Supplementary Material:

Direct Bonding of 6-inch SiC/Si Wafer with Enhanced Thermal Interface

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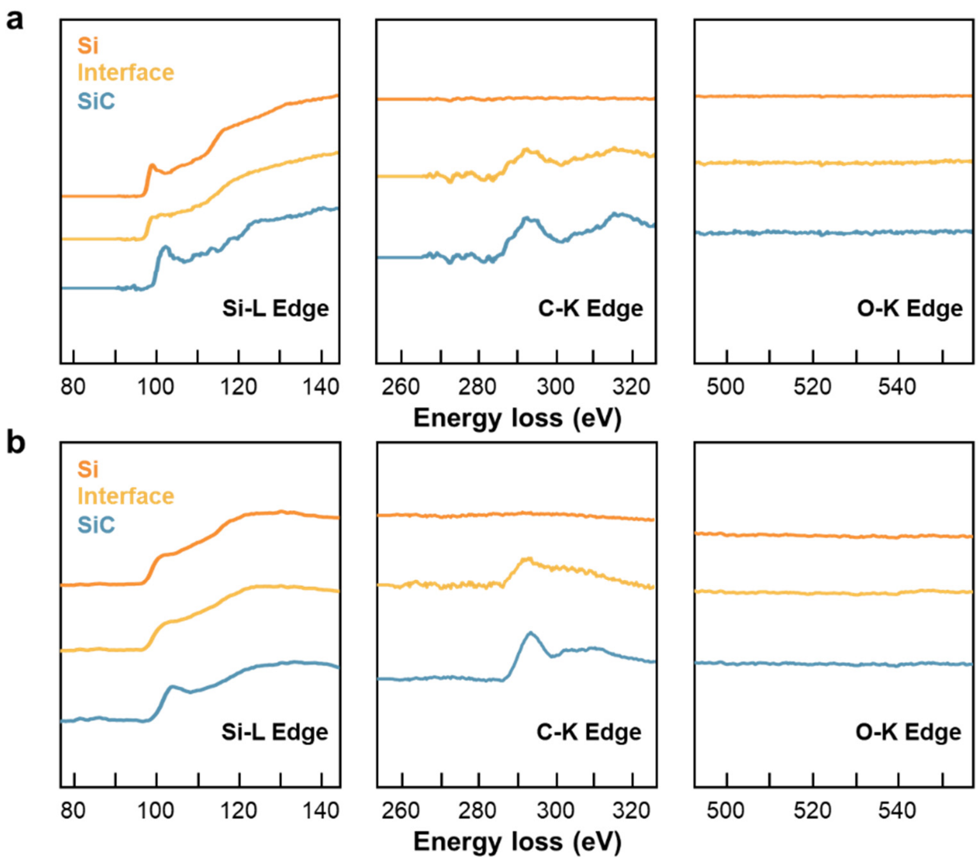

Fig. S1 | EELS elemental analysis of the SiC/Si interface. a, Unannealing and **b,** annealing EELS spectras of 4H-SiC/Si.Spectras are collected for the Si-L edge, C-K edge, and O-K edge in both samples. The results reveal no detectable SiO_2 characteristic signals at the Si-L edge, confirming the absence of oxidation at the interface. Additionally, C signals are observed in the interface region and on the SiC side at the C-K edge. Most importantly, no oxygen signals are detected at the O-K edge. These findings demonstrate that the Surface Activated Bonding (SAB) process successfully achieves a high-quality, oxygen-free SiC/Si bonded interface, effectively mitigating oxidation issues associated with conventional wet chemical processes and plasma activation. This result establishes a strong foundation for high-stability heterogeneous integration.

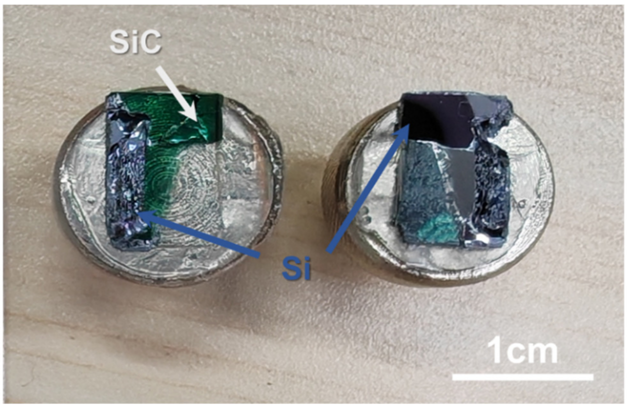

Fig. S2 | Image of 4H-SiC/Si sample after bonding strength testing. Notably, failure does not occur entirely at the SiC/Si interface. Instead, in some cases, fractures are observed within the Si bulk, suggesting that the measured bond strength likely underestimates the actual bonding strength.

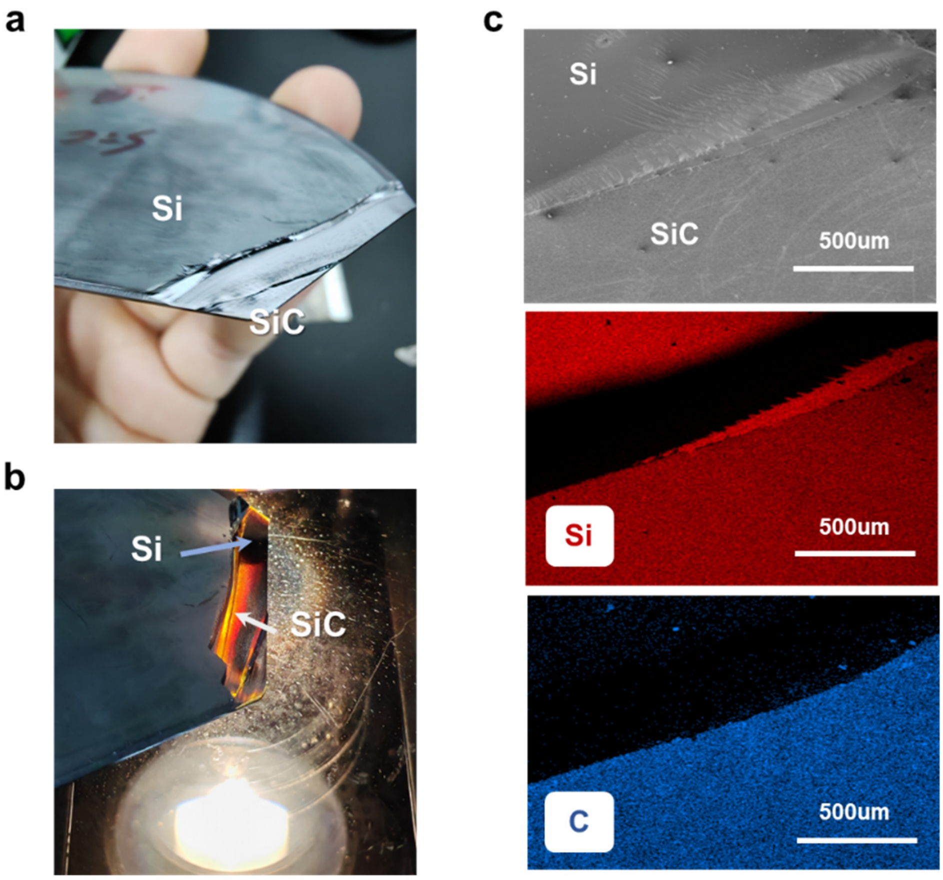

Fig. S3 | Characterization of annealed 4H-SiC/Si samples following bonding strength testing. a, Image of the annealed sample after blade insertion testing**,** where the bond is too strong to allow accurate measurement of the bonding energy.**b,** Optical transparency assessment of the sample. When exposed to strong light, SiC, as a theoretically transparent material, transmits the color of the light source. However, certain regions that are expected to be SiC show partial opacity due to residual Si, further confirming its presence at the bonding interface. **c,** EDS characterization of the annealed sample. Note: Black regions in the EDS map correspond to areas where signal acquisition is not possible due to surface morphology variations. However, this does not affect the confirmation of the heterojunction's chemical composition.

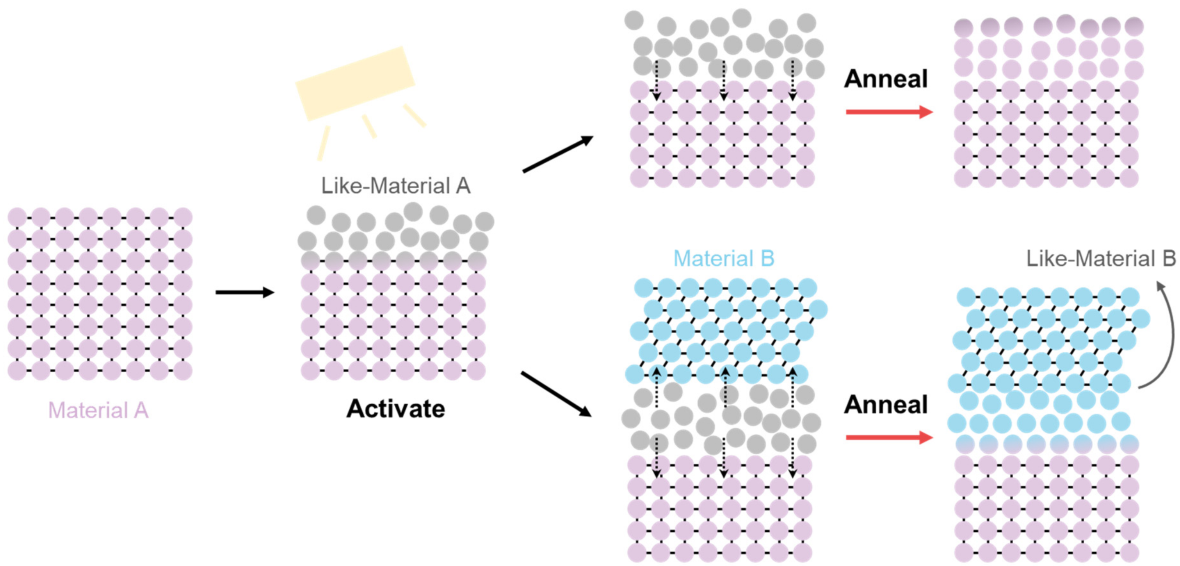

Fig. S4 | Schematic model of interfacial lattice evolution under annealing. Upon activation, the surface of material A becomes covered by a structurally similar layer (like-material A). In the absence of material B, annealing leads to the preservation of material A's original crystal phase, as indicated by the mechanism pathway above. In contrast, in heterojunction systems, the presence of material B—with a distinct crystal structure—drives a phase transformation during annealing, converting the surface layer of material A into a structure resembling material B (like-material B). At the 4H-SiC/Si interface, this transformation results in the formation of a 3C-SiC transition layer from an initially amorphous SiC region, thereby modulating interfacial properties, as illustrated in the mechanism pathway below.

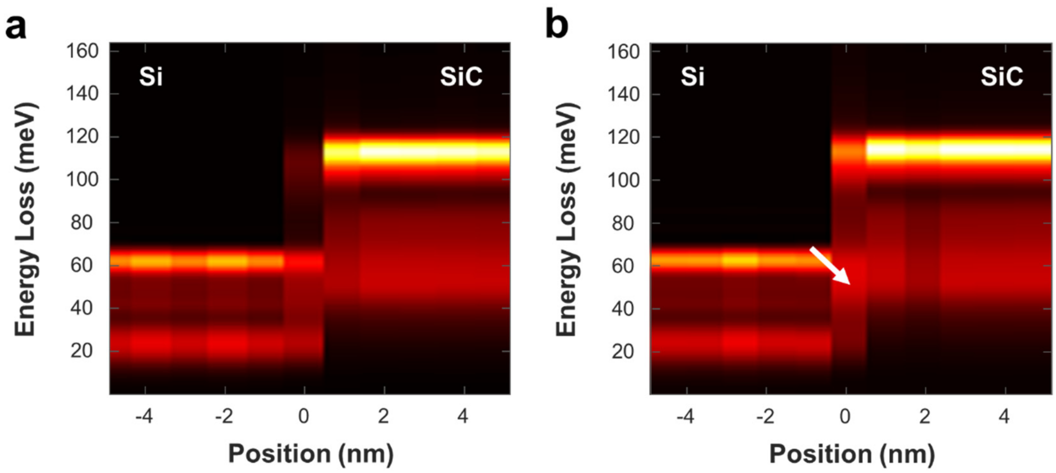

Fig. S5 | Molecular dynamics simulations of the interfacial phonon spectra. a, 4H-SiC/Si system. **b,** 4H-SiC/3C-SiC/Si system , where the thickness of the 3C-SiC layer is modeled as six atomic layers based on experimental data. By comparing the phonon simulation results of both systems, we observe that the 4H-SiC/3C-SiC/Si system exhibits stronger interface vibration modes, which is consistent with the experimental findings. The introduction of 3C-SiC establishes an effective connection within the SiC/Si system, providing sufficient interface modes to facilitate cross-interface energy transport via inelastic scattering, thereby enhancing thermal performance.