

Multi-Domain Data Integration for Plasma Diagnostics in Semiconductor Manufacturing using Tri-Cycle GAN

Minji Kang^{1,2,†}, Sung Kyu Jang^{3,†}, Jihun Kim³, Seongho Kim^{1,2}, Changmin Kim⁴, Hyo-Chang Lee⁵, Wooseok Kang^{1,6}, Min Sup Choi², Hyeongkeun Kim^{3,*}, Hyeong-U Kim^{1,7,*}

¹Semiconductor Manufacturing Research Center, Korea Institute of Machinery and Materials (KIMM), Daejeon 34103, Republic of Korea; kmj0302@kimm.re.kr (M.K.), kimho6433@kimm.re.kr (S.K.), kang@kimm.re.kr (W.K.),

²Department of Materials Science and Engineering, Chungnam National University (CNU), Daejeon 34134, Republic of Korea

³Electronic Convergence Material and Device Research Center, Korea Electronics Technology Institute, Seongnam 13509, Republic of Korea; skjang@keti.re.kr (S.K.J.), kjh96@keti.re.kr (J.K.)

⁴Memory Etch Technology Team, Samsung Electronics, Pyeongtaek 17786, Republic of Korea; cm3.kim@samsung.com (C.K.)

⁵School of Electrical and Computer Engineering, Korea Aerospace University (KAU), Goyang 10540, Republic of Korea; plasma@kau.ac.kr (H.-C.L.)

⁶Mechanical Engineering, KIMM Campus, University of Science & Technology (UST), Daejeon 34113, Republic of Korea

⁷Nano-Mechatronics, KIMM Campus, University of Science & Technology (UST), Daejeon 34113, Republic of Korea

*Correspondence: faithkim99@keti.re.kr (H.K.); guddn418@kimm.re.kr (H.-U.K.)

[†]These authors contributed equally to this work.

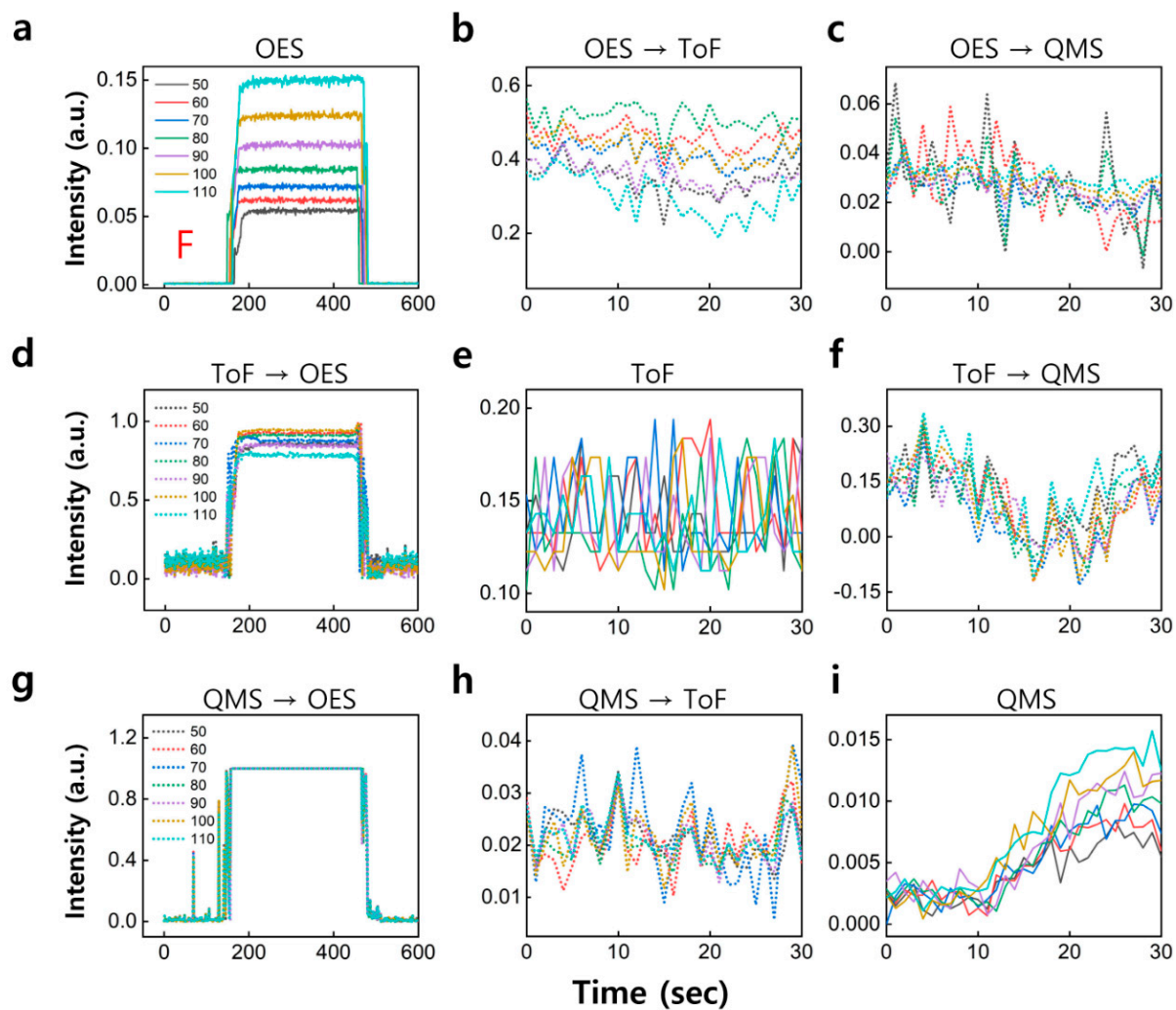


Figure S1. Multi-domain transformations of F-radical data across OES, ToF-MS, and QMS diagnostic techniques using the Tri-CycleGAN model. Each row corresponds to a different original domain: OES (a-c), ToF-MS (d-f), and QMS (g-i), while each column represents the target domain for transformation: OES, ToF-MS, and QMS, respectively. Diagonal subplots (a, e, i) show the real data from each domains, while off-diagonal subplots illustrate transformed data in the target domains. Solid lines indicate real data, and dashed lines represent transformed data.

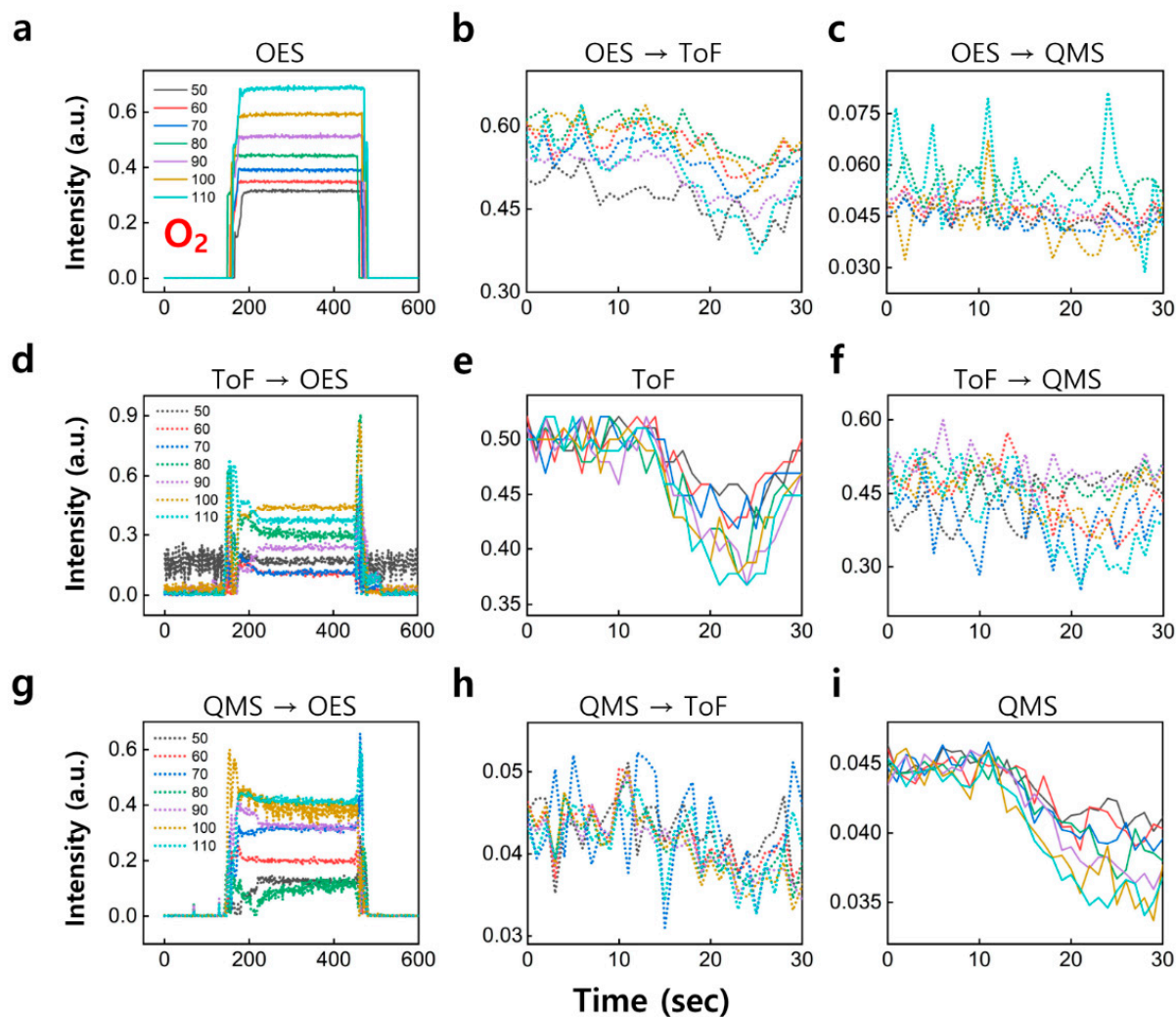


Figure S2. Multi-domain transformations of O_2 data across OES, ToF-MS, and QMS diagnostic techniques using the Tri-CycleGAN model. Each row corresponds to a different original domain: OES (a-c), ToF-MS (d-f), and QMS (g-i), while each column represents the target domain for transformation: OES, ToF-MS, and QMS, respectively. Diagonal subplots (a, e, i) show the real data from each domains, while off-diagonal subplots illustrate transformed data in the target domains. Solid lines indicate real data, and dashed lines represent transformed data.

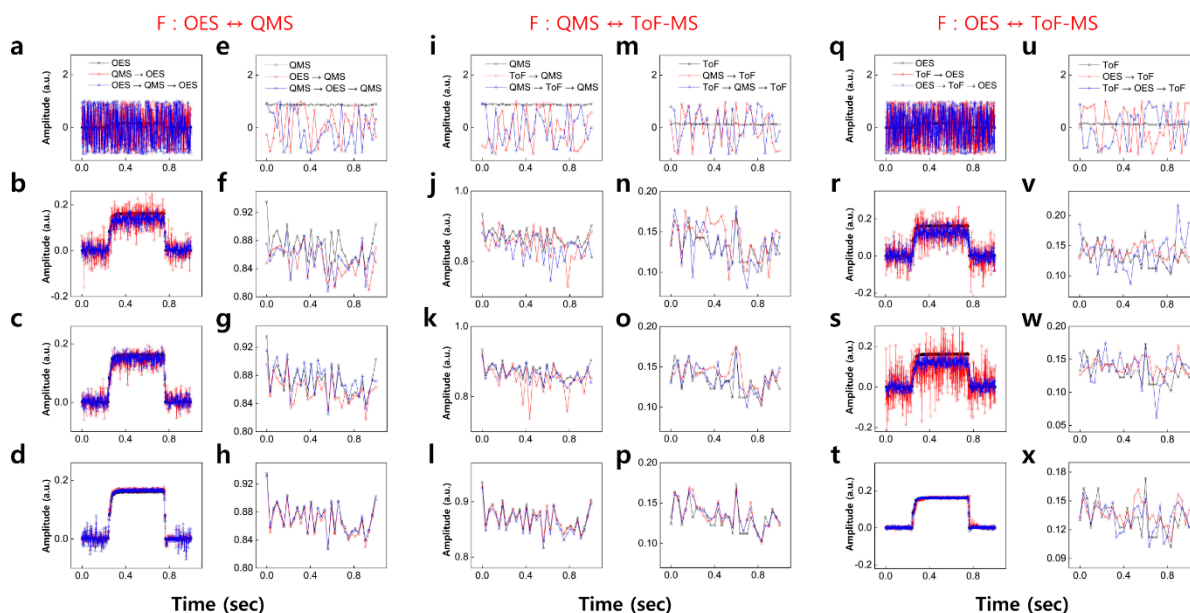


Figure S3. Training progress of the Tri-CycleGAN model for F-radical data transformations across the OES, QMS, and ToF-MS domains. Sections (a-h), (i-p), and (q-x) show transformations between OES and QMS, QMS and ToF-MS, and OES and ToF-MS domains, respectively. Columns represent different training stages: initial state (epoch 0), epoch 500, epoch 1000, and the fully trained model. In each plot, black lines show the real data, red lines indicate generated data, and blue lines represent reconstructed data

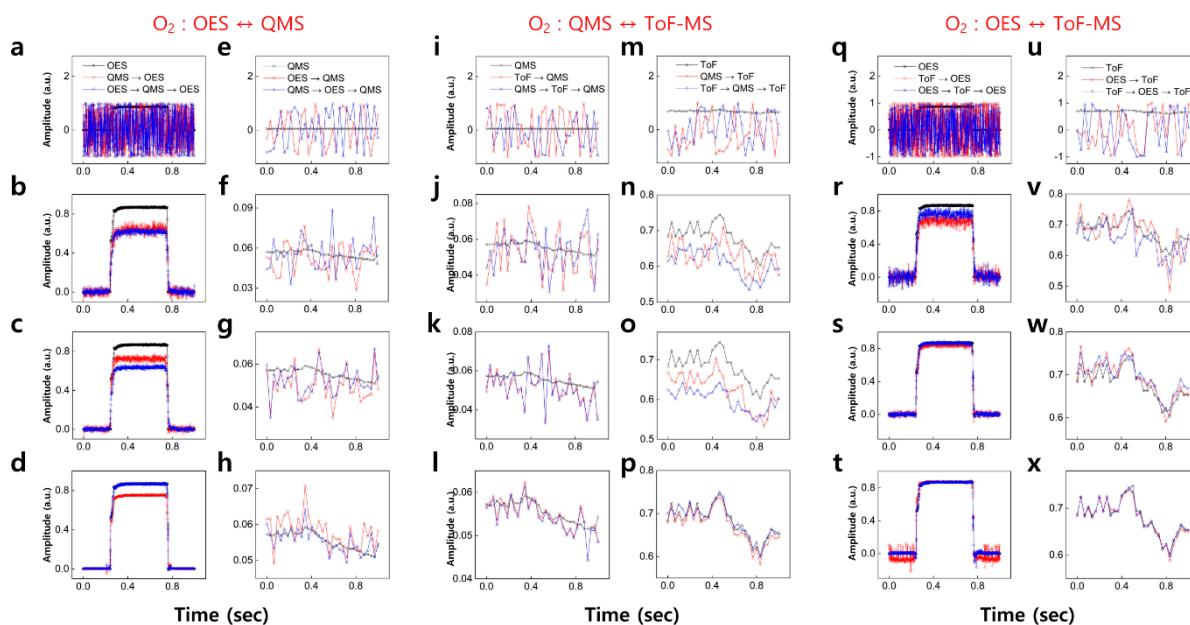


Figure S4. Training progress of the Tri-CycleGAN model for O₂ data transformations across the OES, QMS, and ToF-MS domains. Sections (a-h), (i-p), and (q-x) show transformations between OES and QMS, QMS and ToF-MS, and OES and ToF-MS domains, respectively. Columns represent different training stages: initial state (epoch 0), epoch 500, epoch 1000,

and the fully trained model. In each plot, black lines show the real data, red lines indicate generated data, and blue lines represent reconstructed data

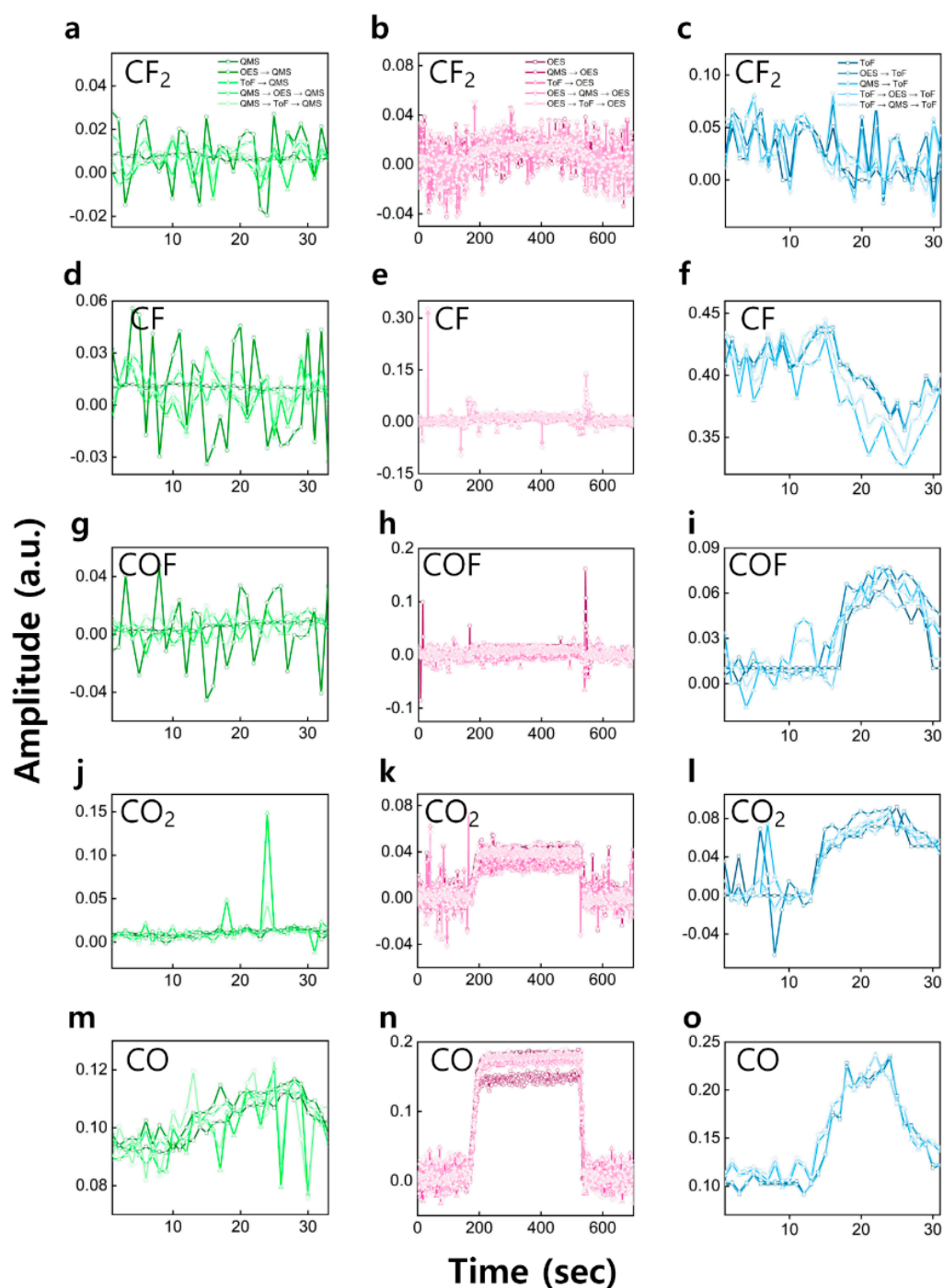


Figure S5. Comparison of real data, generated data from different source domains and the reconstructed data from different transformation pathways for CF_2 , CF , COF , CO_2 , and CO across OES, ToF-MS, and QMS domains.

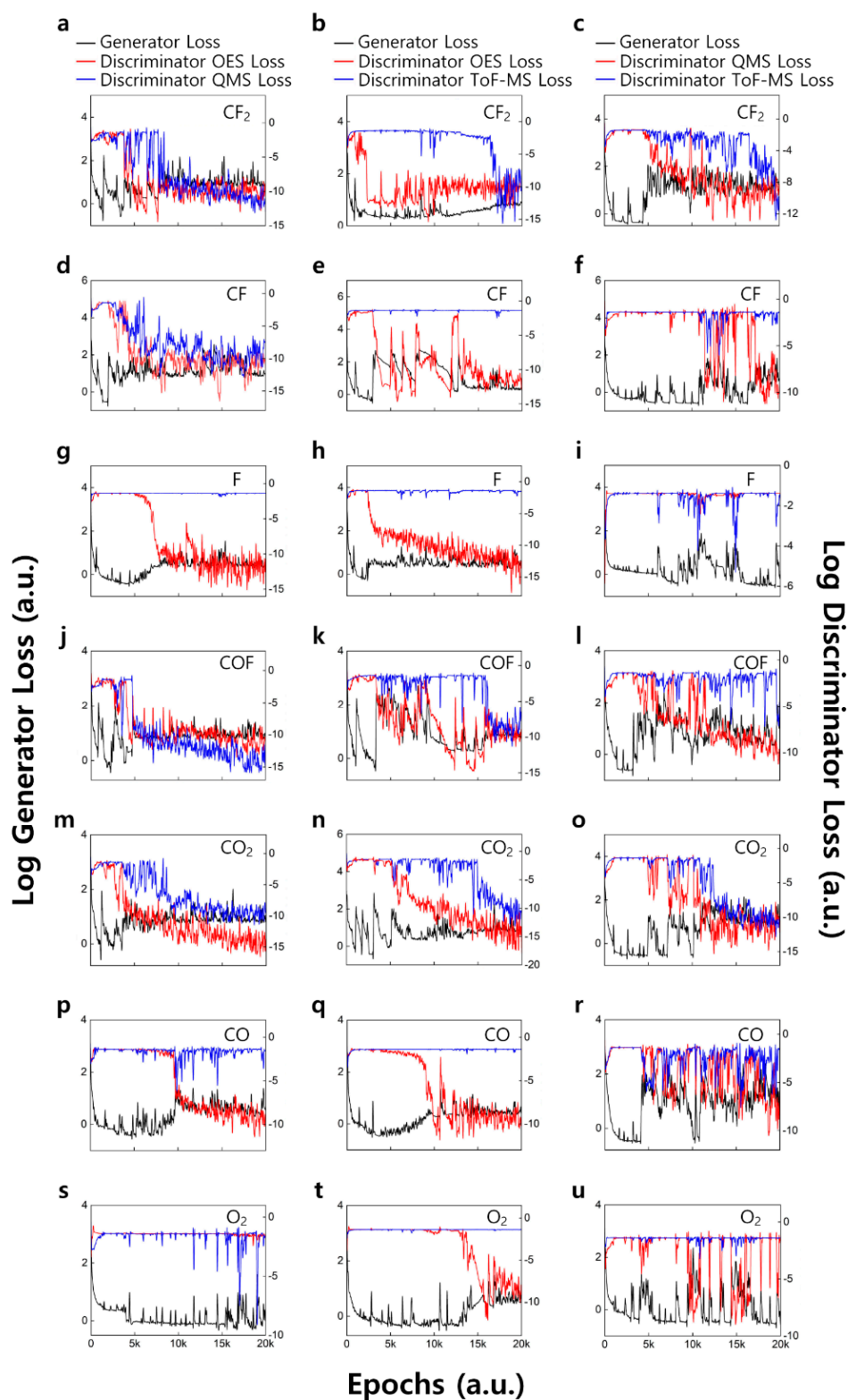


Figure S6. Logarithmic changes in the loss functions during the training process of the Tri-CycleGAN model. The left y-axis shows the generator loss, while the right y-axis displays the discriminator loss.