

Investigation of the Reliability of Nano- Crystalline Ni/Nb based Multilayer Thin Films Deposited on Polymer Substrates for Flexible Electronic Applications

Rahul Sahay^{1,7*}, Yen-Cheng Tu², Izzat Aziz³, Arief S. Budiman^{1,4,5,6*}, Cher Ming Tan², Pooi

See Lee³, Olivier Thomas⁷ and Nagarajan Raghavan^{8*}

SUPPLEMENTARY MATERIALS

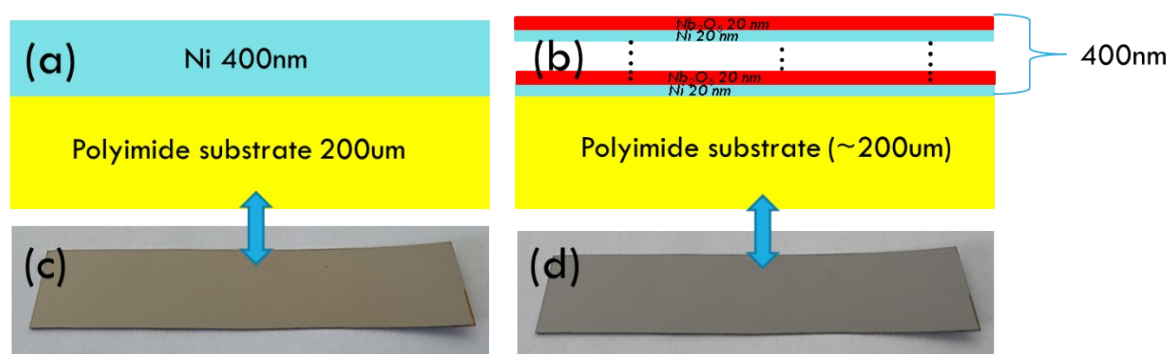


Figure. S1. The structure of the samples (a) Nickel/PI and (b) Nickel-Niobium oxide/PI (Ni-Nb₂O₅-PI), where 20 alternate layers (thickness = 20 nm) of Ni and Niobium oxide (Nb₂O₅) were deposited on PI.

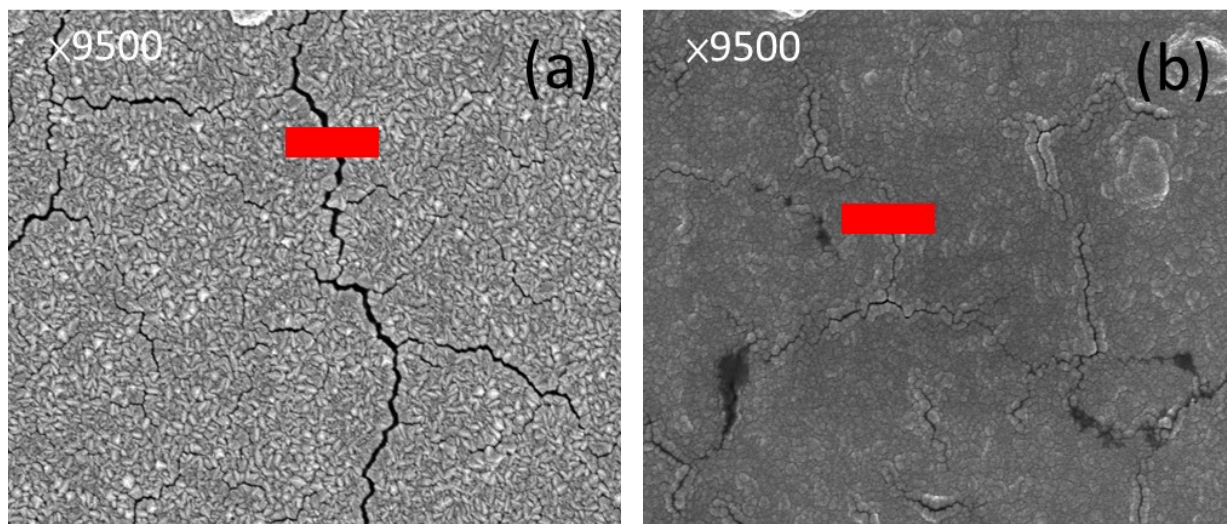


Figure S2. Location of the surface crack on the sample used for the fabrication of lamella through focused-ion beam (FIB). FIB lamella was cut perpendicular to surface cracks for (a) Ni-PI and (b) Ni-Nb₂O₅-PI. The images showing the cross-sectional TEM profiles of each of these samples can be found in Figures 4 to 6 of the main manuscript.

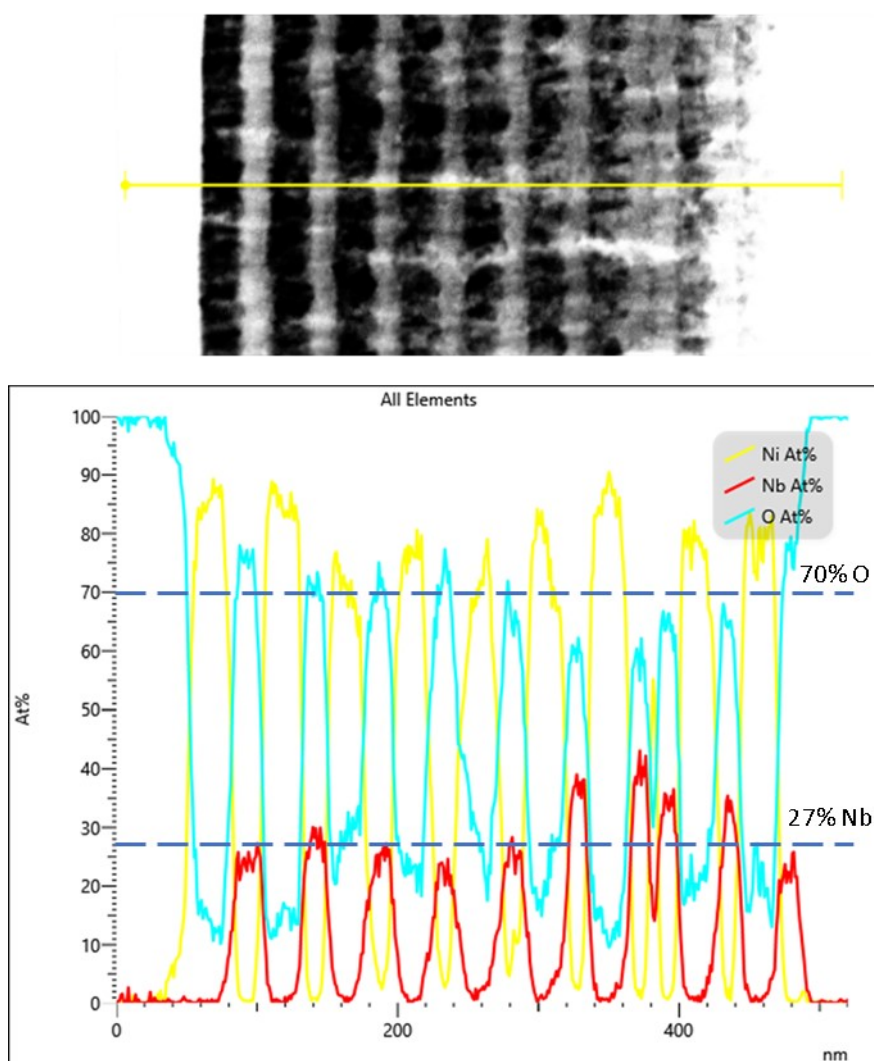


Figure S3. EDX along the cross-section of the Ni-Nb₂O₅-PI shows the presence of oxygen (O), nickel (Ni) as well as niobium (Nb) in the nanolayers. The presence of Ni is confirmed by the yellow line (at% ranging from ~77% to ~92%). The space between the alternate yellow line roughly depicts the thickness of Ni nanolayers. The green (at% ranging from ~62% to ~78%) and red (at% ranging from ~36% to ~44%) line represent O and Nb, respectively, which depict the presence of Nb₂O₅ based on at% calculations, discussed in detail in the main text.

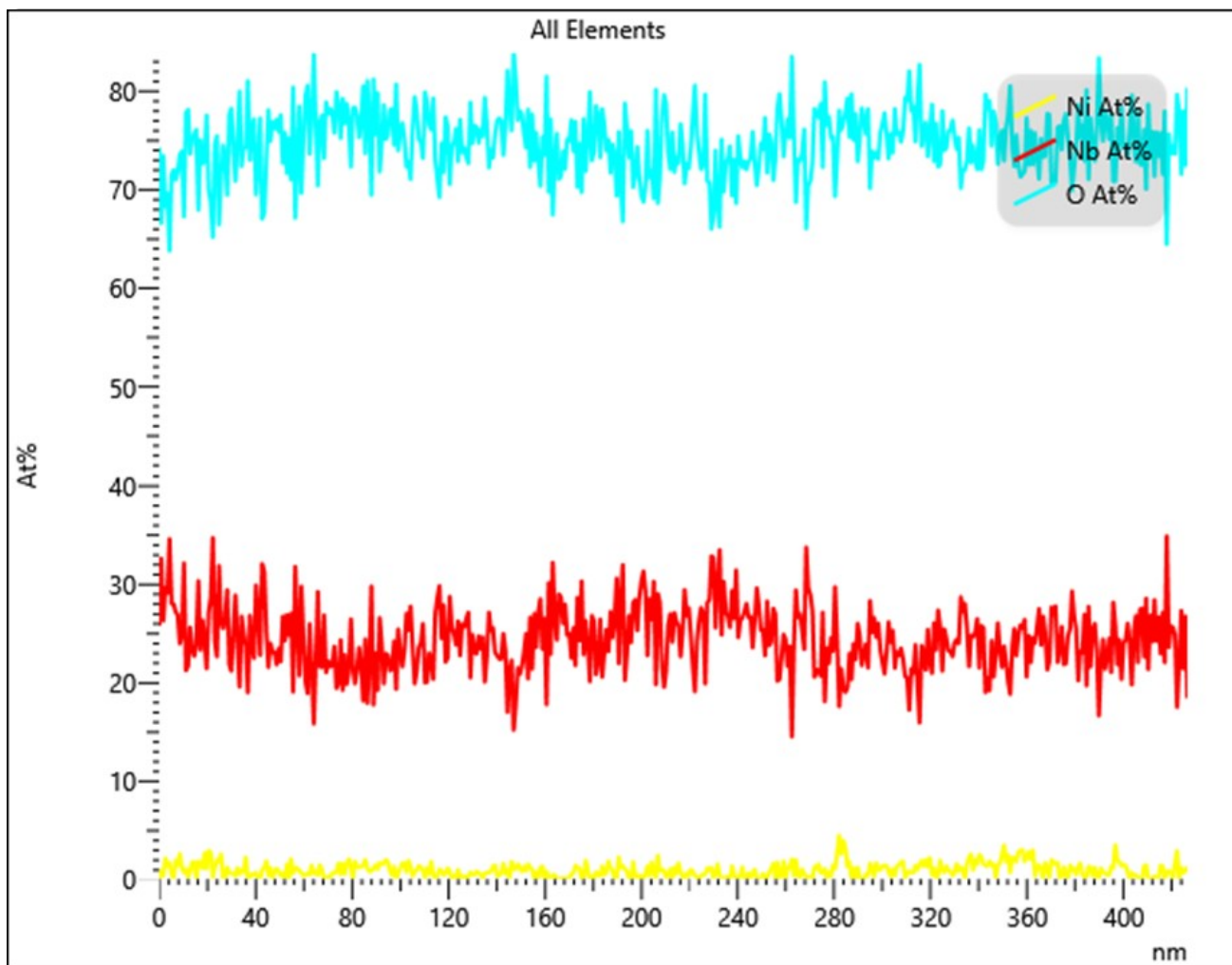
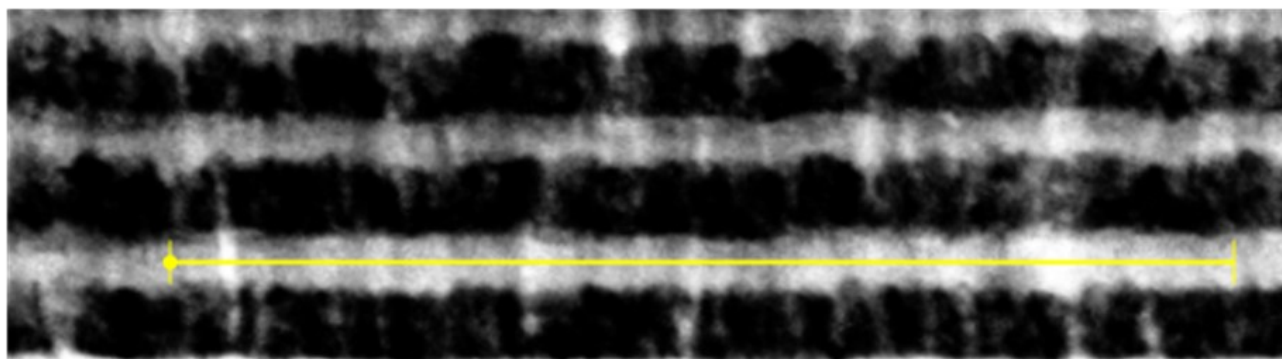


Figure S4. EDX line scan along the amorphous layer of the Ni-Nb₂O₅-PI shows the presence of oxygen (O) as well as niobium (Nb) in the amorphous layer depicting the formation of niobium oxide (Nb₂O₅).

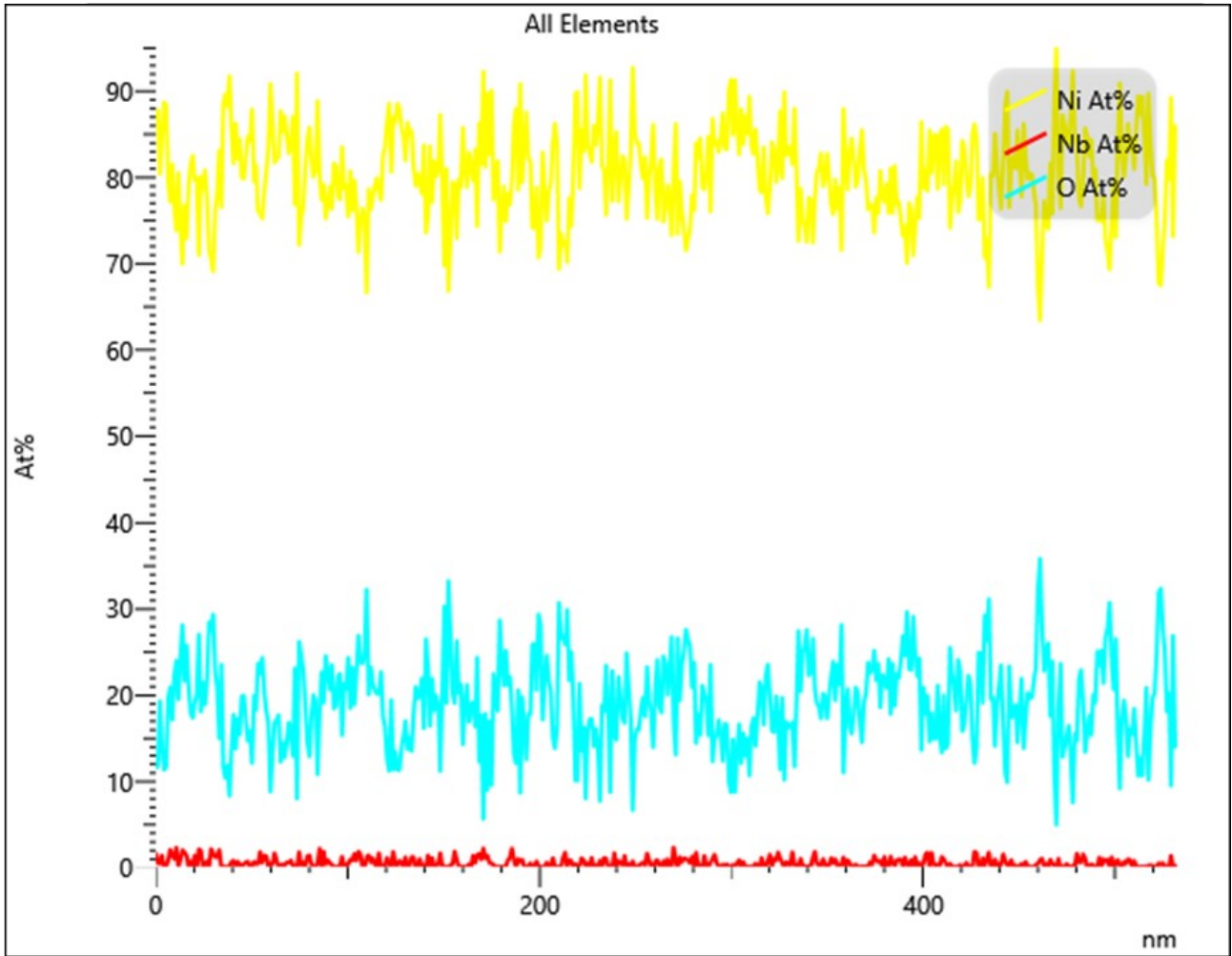
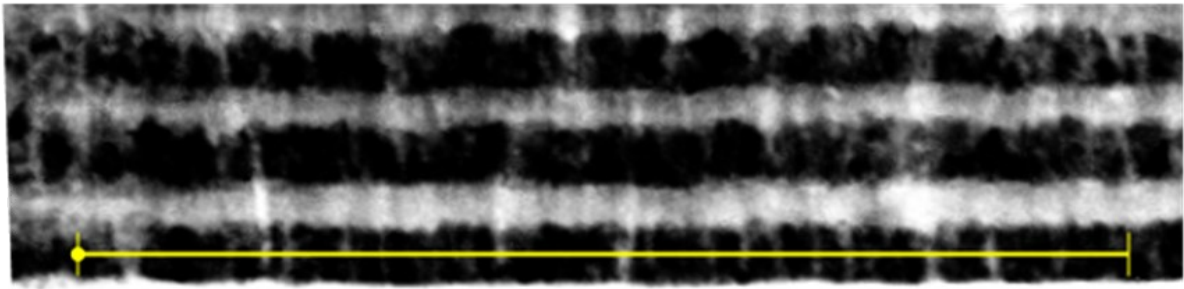


Figure S5. EDX line scan along the crystalline layer of the Ni-PI sample shows the presence of mainly Ni and a negligible proportion of Nb and O.

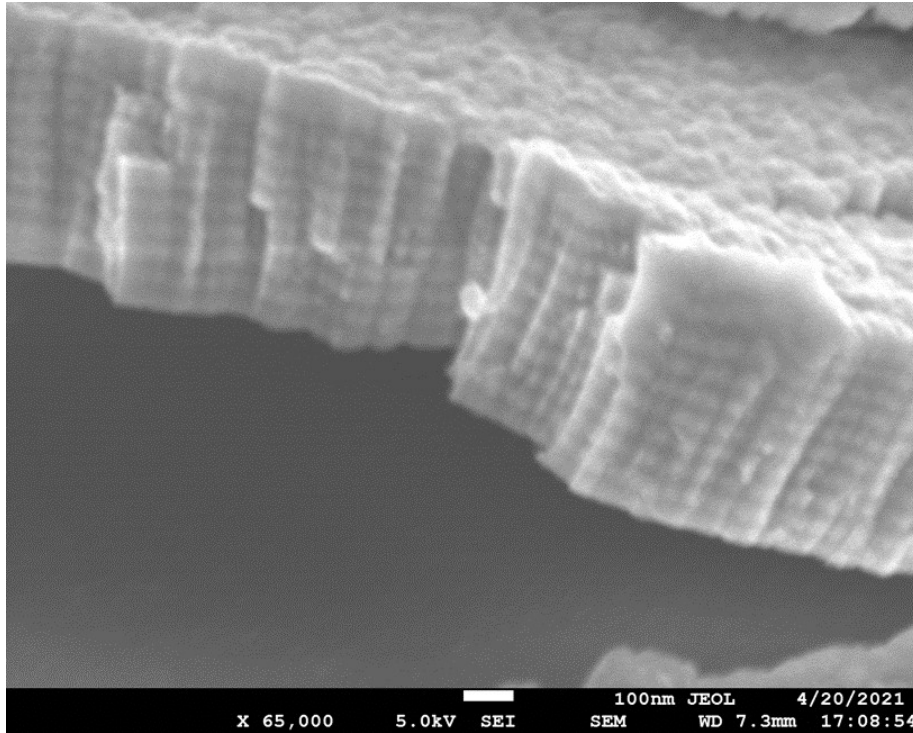


Figure S6. SEM image of Ni-Nb₂O₅-PI sample showing its columnar cross-section obtained after rate-dependent bending failure/fracture test.

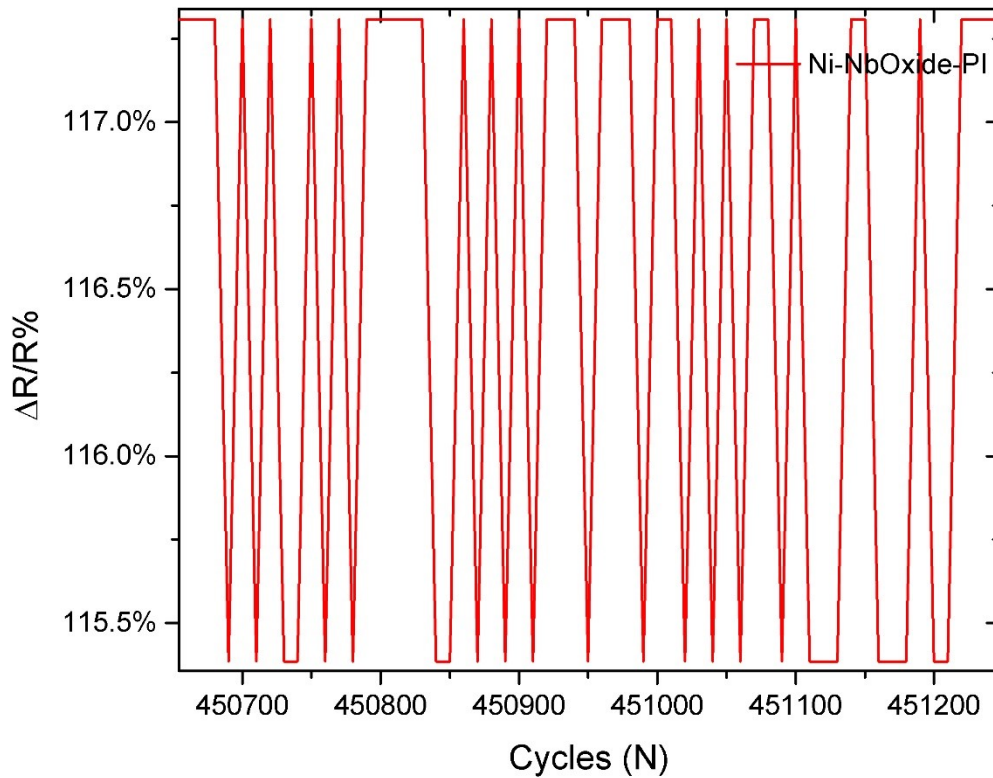


Figure S7. The $\Delta R/R\%$ of Ni-Nb₂O₅-PI as a function of loading cycles depicting the variation of initial resistance oscillation peaks (shown by a dotted box in Figure 2(a)).

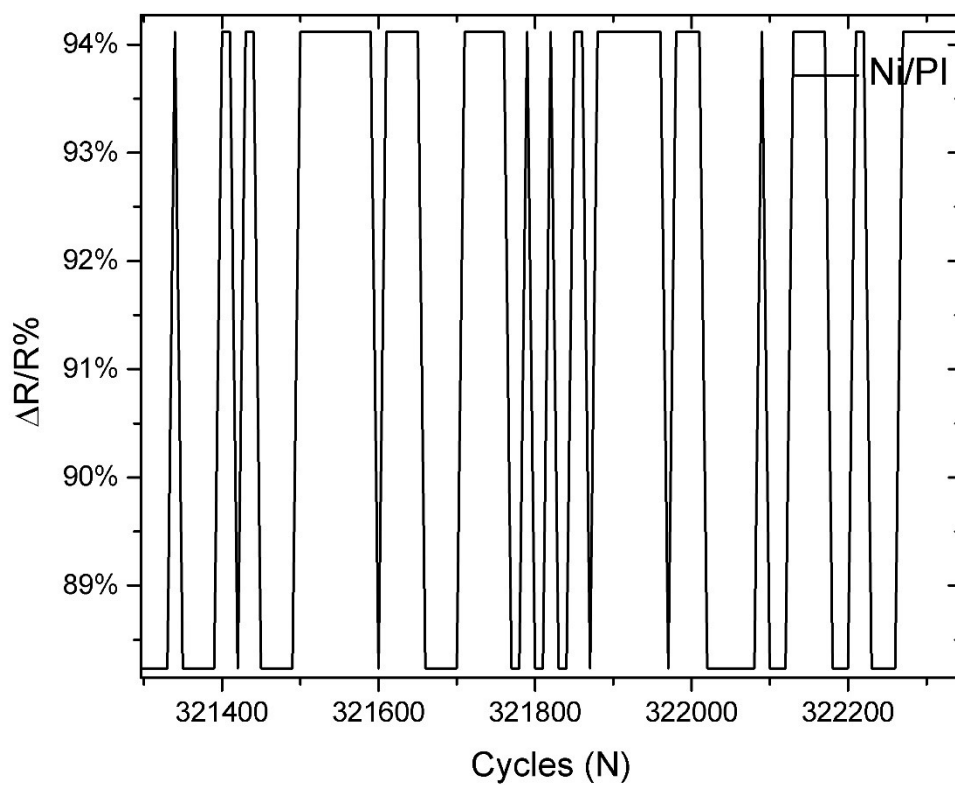


Figure S8. The $\Delta R/R\%$ of Ni-PI as a function of loading cycles depicting the variation of initial resistance oscillation peaks (shown by a dotted box in Figure 2(a)).

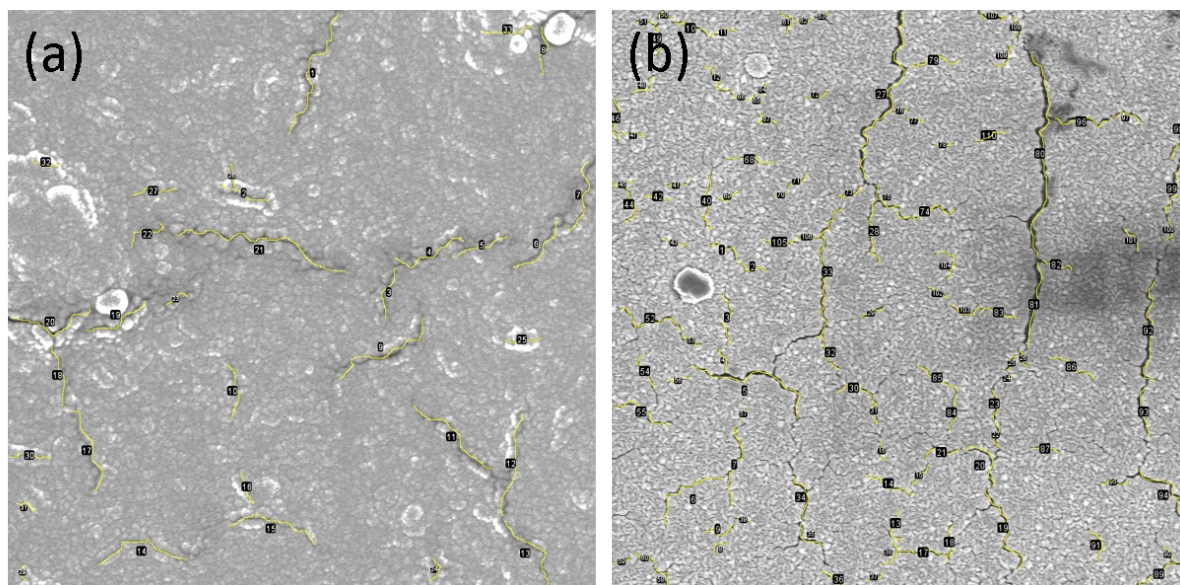


Figure S9. Representative image showing crack density and crack dimensions of the (a) Ni-Nb₂O₅-PI sample and (b) Ni-PI sample measured with *ImageJ* image processing software.

