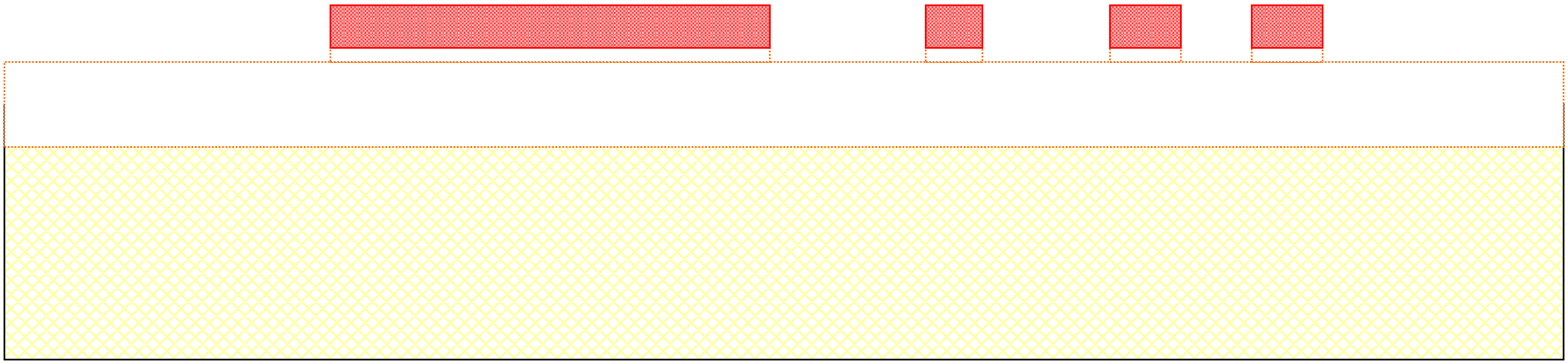

Poly1 Mask
A
A'
B
B'


Poly1 Mask
A
A'
B
B'

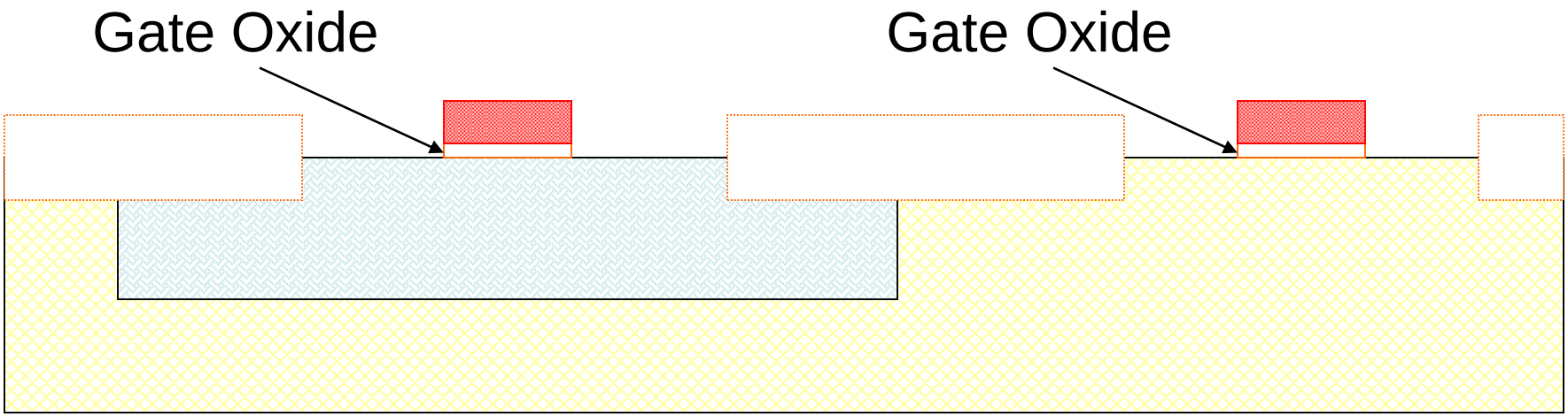
Poly plays a key role in all four types of devices !



Poly 1 Mask



A-A’ Section



B-B’ Section

TABLE 2B.1
Process scenario of major process steps in typical n-well CMOS process[a]

1.	Clean wafer	
2.	GROW THIN OXIDE	
3.	Apply photoresist	
4.	PATTERN **n-well**	(MASK #1)
5.	Develop photoresist	
6.	Deposit and diffus n-type impurities	
7.	Strip photoresist	
8.	Strip thin oxide	
9.	Grow thin oxide	
10.	Apply layer of Si_3N_4	
11.	Apply photoresist	
12.	PATTERN Si_3N_4 (active area definition)	(MASK #2)
13.	Develop photoresist	
14.	Etch Si_3N_4	
15.	Strip photoresist	
	Optional field threshold voltage adjust	
	A.1 Apply photoresist	
	A.2 PATTERN ANTIMOAT IN SUBSTRATE	(MASK #A1)
	A.3 Develop photoresist	
	A.4 FIELD IMPLANT p-type)	
	A.5 Strip photoresist	
16.	GROW FIELD OXIDE	
17.	Strip Si_3N_4	
18.	Strip thin oxide	
19.	GROW GATE OXIDE	
20.	POLYSILICON DEPOSITION (POLY I)	
21.	Apply photoresist	
22.	PATTERN POLYSILICON	(MASK #3)
23.	Develop photoresist	
24.	ETCH POLYSILICON	

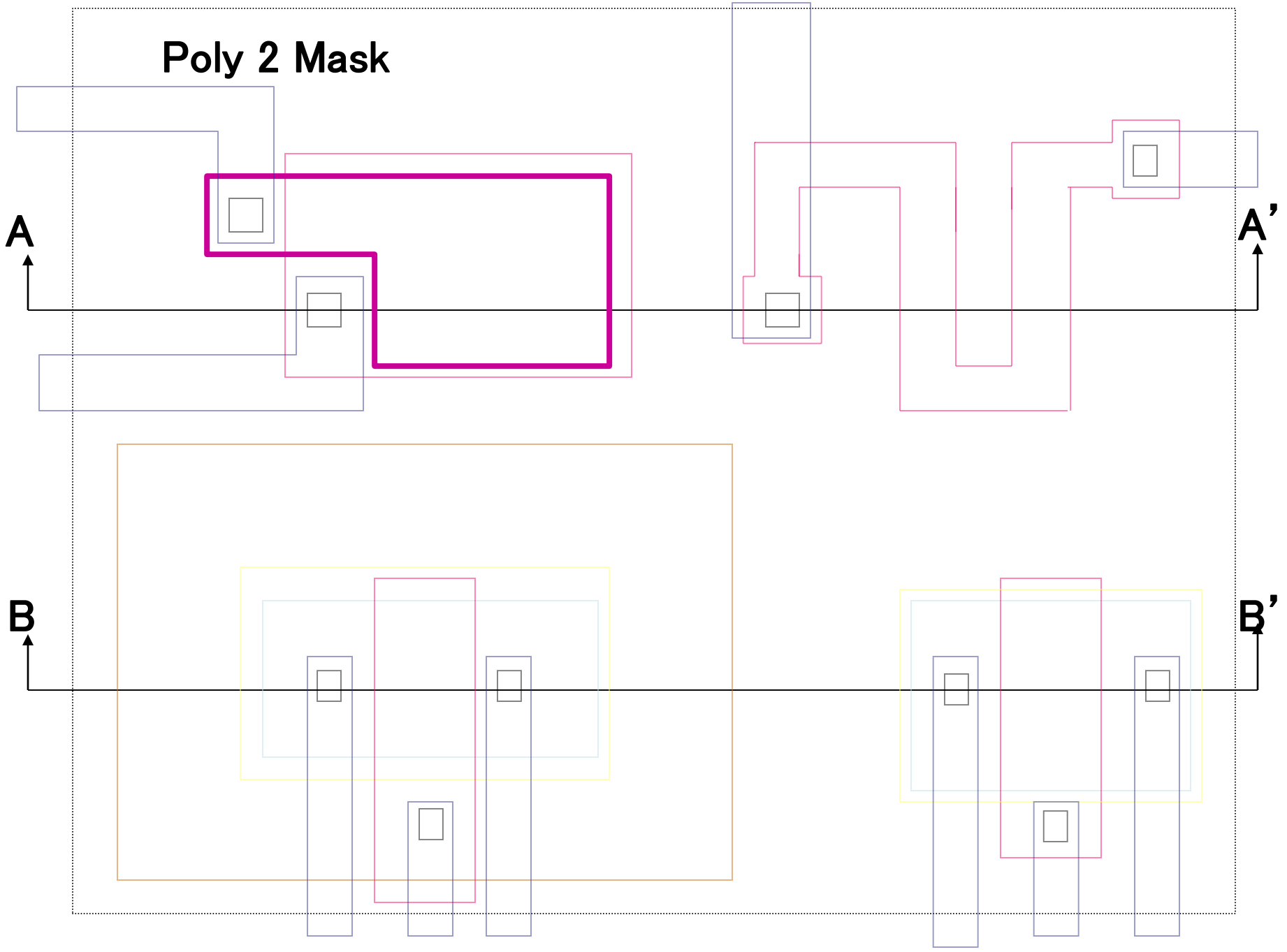
25. Strip photoresist

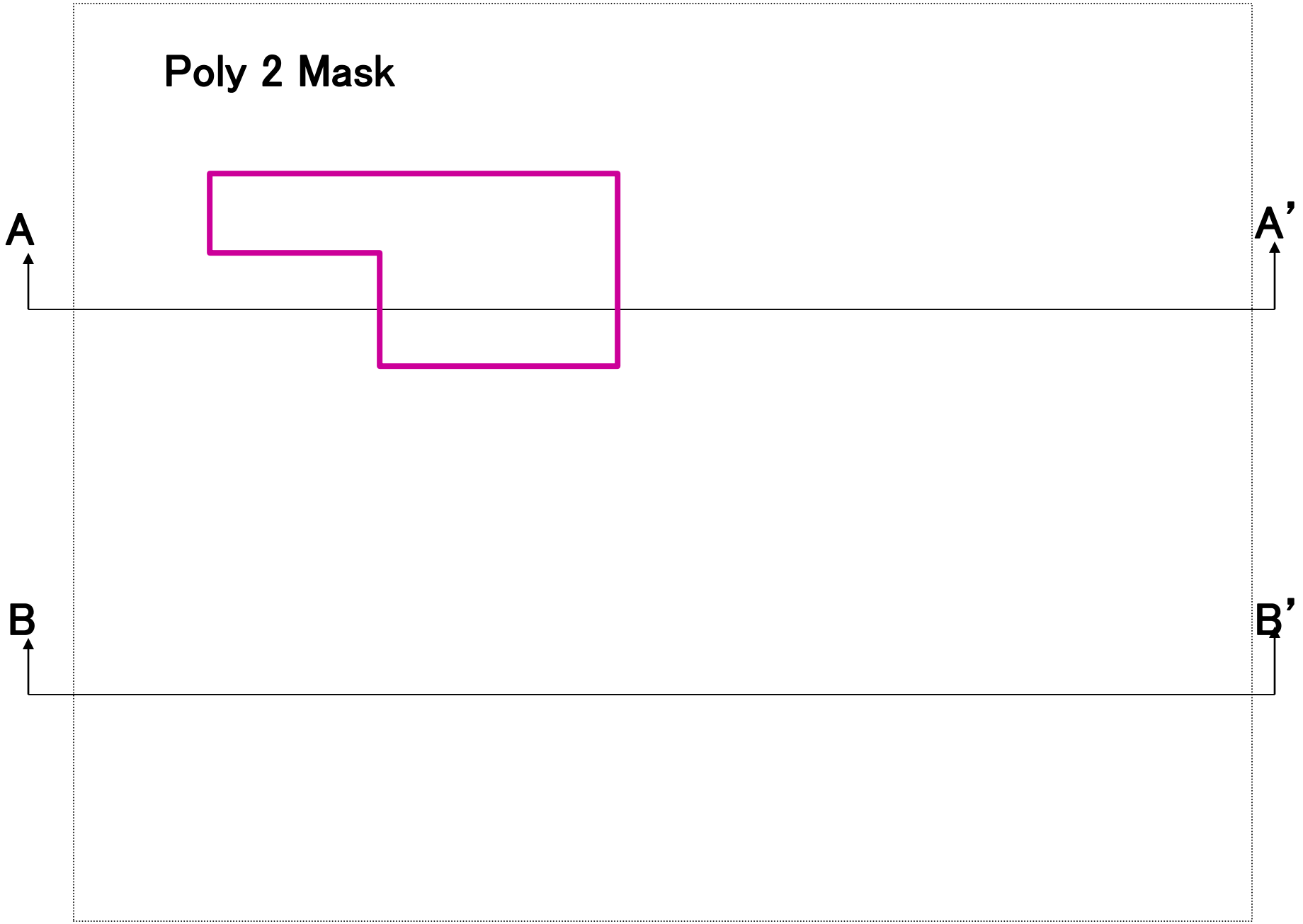
Optional steps for double polysilicon process

B.1 Strip thin oxide
B.2 GROW THIN OXIDE
B.3 POLYSILICON DEPOSITION (POLY II)
B.4 Apply photoresist
B.5 PATTERN POLYSILICON (MASK #B1)
B.6 Develop photoresist
B.7 ETCH POLYSILICON
B.8 Strip photoresist
B.9 Strip thin oxide

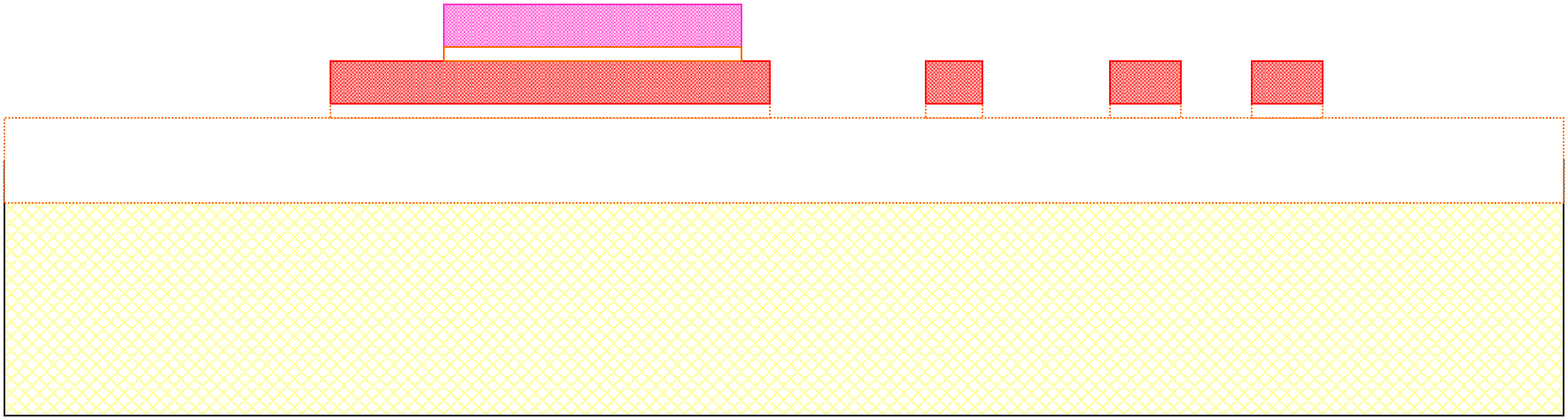
Poly II mask

26. Apply photoresist
27. PATTERN P-CHANNEL DRAINS AND SOURCES AND P^+ GUARD RINGS (p-well ohmic contacts) (MASK #4)
28. Develop photoresist
29. p^+ IMPLANT
30. Strip photoresist
31. Apply photoresist
32. PATTERN N-CHANNEL DRAINS AND SOURCES AND N^+ GUARD RINGS (top ohmic contact to substrate) (MASK #5)
33. Develop photoresist
34. n^+ IMPLANT
35. Strip photoresist
36. Strip thin oxide
37. Grow oxide
38. Apply photoresist
39. PATTERN CONTACT OPENINGS (MASK #6)
40. Develop photoresist
41. Etch oxide
42. Strip photoresist

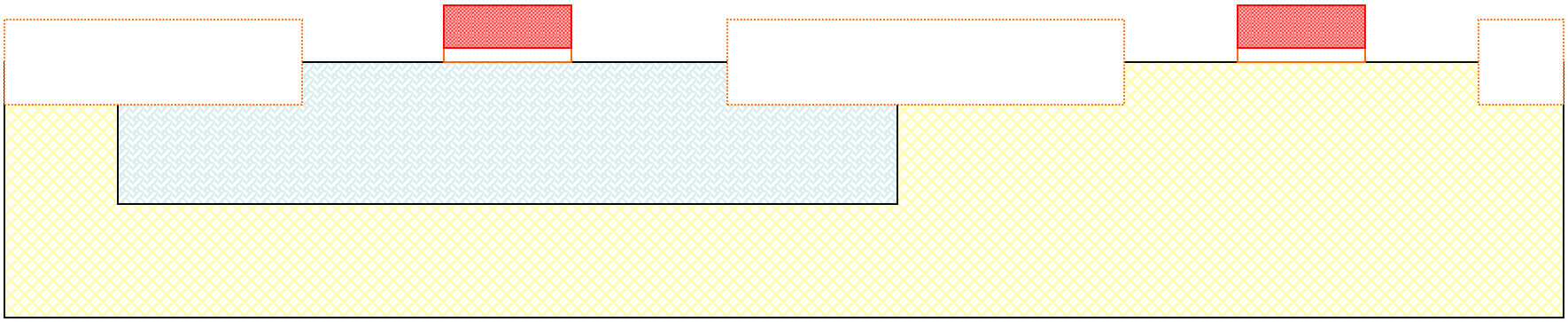

Poly 2 Mask
A
A'
B
B'


Poly 2 Mask
A
A'
B
B'

Poly 2 Mask



A-A’ Section



B-B’ Section

TABLE 2B.1
Process scenario of major process steps in typical n-well CMOS process[a]

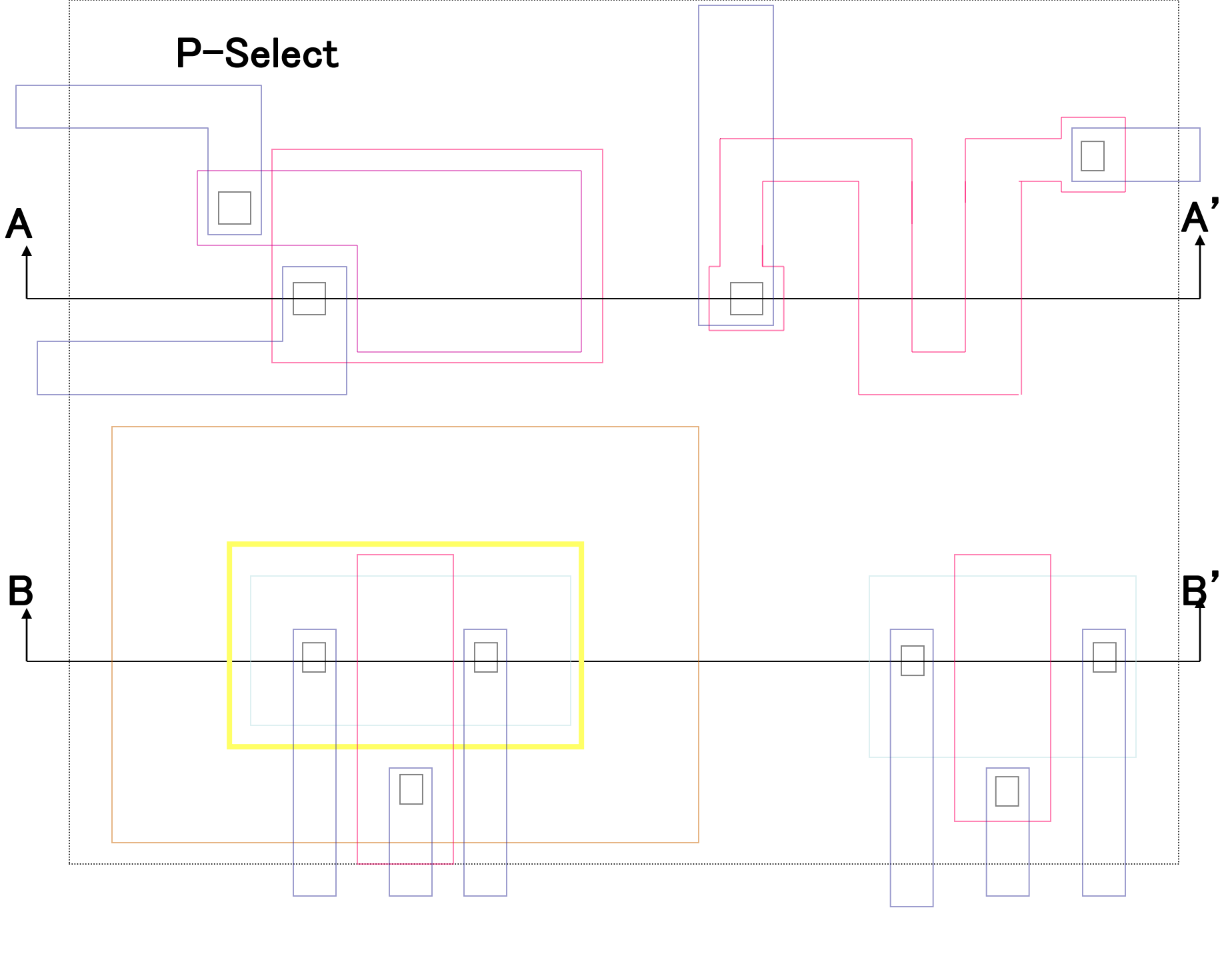
1.	Clean wafer	
2.	GROW THIN OXIDE	
3.	Apply photoresist	
4.	PATTERN **n-well**	(MASK #1)
5.	Develop photoresist	
6.	Deposit and diffus n-type impurities	
7.	Strip photoresist	
8.	Strip thin oxide	
9.	Grow thin oxide	
10.	Apply layer of Si_3N_4	
11.	Apply photoresist	
12.	PATTERN Si_3N_4 (active area definition)	(MASK #2)
13.	Develop photoresist	
14.	Etch Si_3N_4	
15.	Strip photoresist	
	Optional field threshold voltage adjust	
	A.1 Apply photoresist	
	A.2 PATTERN ANTIMOAT IN SUBSTRATE	(MASK #A1)
	A.3 Develop photoresist	
	A.4 FIELD IMPLANT p-type)	
	A.5 Strip photoresist	
16.	GROW FIELD OXIDE	
17.	Strip Si_3N_4	
18.	Strip thin oxide	
19.	GROW GATE OXIDE	
20.	POLYSILICON DEPOSITION (POLY I)	
21.	Apply photoresist	
22.	PATTERN POLYSILICON	(MASK #3)
23.	Develop photoresist	
24.	ETCH POLYSILICON	

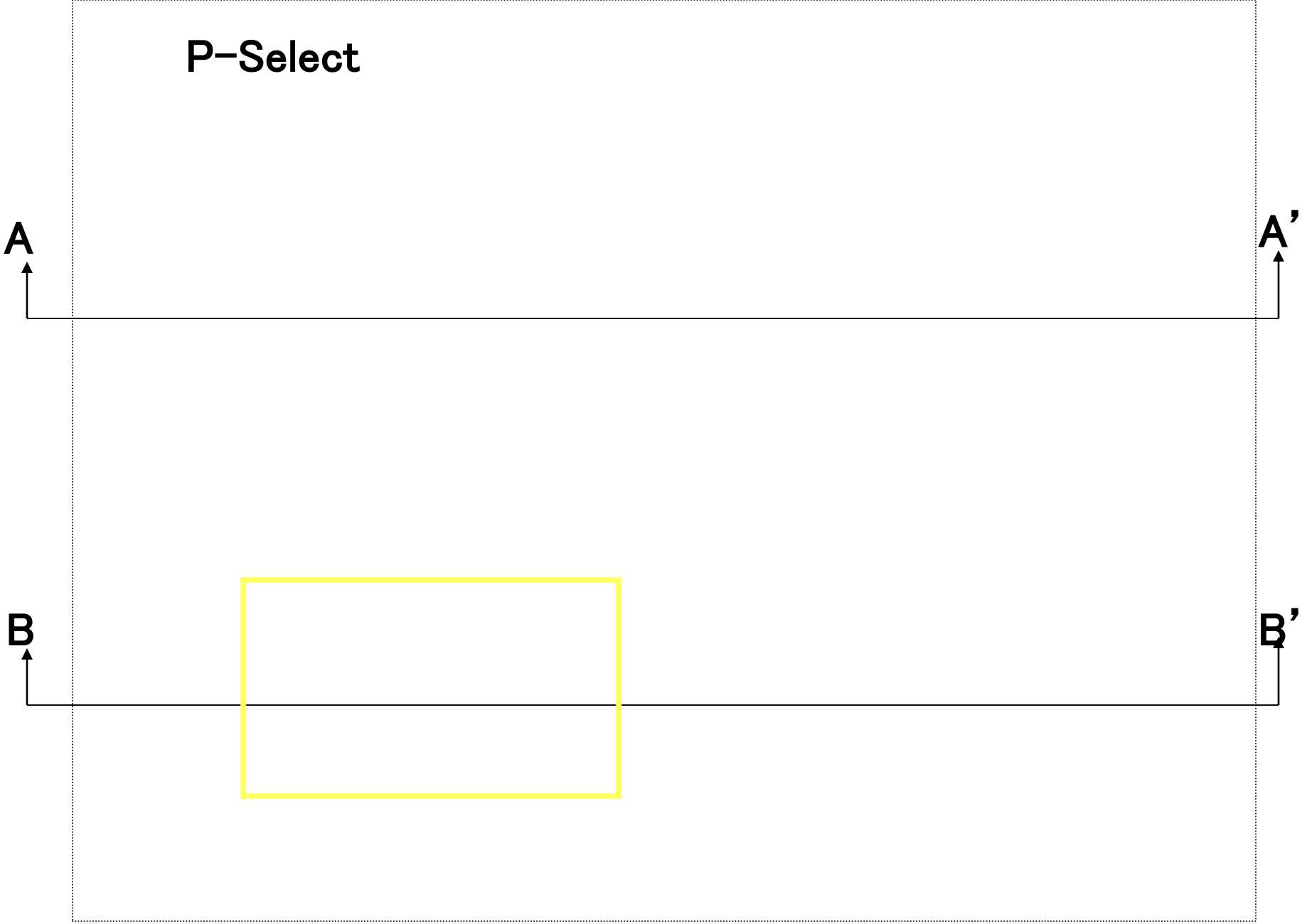
25.	Strip photoresist	
	Optional steps for double polysilicon process	
	B.1 Strip thin oxide	
	B.2 GROW THIN OXIDE	
	B.3 POLYSILICON DEPOSITION (POLY II)	
	B.4 Apply photoresist	
	B.5 PATTERN POLYSILICON	(MASK #B1)
	B.6 Develop photoresist	
	B.7 ETCH POLYSILICON	
	B.8 Strip photoresist	
	B.9 Strip thin oxide	
26.	Apply photoresist	
27.	PATTERN P-CHANNEL DRAINS AND SOURCES AND P^+ GUARD RINGS (p-well ohmic contacts)	(MASK #4)
28.	Develop photoresist	
29.	p^+ IMPLANT	
30.	Strip photoresist	
31.	Apply photoresist	
32.	PATTERN N-CHANNEL DRAINS AND SOURCES AND N^+ GUARD RINGS (top ohmic contact to substrate)	(MASK #5)
33.	Develop photoresist	
34.	n^+ IMPLANT	
35.	Strip photoresist	
36.	Strip thin oxide	
37.	Grow oxide	
38.	Apply photoresist	
39.	PATTERN CONTACT OPENINGS	(MASK #6)
40.	Develop photoresist	
41.	Etch oxide	
42.	Strip photoresist	

Poly II mask

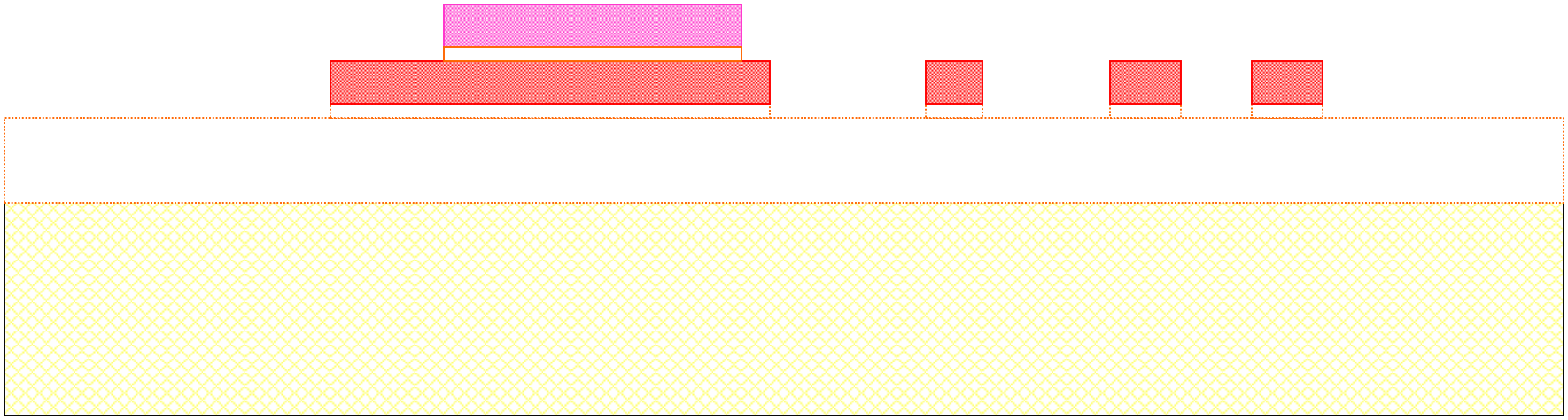
p-select mask

n-select mask

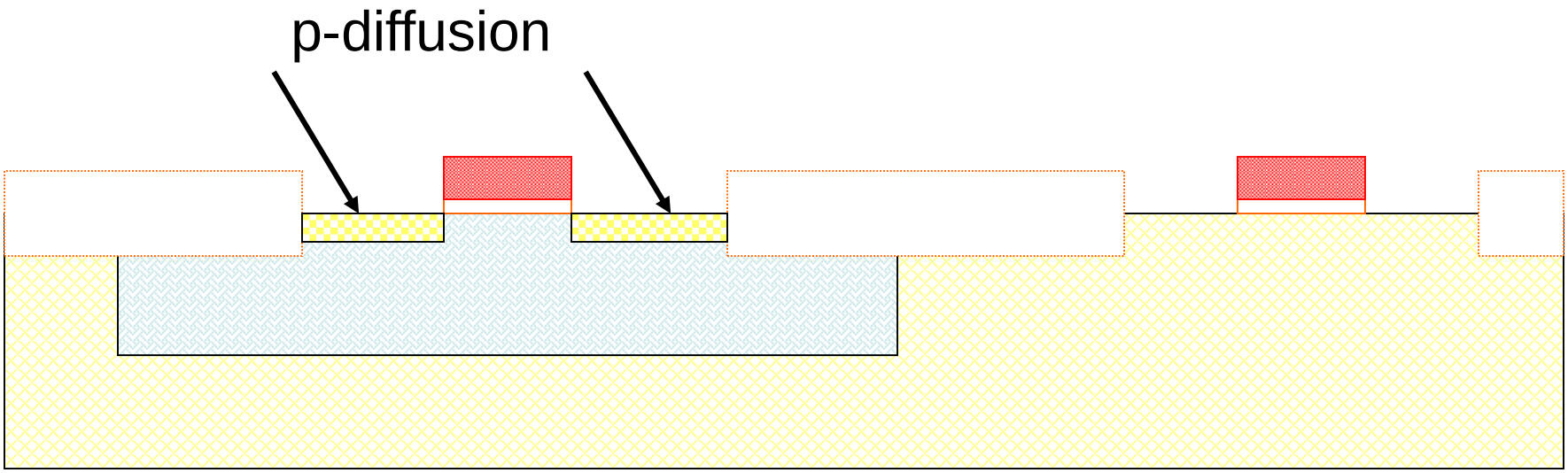

P–Select
A
A’
B
B’


P–Select
A
A’
B
B’

P-Select Mask – p-diffusion



A–A’ Section

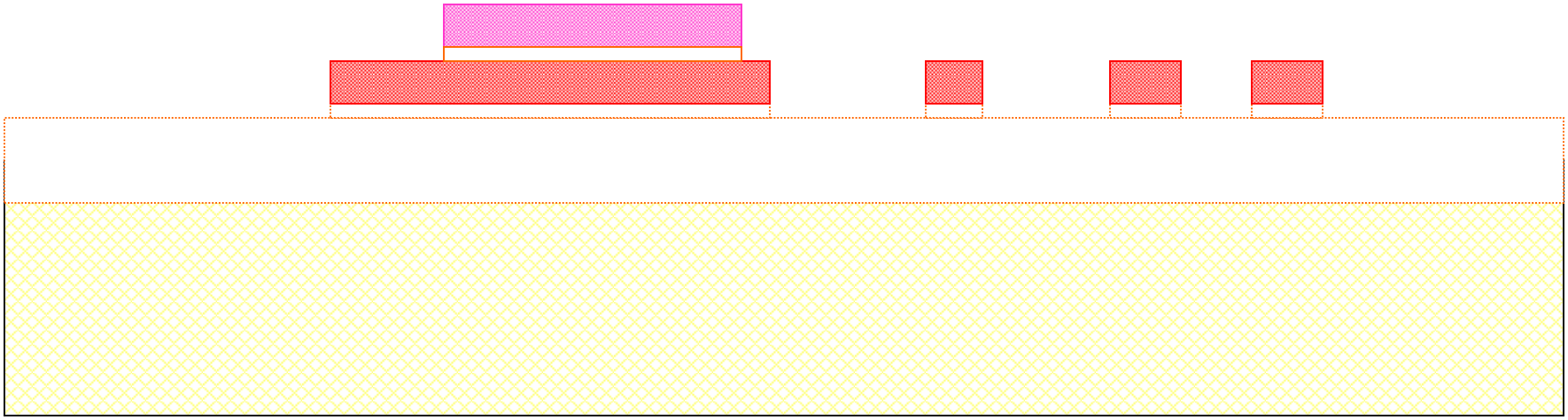


B–B’ Section

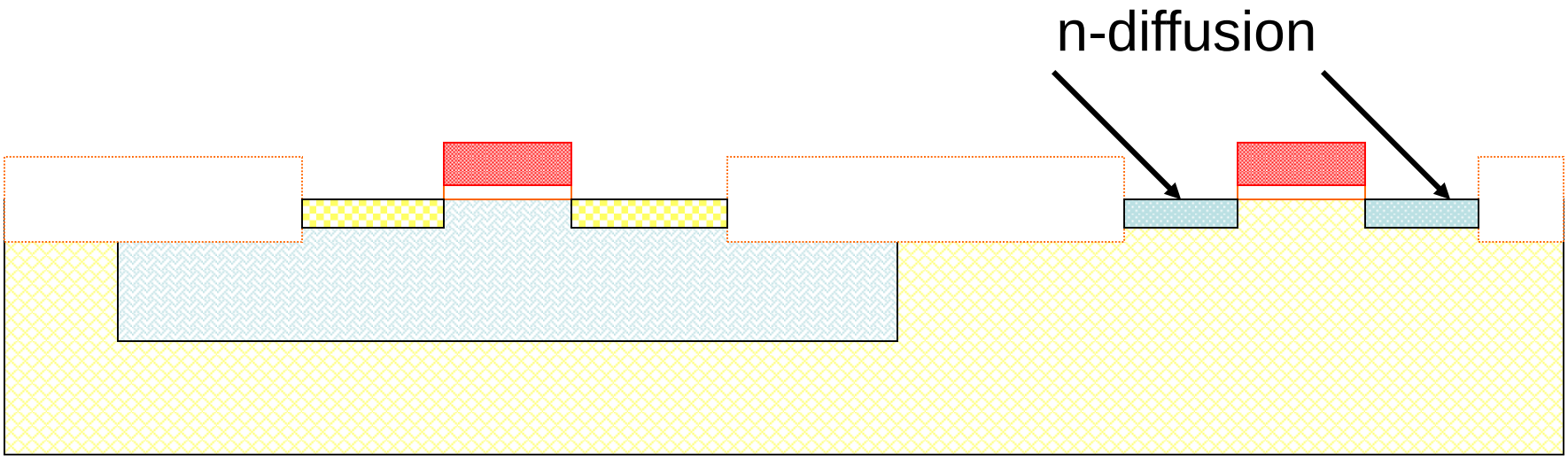
Note the gate is self aligned !!

Note $C_{OXn}=C_{OXp}$!!

n-Select Mask – n-diffusion



A-A’ Section



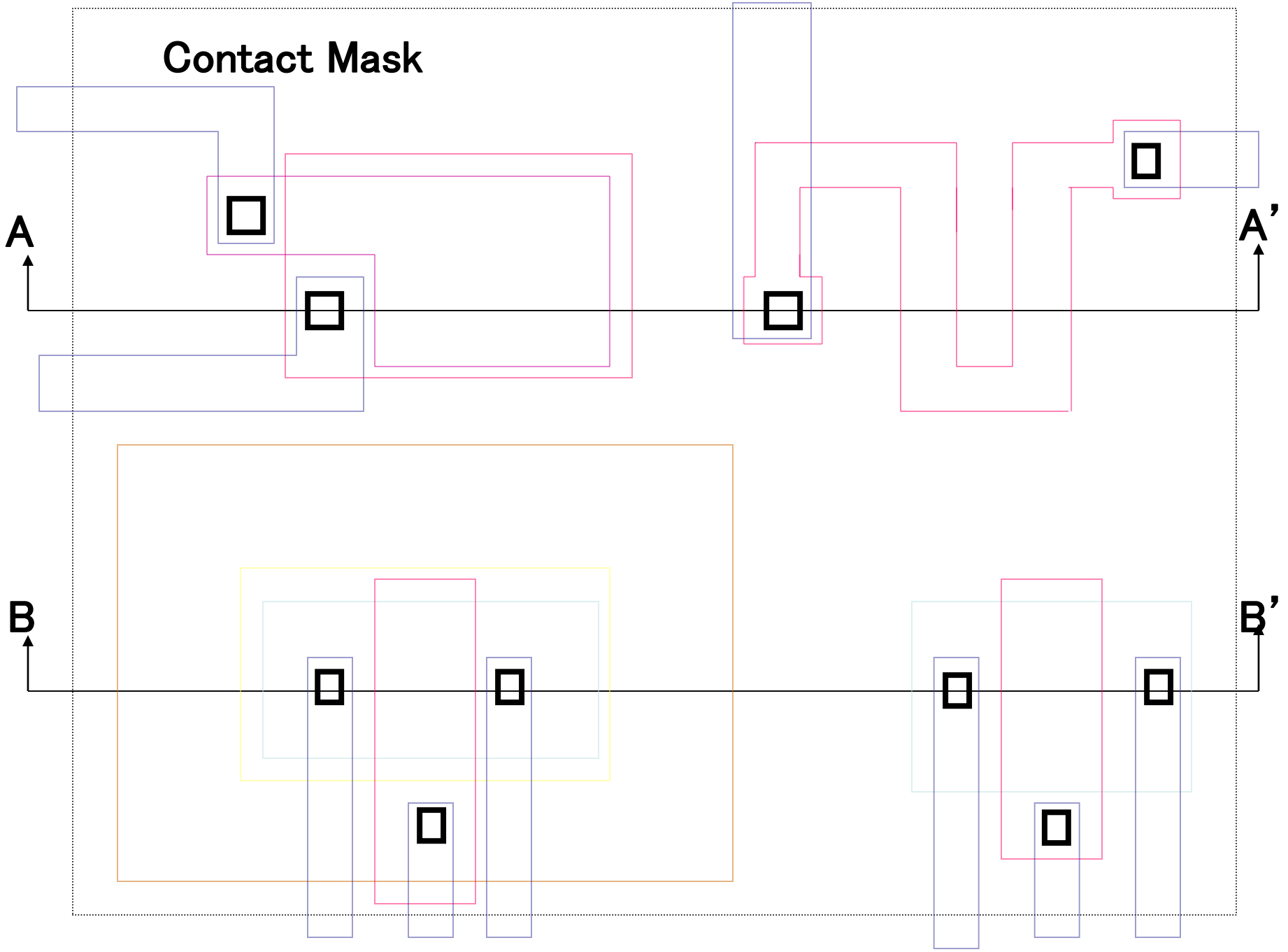
B-B’ Section

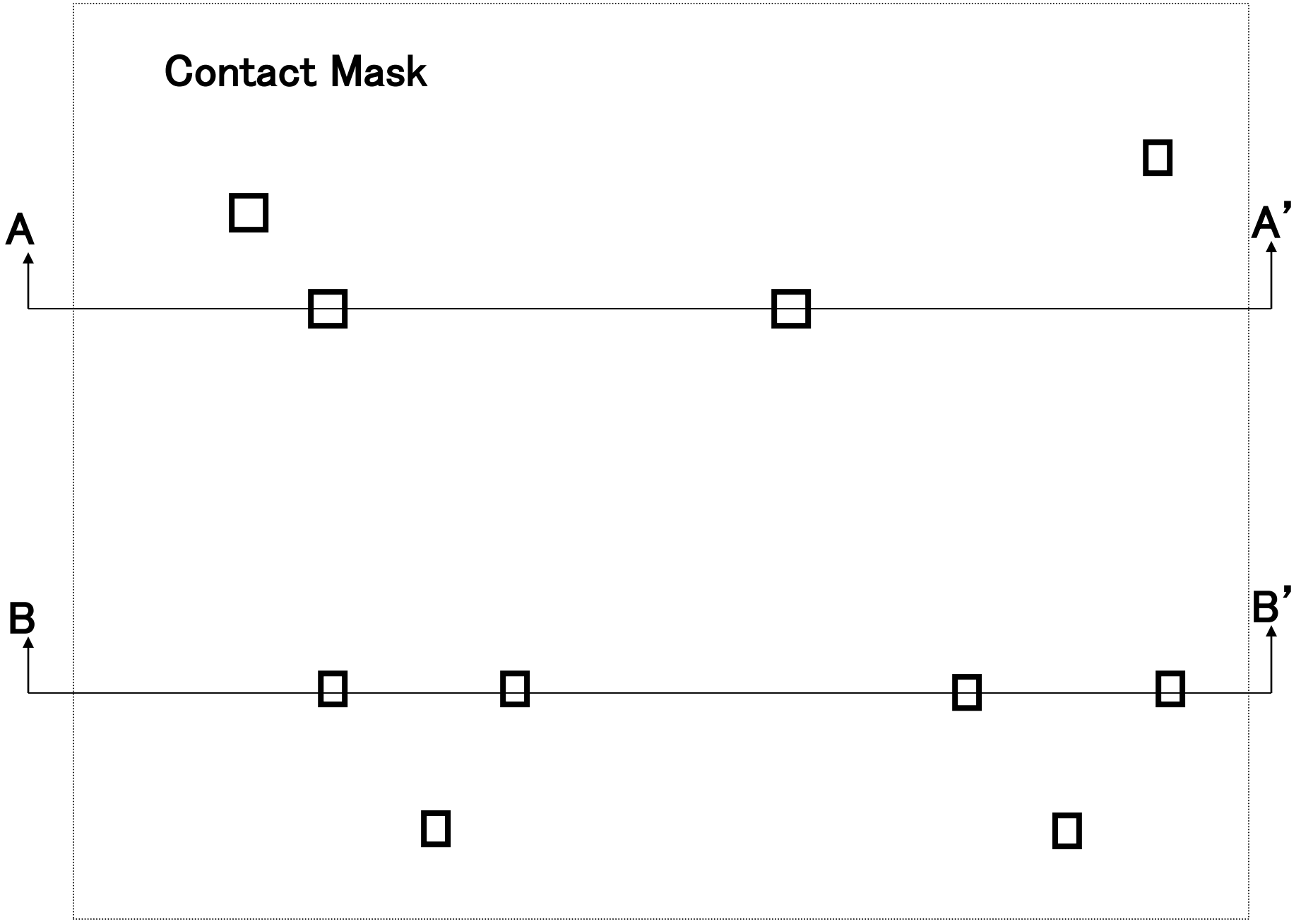
TABLE 2B.1
Process scenario of major process steps in typical n-well CMOS process[a]

1.	Clean wafer	
2.	GROW THIN OXIDE	
3.	Apply photoresist	
4.	PATTERN **n-well**	(MASK #1)
5.	Develop photoresist	
6.	Deposit and diffus n-type impurities	
7.	Strip photoresist	
8.	Strip thin oxide	
9.	Grow thin oxide	
10.	Apply layer of Si_3N_4	
11.	Apply photoresist	
12.	PATTERN Si_3N_4 (active area definition)	(MASK #2)
13.	Develop photoresist	
14.	Etch Si_3N_4	
15.	Strip photoresist	
	Optional field threshold voltage adjust	
	A.1 Apply photoresist	
	A.2 PATTERN ANTIMOAT IN SUBSTRATE	(MASK #A1)
	A.3 Develop photoresist	
	A.4 FIELD IMPLANT p-type)	
	A.5 Strip photoresist	
16.	GROW FIELD OXIDE	
17.	Strip Si_3N_4	
18.	Strip thin oxide	
19.	GROW GATE OXIDE	
20.	POLYSILICON DEPOSITION (POLY I)	
21.	Apply photoresist	
22.	PATTERN POLYSILICON	(MASK #3)
23.	Develop photoresist	
24.	ETCH POLYSILICON	

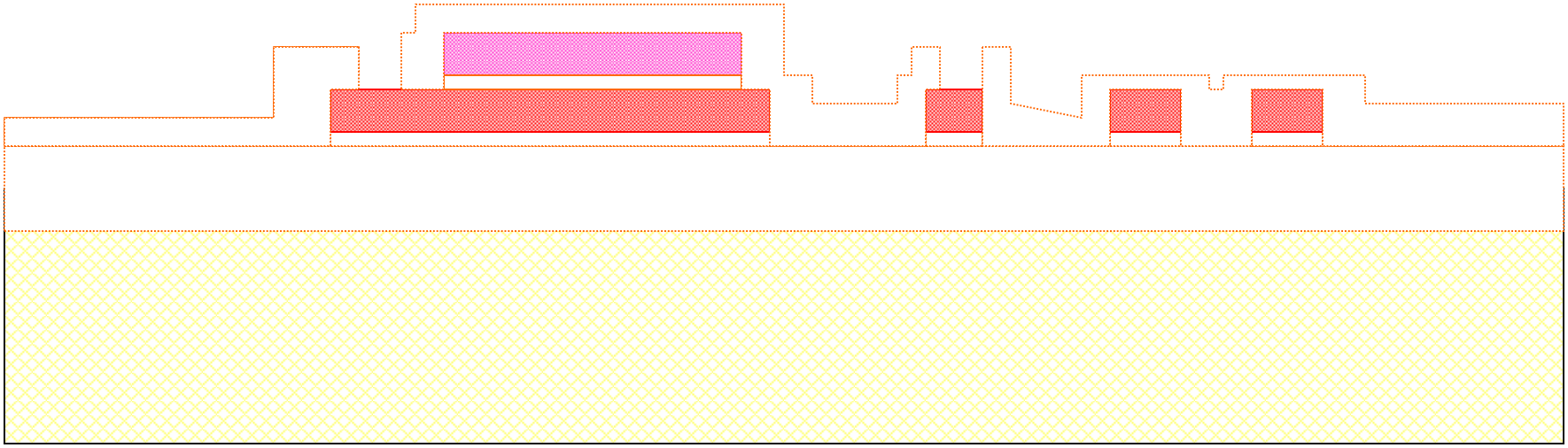
25.	Strip photoresist		
	Optional steps for double polysilicon process		
	B.1 Strip thin oxide		
	B.2 GROW THIN OXIDE		
	B.3 POLYSILICON DEPOSITION (POLY II)		
	B.4 Apply photoresist		
	B.5 PATTERN POLYSILICON	(MASK #B1)	Poly II mask
	B.6 Develop photoresist		
	B.7 ETCH POLYSILICON		
	B.8 Strip photoresist		
	B.9 Strip thin oxide		
26.	Apply photoresist		
27.	PATTERN P-CHANNEL DRAINS AND SOURCES AND P^+ GUARD RINGS (p-well ohmic contacts)	(MASK #4)	p-select mask
28.	Develop photoresist		
29.	p^+ IMPLANT		
30.	Strip photoresist		
31.	Apply photoresist		
32.	PATTERN N-CHANNEL DRAINS AND SOURCES AND N^+ GUARD RINGS (top ohmic contact to substrate)	(MASK #5)	n-select mask
33.	Develop photoresist		
34.	n^+ IMPLANT		
35.	Strip photoresist		
36.	Strip thin oxide		
37.	Grow oxide		
38.	Apply photoresist		
39.	PATTERN CONTACT OPENINGS	(MASK #6)	contact mask
40.	Develop photoresist		
41.	Etch oxide		
42.	Strip photoresist		

43.	APPLY METAL	
44.	Apply photoresist	
45.	PATTERN METAL	(MASK #7)
46.	Develop photoresist	
47.	Etch metal	
48.	Strip photoresist	
	Optional steps for double metal process	
	C.1 Strip thin oxide	
	C.2 DEPOSIT INTERMETAL OXIDE	
	C.3 Apply photoresist	
	C.4 PATTERN VIAS	(MASK #C1)
	C.5 Develop photoresist	
	C.6 Etch oxide	
	C.7 Strip photoresist	
	C.8 APPLY METAL (Metal 2)	
	C.9 Apply photoresist	
	C.10 PATTERN METAL	(MASK #C2)
	C.11 Develop photoresist	
	C.12 Etch metal	
	C.13 Strip photoresist	
49.	APPLY PASSIVATION	
50.	Apply photoresist	
51.	PATTERN PAD OPENINGS	(MASK #8)
52.	Develop photoresist	
53.	Etch passivation	
54.	Strip photoresist	
55.	ASSEMBLE, PACKAGE AND TEST	

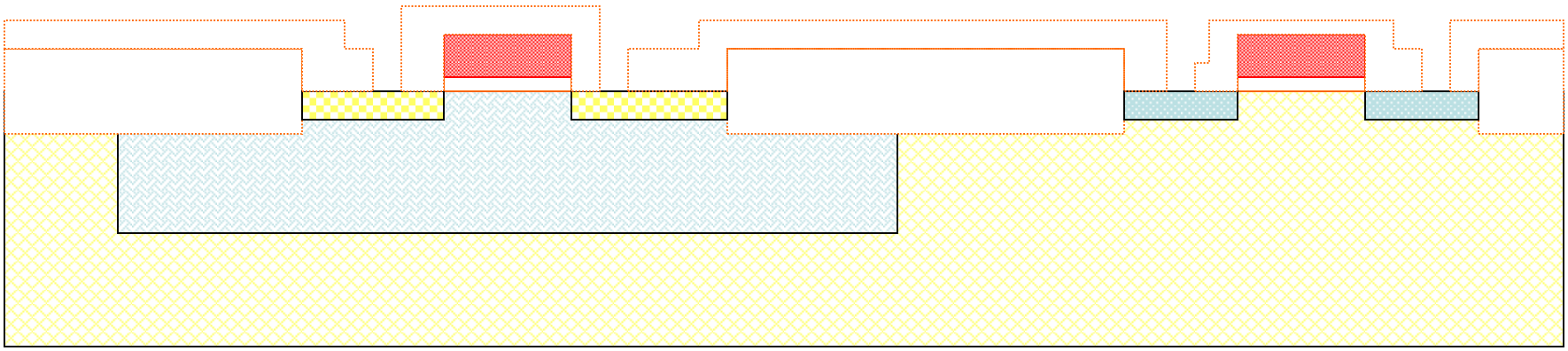

Contact Mask
A
A'
B
B'


Contact Mask
A
A'
B
B'

Contact Mask



A-A’ Section



B-B’ Section

TABLE 2B.1
Process scenario of major process steps in typical n-well CMOS process[a]

1.	Clean wafer	
2.	GROW THIN OXIDE	
3.	Apply photoresist	
4.	PATTERN **n-well**	(MASK #1)
5.	Develop photoresist	
6.	Deposit and diffus n-type impurities	
7.	Strip photoresist	
8.	Strip thin oxide	
9.	Grow thin oxide	
10.	Apply layer of Si_3N_4	
11.	Apply photoresist	
12.	PATTERN Si_3N_4 (active area definition)	(MASK #2)
13.	Develop photoresist	
14.	Etch Si_3N_4	
15.	Strip photoresist	
	Optional field threshold voltage adjust	
	A.1 Apply photoresist	
	A.2 PATTERN ANTIMOAT IN SUBSTRATE	(MASK #A1)
	A.3 Develop photoresist	
	A.4 FIELD IMPLANT p-type)	
	A.5 Strip photoresist	
16.	GROW FIELD OXIDE	
17.	Strip Si_3N_4	
18.	Strip thin oxide	
19.	GROW GATE OXIDE	
20.	POLYSILICON DEPOSITION (POLY I)	
21.	Apply photoresist	
22.	PATTERN POLYSILICON	(MASK #3)
23.	Develop photoresist	
24.	ETCH POLYSILICON	

25. Strip photoresist
Optional steps for double polysilicon process
B.1 Strip thin oxide
B.2 GROW THIN OXIDE
B.3 POLYSILICON DEPOSITION (POLY II)
B.4 Apply photoresist
B.5 PATTERN POLYSILICON (MASK #B1)
B.6 Develop photoresist
B.7 ETCH POLYSILICON
B.8 Strip photoresist
B.9 Strip thin oxide

26. Apply photoresist
27. PATTERN P-CHANNEL DRAINS AND SOURCES AND P^+ GUARD RINGS (p-well ohmic contacts) (MASK #4)
28. Develop photoresist
29. p^+ IMPLANT
30. Strip photoresist
31. Apply photoresist
32. PATTERN N-CHANNEL DRAINS AND SOURCES AND N^+ GUARD RINGS (top ohmic contact to substrate) (MASK #5)
33. Develop photoresist
34. n^+ IMPLANT
35. Strip photoresist
36. Strip thin oxide
37. Grow oxide
38. Apply photoresist
39. PATTERN CONTACT OPENINGS (MASK #6)
40. Develop photoresist
41. Etch oxide
42. Strip photoresist

43. APPLY METAL
44. Apply photoresist
45. PATTERN METAL
46. Develop photoresist
47. Etch metal
48. Strip photoresist

Optional steps for double metal process

C.1 Strip thin oxide
C.2 DEPOSIT INTERMETAL OXIDE
C.3 Apply photoresist
C.4 PATTERN VIAS
C.5 Develop photoresist
C.6 Etch oxide
C.7 Strip photoresist
C.8 APPLY METAL (Metal 2)
C.9 Apply photoresist
C.10 PATTERN METAL
C.11 Develop photoresist
C.12 Etch metal
C.13 Strip photoresist

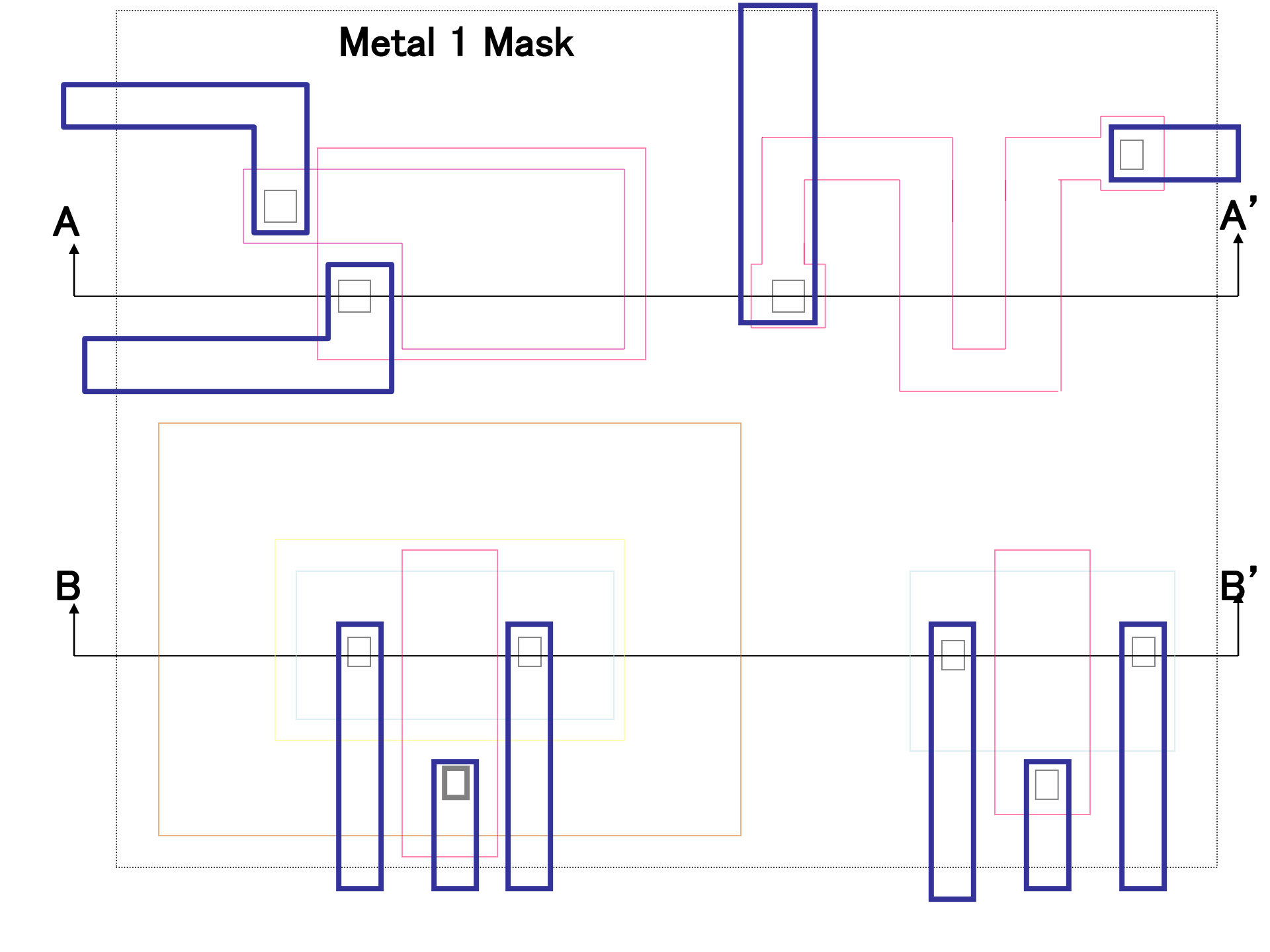
49. APPLY PASSIVATION
50. Apply photoresist
51. PATTERN PAD OPENINGS
52. Develop photoresist
53. Etch passivation
54. Strip photoresist
55. ASSEMBLE, PACKAGE AND TEST

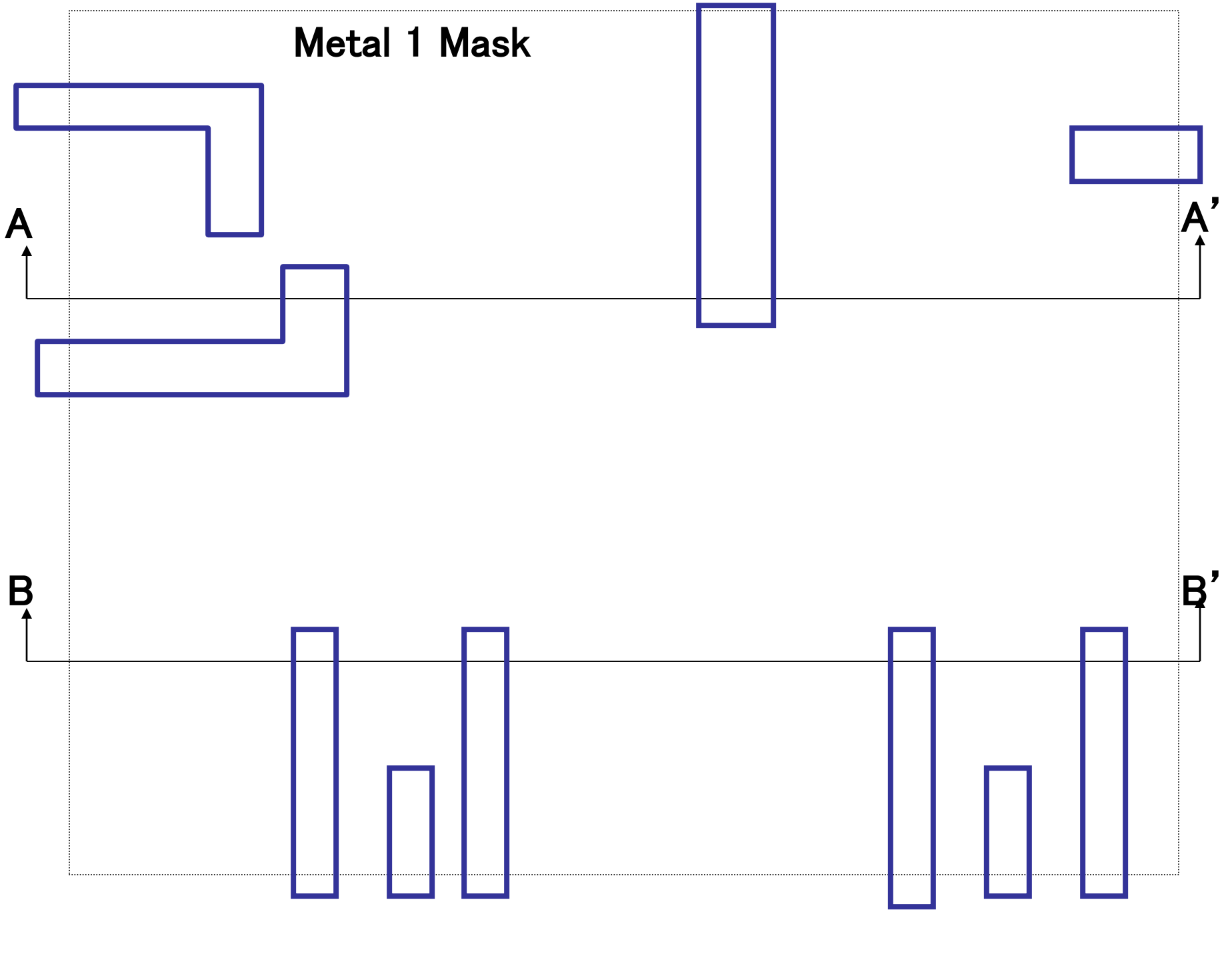
(MASK #7) Metal 1 mask

(MASK #C1) Via mask

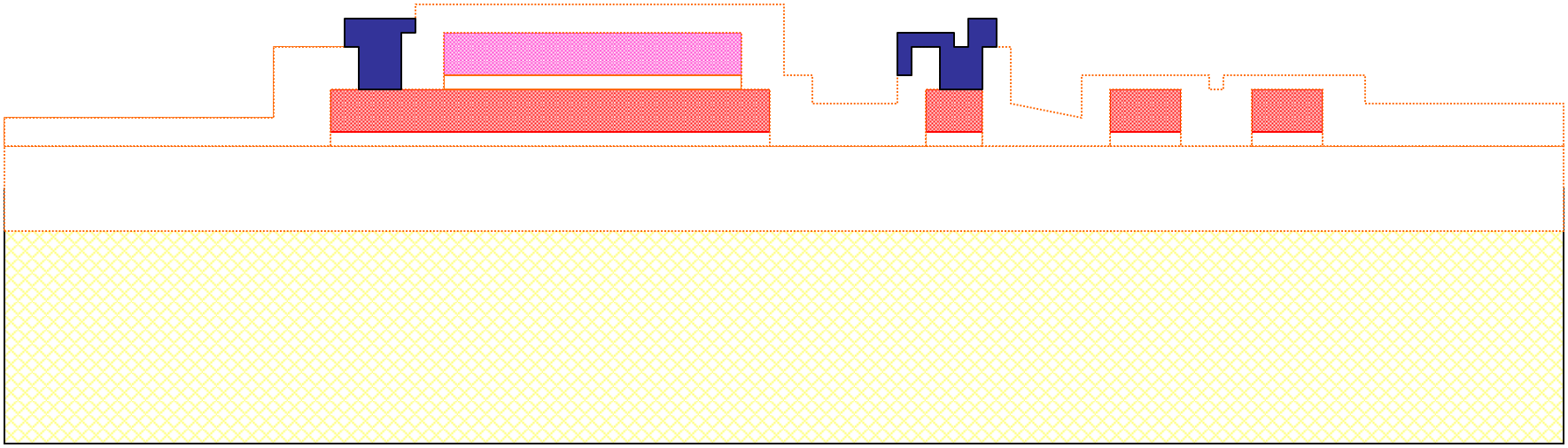
(MASK #C2) Metal 2 mask

(MASK #8) Pad Open mask

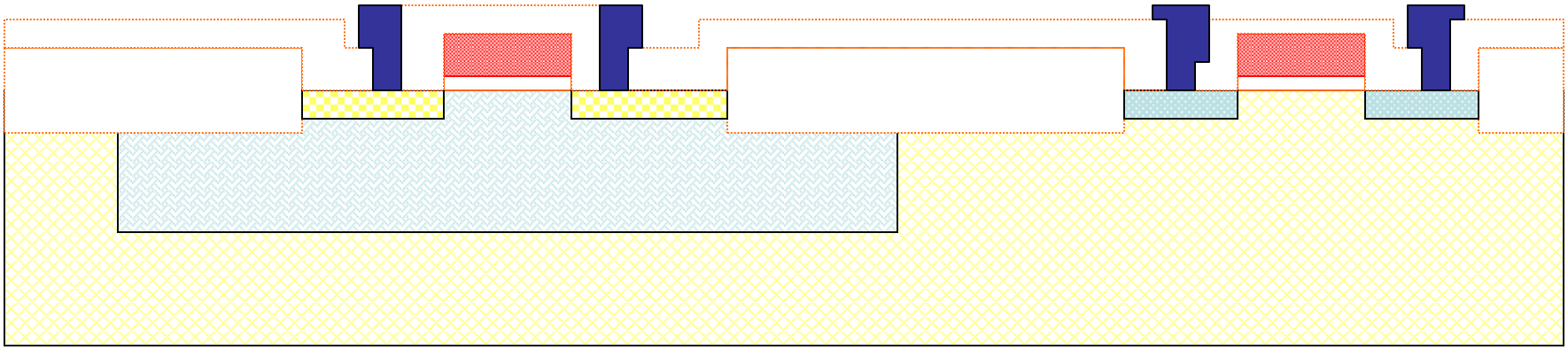

Metal 1 Mask
A
A'
B
B'


Metal 1 Mask
A
A'
B
B'

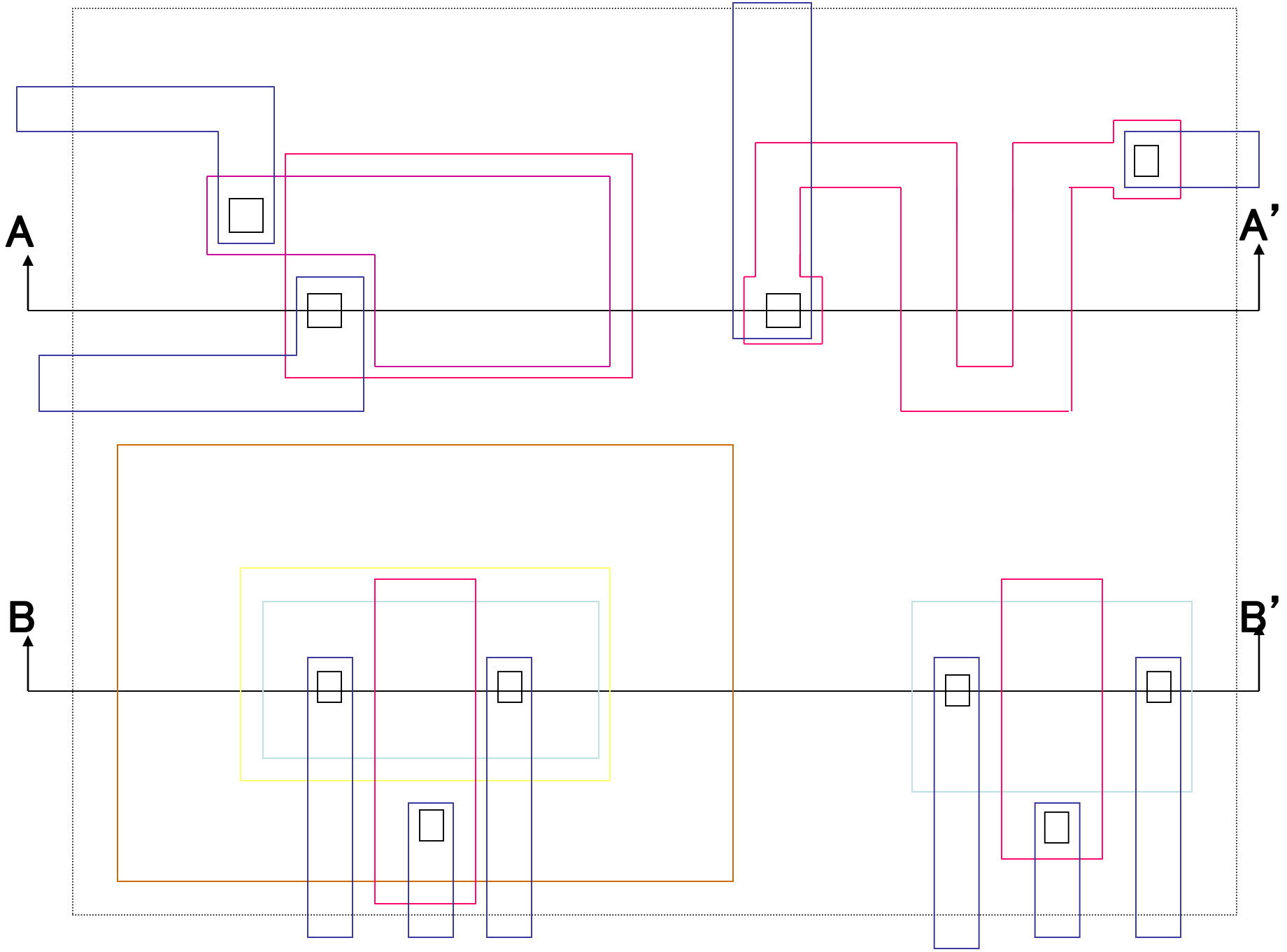
Metal Mask

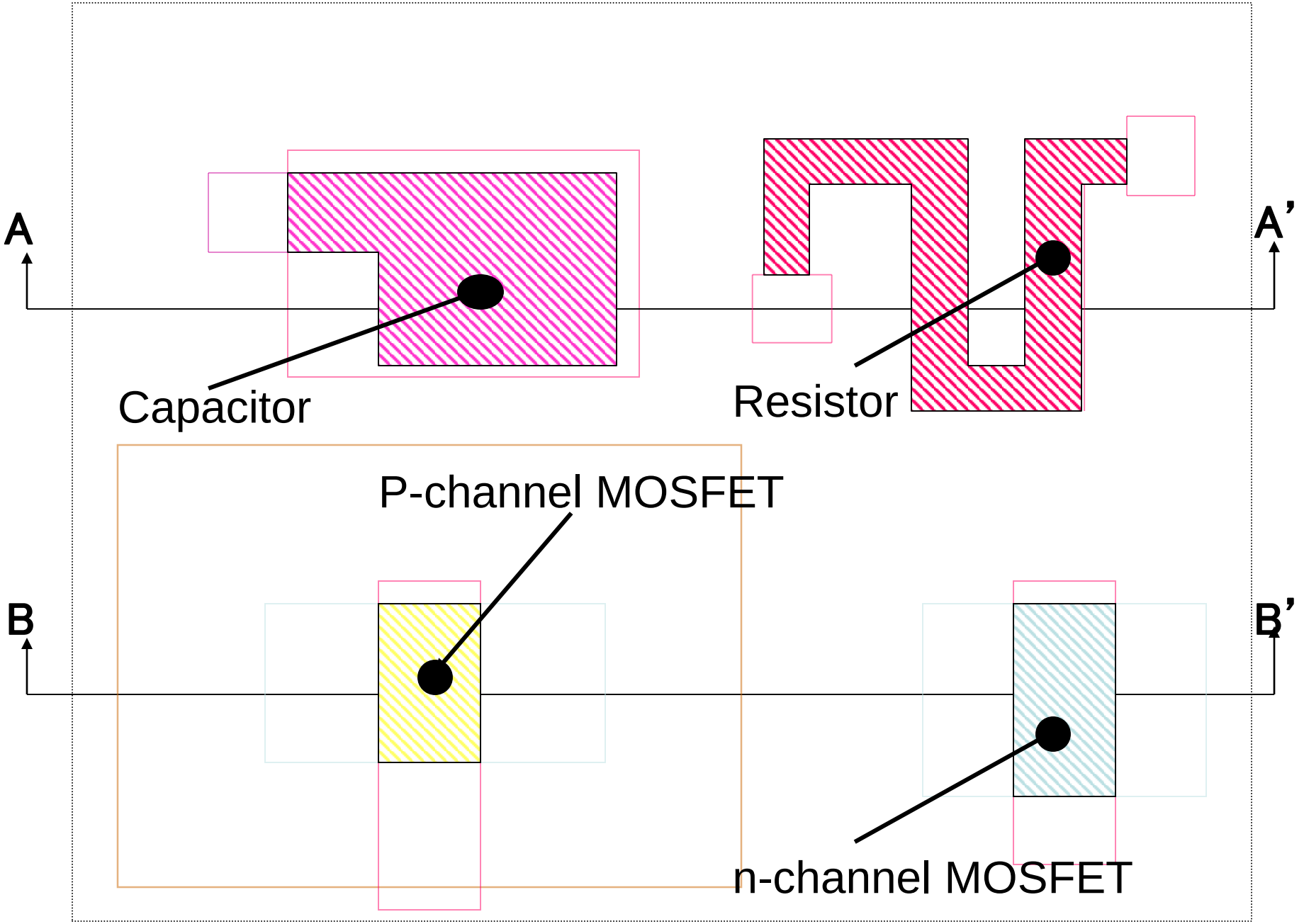


A-A’ Section



B-B’ Section


A
A'
B
B'


A
A'
Capacitor
Resistor
P-channel MOSFET
B
B'
n-channel MOSFET

Should now know what you can do in this process !!

Can metal connect to active?

Can metal connect to substrate when on top of field oxide?

How can metal be connected to substrate?

Can poly be connected to active under gate?

Can poly be connected to active any place?

Can metal be placed under poly to isolate it from bulk?

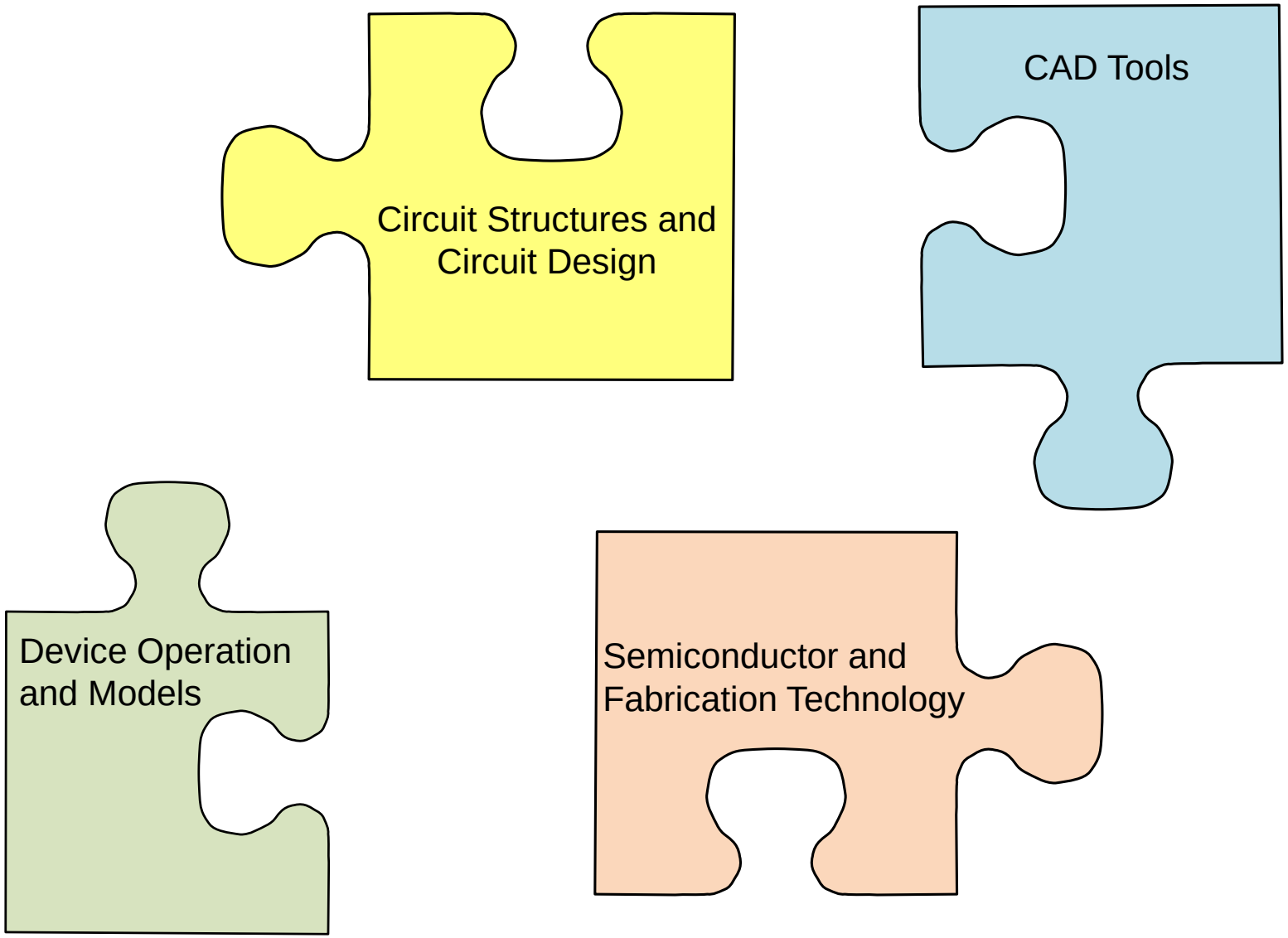
Can metal 2 be connected directly to active?

Can metal 2 be connected to metal 1?

Can metal 2 pass under metal 1?

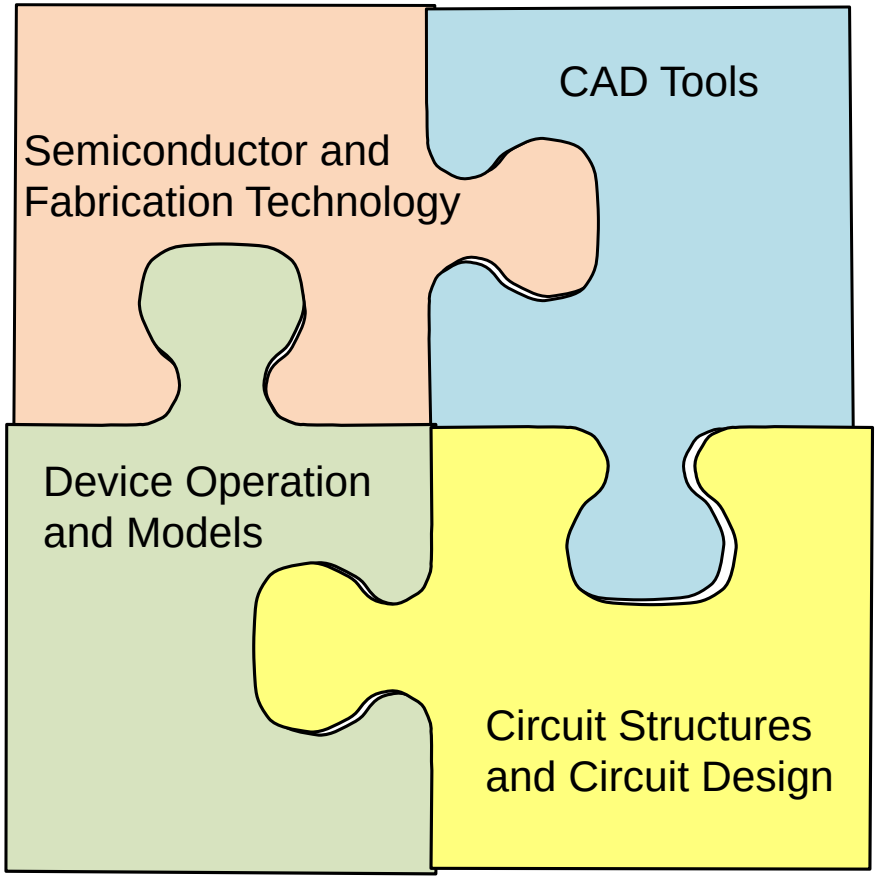
Could a process be created that will result in an answer of YES to most of above?

How we started this course



Thanks for your patience !!

The basic concepts should have now come together



Stay Safe and Stay Healthy !

End of Lecture 18