Member

Conquering Heat Issues in eBeam Lithography – Past, Present and the Future

Noriaki Nakayamada

NuFlare Technology Inc.

April 20th, 2015

Introduction

Heat has been a precious resource

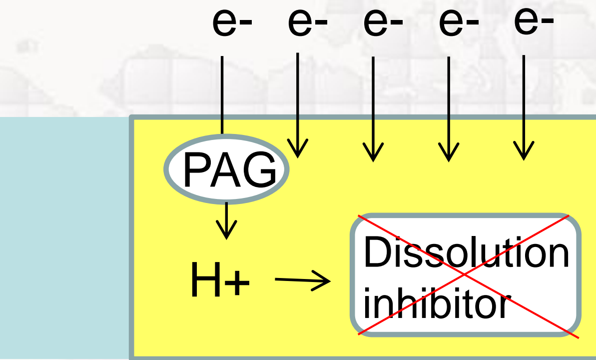
- Since the Greek God Prometheus gave fire to the mankind
- Without heat, you can enjoy only Sashimi, not even Sushi

But too much heat can be also a serious threat for our survival

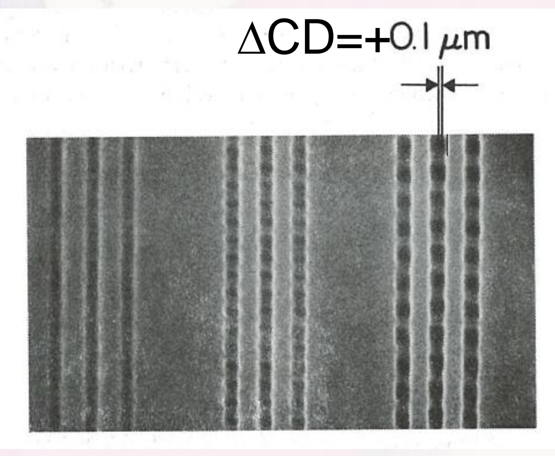
- e.g. global warming

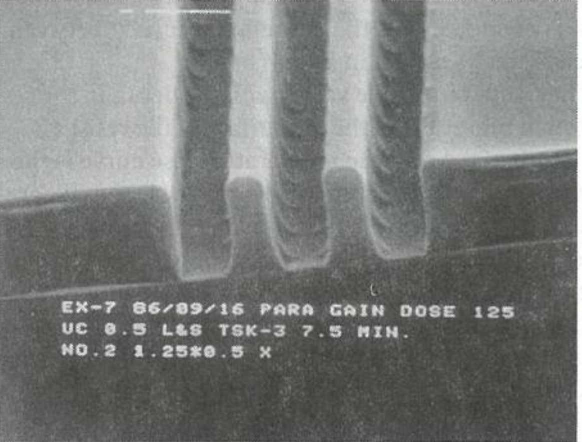
Introduction

- **Heat is also an important resource in ebeam lithography**



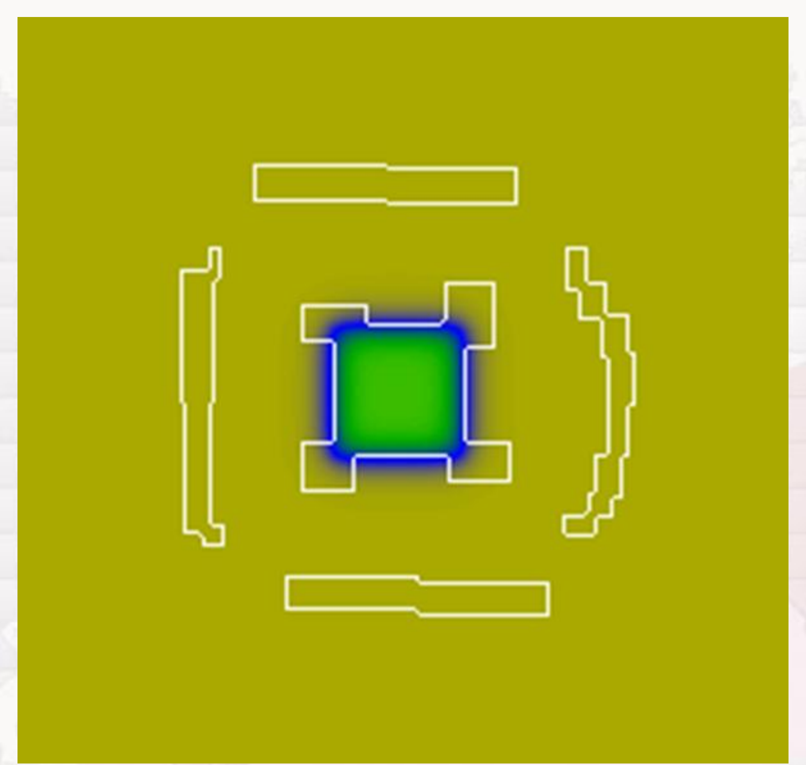
- **Again, too much heat is problematic**

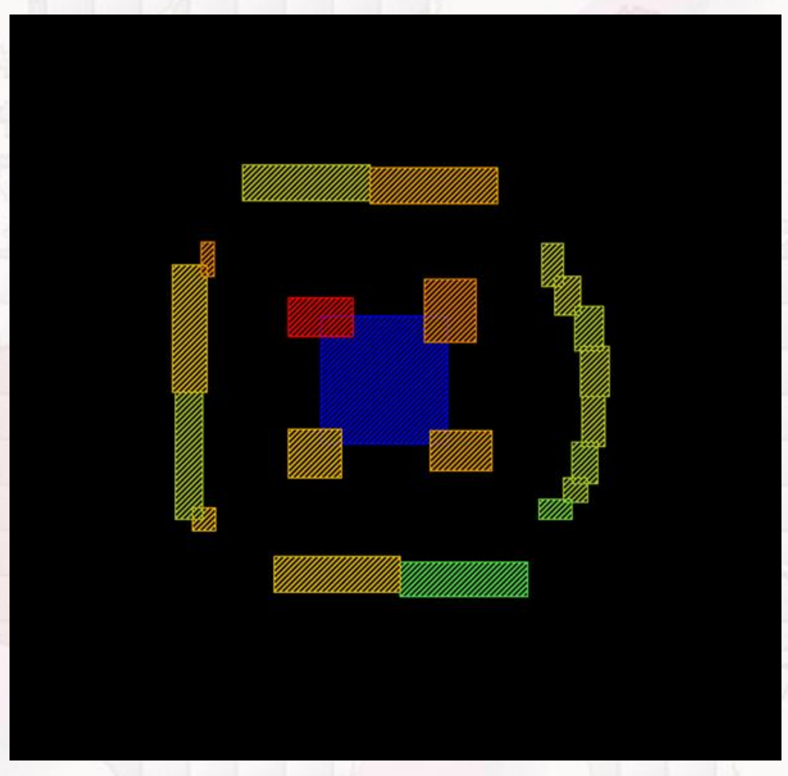




T. Abe et al, “Resist heating effect in direct electron beam writing, JVST-B Vol.6 1988

Inconvenient Truth



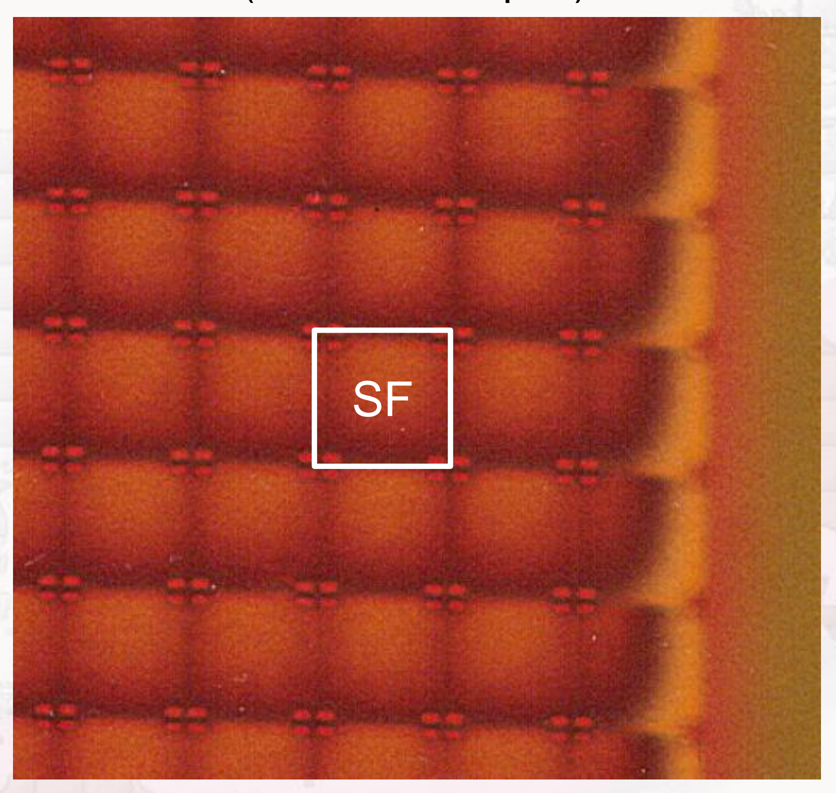


- **Heat transfer from one shot to another causes ‘proximity’ heating effect**

PAST
NuFLARE

Solution in Old Days

EBM-3000, ZEP7000, 10uC/cm^2, 1pass, (under-developed)



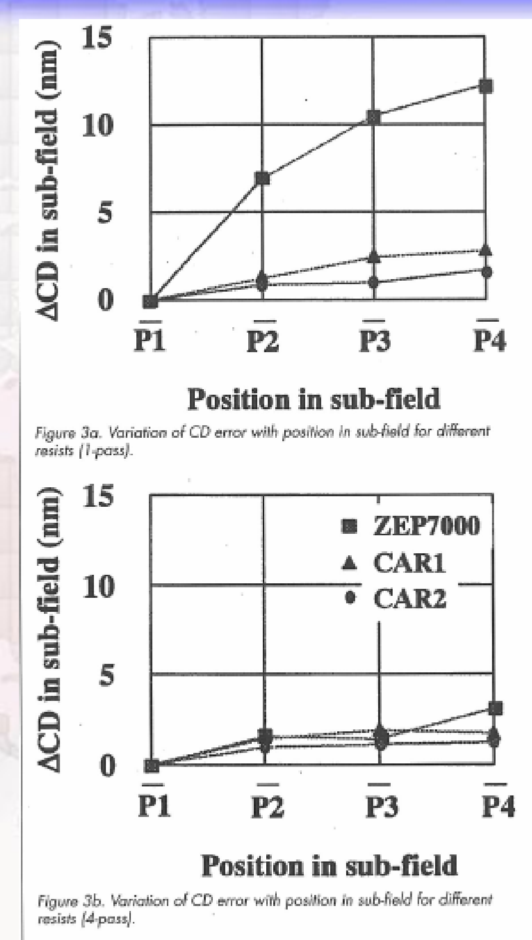


Figure 3a. Variation of CD error with position in sub-field for different resists (1-pass).

Figure 3b. Variation of CD error with position in sub-field for different resists (4-pass).

H. Sakurai et al, "Resist heating effect on 50keV EB mask writing, SPIE 3748, 1999

Solution.1.1 → increase the pass count

Other Solutions

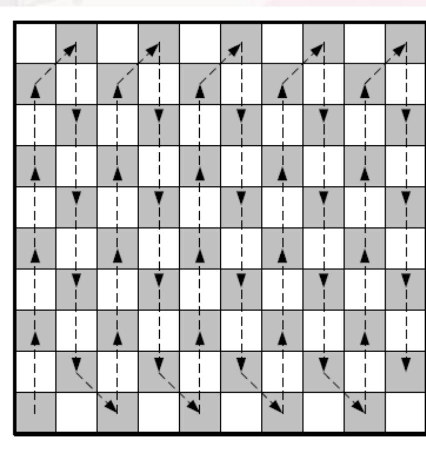
Solution.1.2 well spaced writing order

1	17	33	49	65	81	97	113	129	145	161	177	193	209	225	241
248	8	24	40	56	72	88	104	120	136	152	168	184	200	216	232
239	255	15	31	47	63	79	95	111	127	143	159	175	191	207	223
214	230	246	6	22	38	54	70	86	102	118	134	150	166	182	198
205	221	237	253	13	29	45	61	77	93	109	125	141	157	173	189
180	196	212	228	244	4	20	36	52	68	84	100	116	132	148	164
171	187	203	219	235	251	11	27	43	59	75	91	107	123	139	155
146	162	178	194	210	226	242	2	18	34	50	66	82	98	114	130
137	153	169	185	201	217	233	249	9	25	41	57	73	89	105	121
128	144	160	176	192	208	224	240	256	16	32	48	64	80	96	112
103	119	135	151	167	183	199	215	231	247	7	23	39	55	71	87
94	110	126	142	158	174	190	206	222	238	254	14	30	46	62	78
69	85	101	117	133	149	165	181	197	213	229	245	5	21	37	53
60	76	92	108	124	140	156	172	188	204	220	236	252	12	28	44
35	51	67	83	99	115	131	147	163	179	195	211	227	243	3	19
26	42	58	74	90	106	122	138	154	170	186	202	218	234	250	10

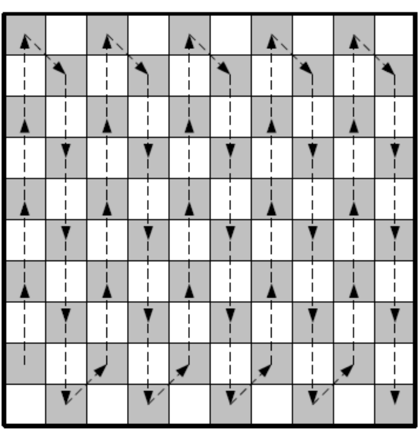
Figure 2. Subfield writing sequence for 16×16 Lagarias scheduling

S. Babin et al, “Resist heating dependence on subfield scheduling in 50kV electron beam maskmaking”, SPIE 5130, 2003

Solution.1.3 alternate subfield writing order



(a)



(b)

Fig. 2. Alternate sub-field order writing. Its first stage (a) and second stage (b).

K. Goto et al, “Reduction of resist heating effect by writing order optimization, part II”, SPIE 6607, 2007

PRESENT

Situation Getting Worse

- **Exposure dose is getting higher**
  - <10uC in ~2005
  - 10~15uC in 2005~2010
  - 15uC~20uC in 2010~2015
  - >20uC in 2015~ → back to non-CAR era
- **Write time is getting longer, so we cannot easily increase the pass count any more**
- **Solution.2 → correct the resist heating effect**

Difficulty in Correction

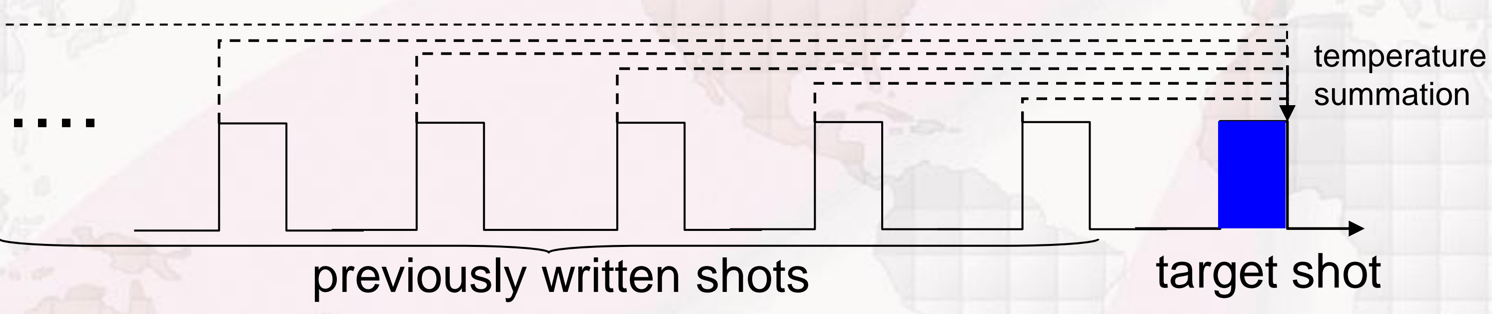
Write time ∝N

$$\text{write time} = \mathrm{N} \times \left(\frac{D}{J} + s \times npass\right) + overhead$$

N: shot count
D: exposure dose
J: current density
s: settling time
npass: pass count

Heating calculation cost ∝N^2

Total calculation cost ∝ 1+2+3+..+(N-1)=N(N-1)/2

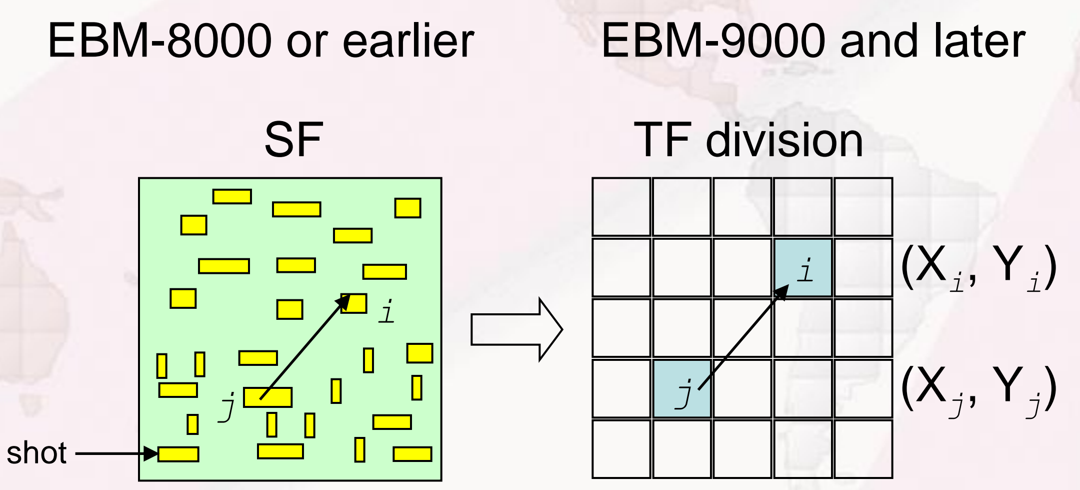


Correction calculation time can rapidly take over the write time

New Solution (1)

Solution.2.1 → correction per tertiary field

- Faster correction can be achieved by per tertiary-field basis, instead of per shot basis
- Tertiary field count is fixed once the die size is fixed. Easier to estimate the maximum (worst) correction time.

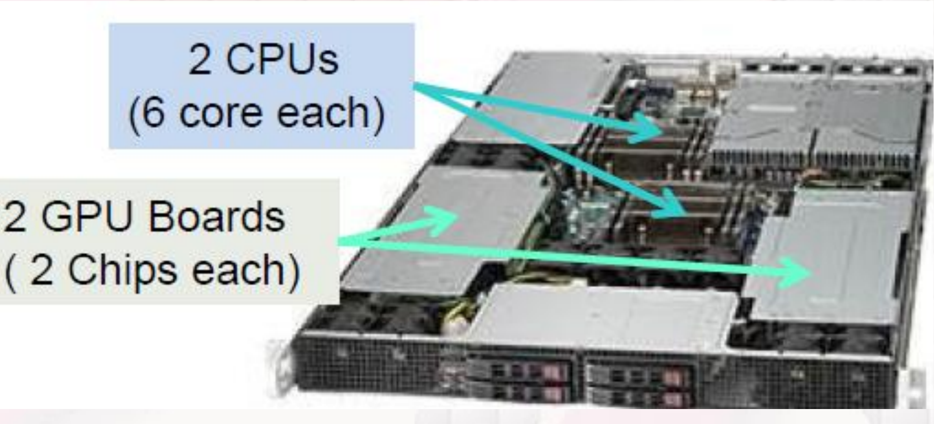


New Solution (2)

Solution.2.2 → GPU technology

Total 350TFlops … ref. ~10PFlops by super computer “Kei” in 2012

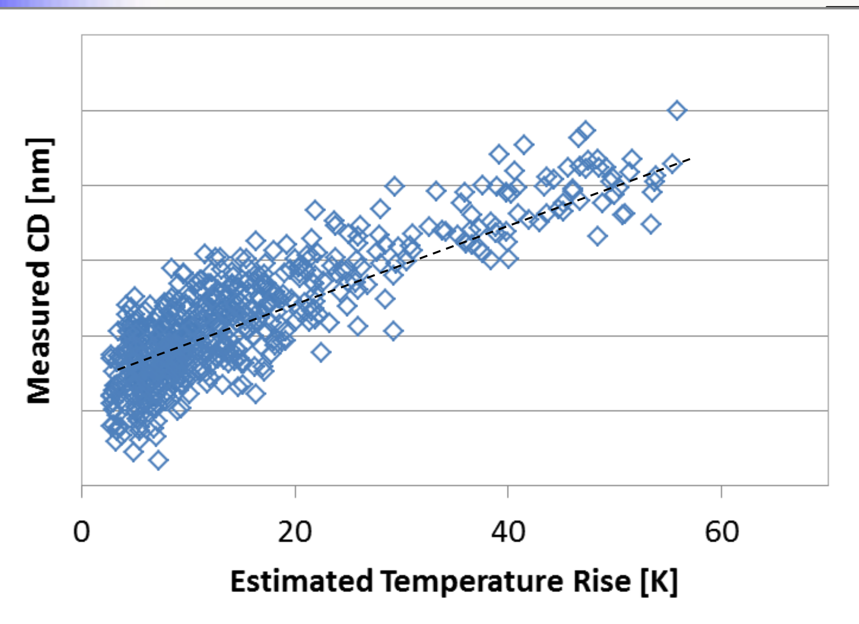
CDP (Computational Design Platform)

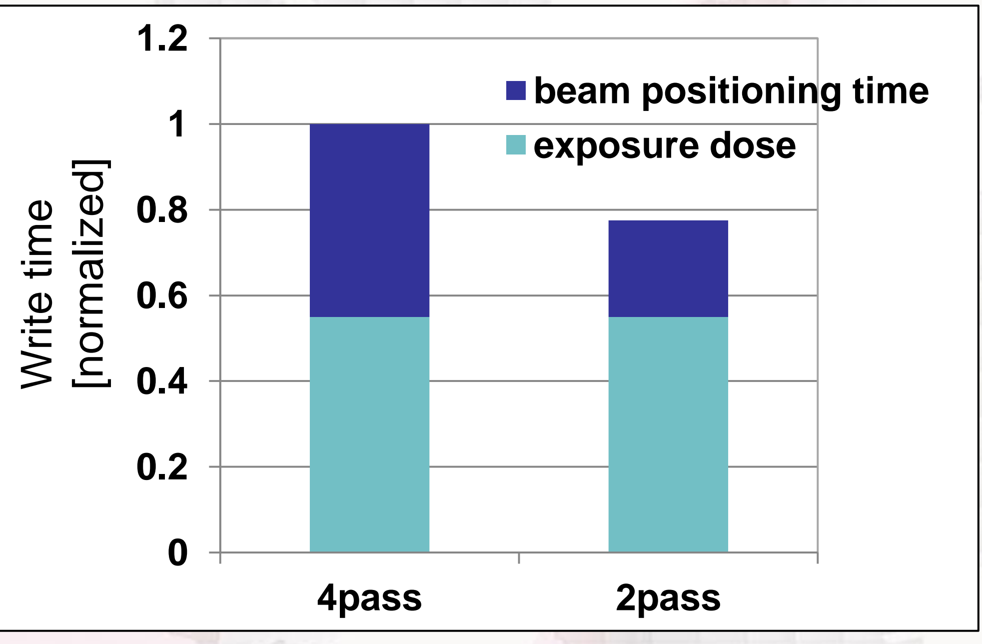


Benefit of Correction

CD benefit

Write time benefit





Condition
Current density : $800\,A/cm^2$, Beam positioning time : $12.8ns$
Resist sensitivity : $50\,uC/cm^2$

- **By applying resist heating correction,**
- **CD error should be reduced by >60%**
- **Write time should be also reduced by >20%**

For More Detail

- **Oral session**
  - 4/21(Tue) 11:50~ Session 4-3
  - M.Suganuma, "Correction of Resist Heating Effect on VSB Mask Writer"
- **Poster session**
  - 4/21(Tue) 17:25~ Poster 7b-1
  - H.Nomura, "Study on Modeling of Resist Heating Effect: Correction in EB Mask Writer, EBM-9000"

FUTURE

MB is the Next Solution

- Multi-beam technology is believed to bring the situation back to old peaceful days by its
- Low current per beamlet and
- Increased pass count

- Further in future, it may be necessary to cope with heating effect correction again even on the multi-beam

Conclusion

- **NuFlare and D2S have developed resist heating correction system**
- **This technology brings benefits in both**
  - Better CD control and
  - Higher throughput with reduced pass count
- **Resist heating effect has been present since the beginning of ebeam lithography, but its correction has been finally realized by the power of GPU cluster**
- **We will introduce this new correction for EBM-9500 and EBM-9000 upgrade**