

Electronic Supplementary Information for

Facile Synthesis of High-entropy Alloy Nanoparticles on Germanane, Ge Nanoparticles and Wafers

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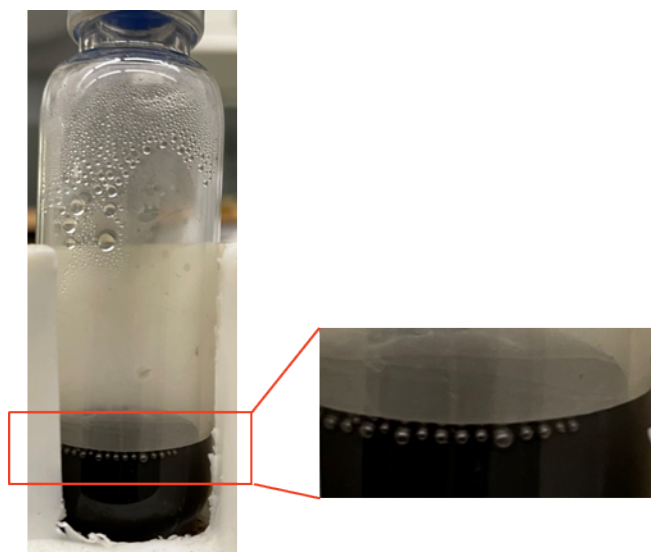


Figure S1. Photograph of the reaction forming HEA NPs@GeNSs showing evolution of hydrogen bubbles.

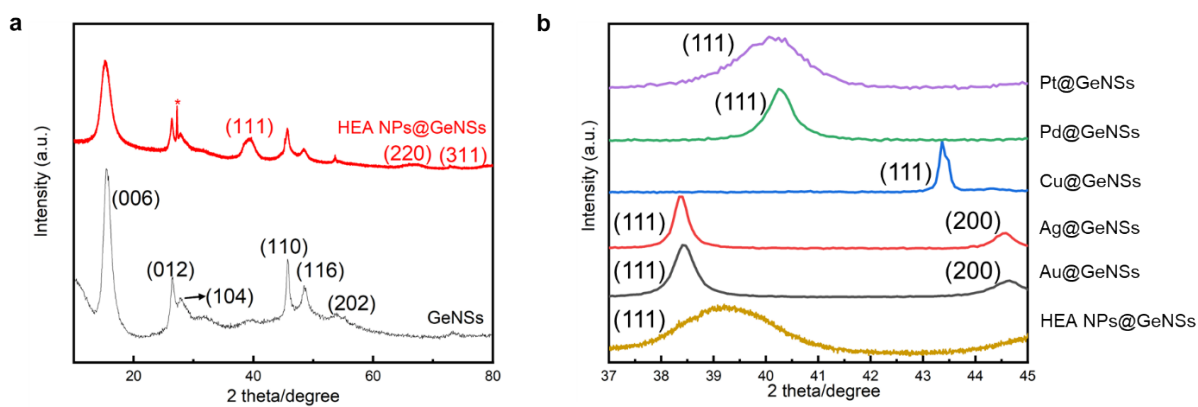


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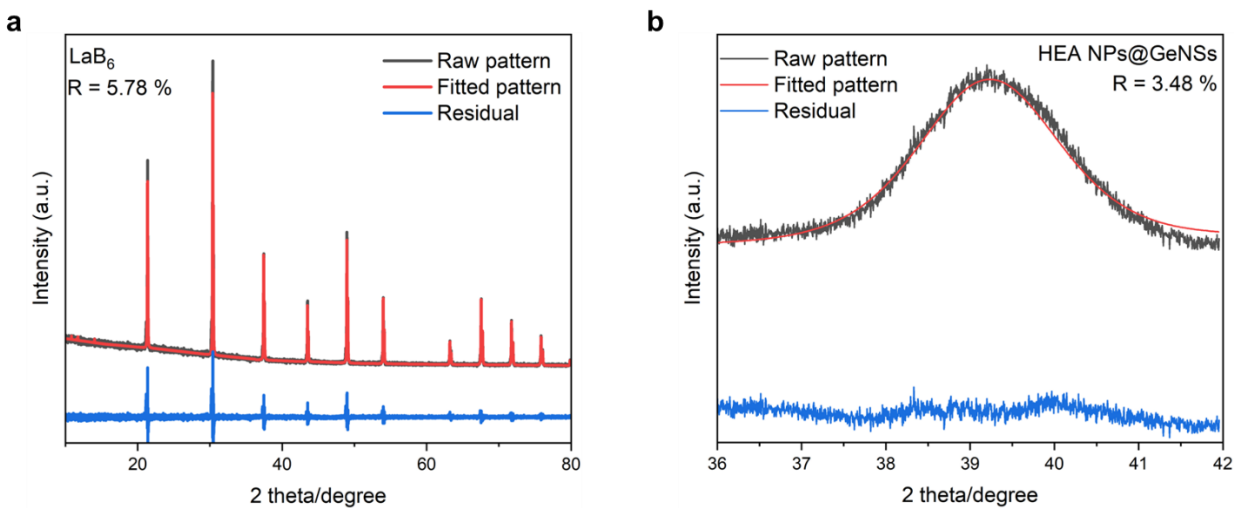


Figure S3. XRD patterns and corresponding fitting results for (a) LaB₆ standard sample, and (b) the (111) reflection in the laboratory-based X-ray diffraction pattern for HEA NPs@GeNSs corresponding to an HEA nanocrystal domain size of 5.5 nm.

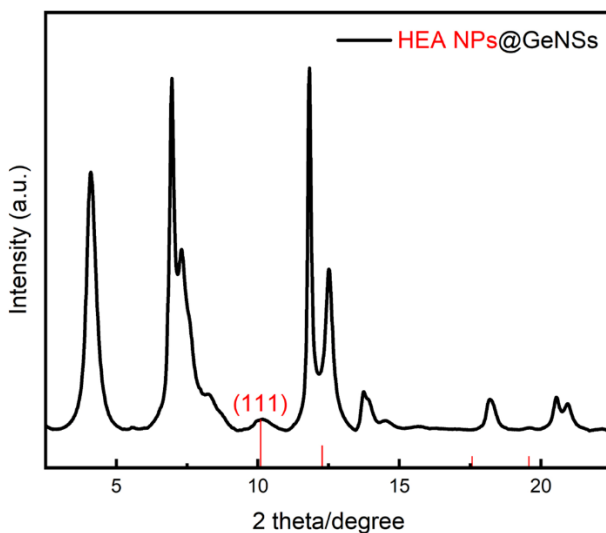


Figure S4. Synchrotron XRD ($\lambda = 0.40867 \text{ \AA}$) pattern of HEA NPs@GeNSs exhibiting the (111) reflections from the HEA NPs and other intense reflections from GeNSs.

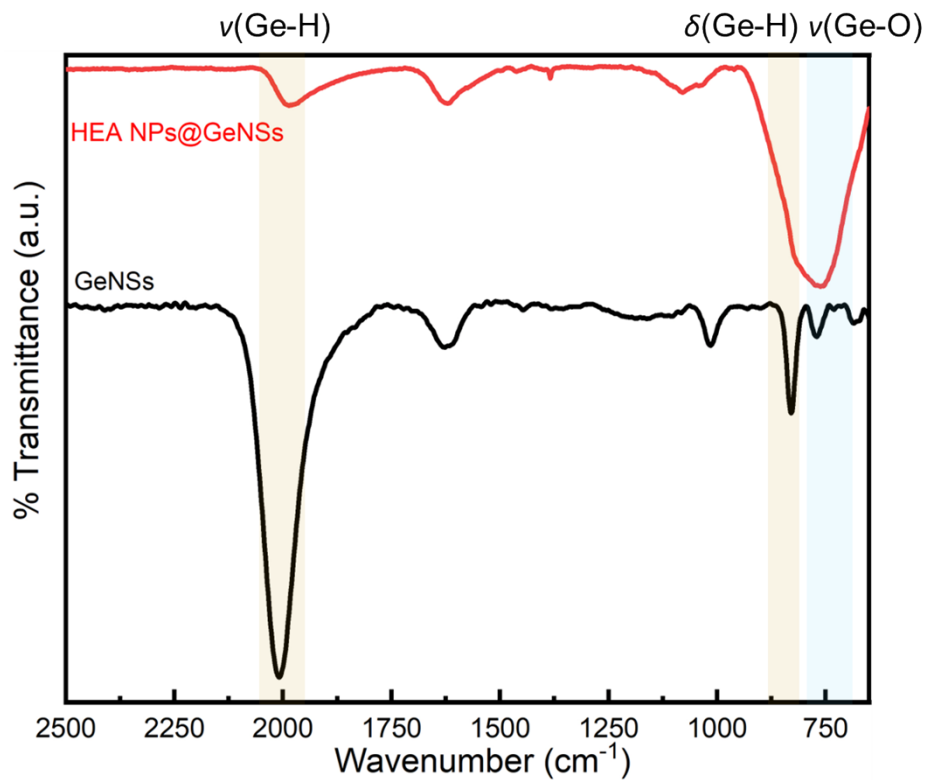


Figure S5. Representative FTIR spectra of GeNSs before (black) and after (red) HEA NPs deposition.

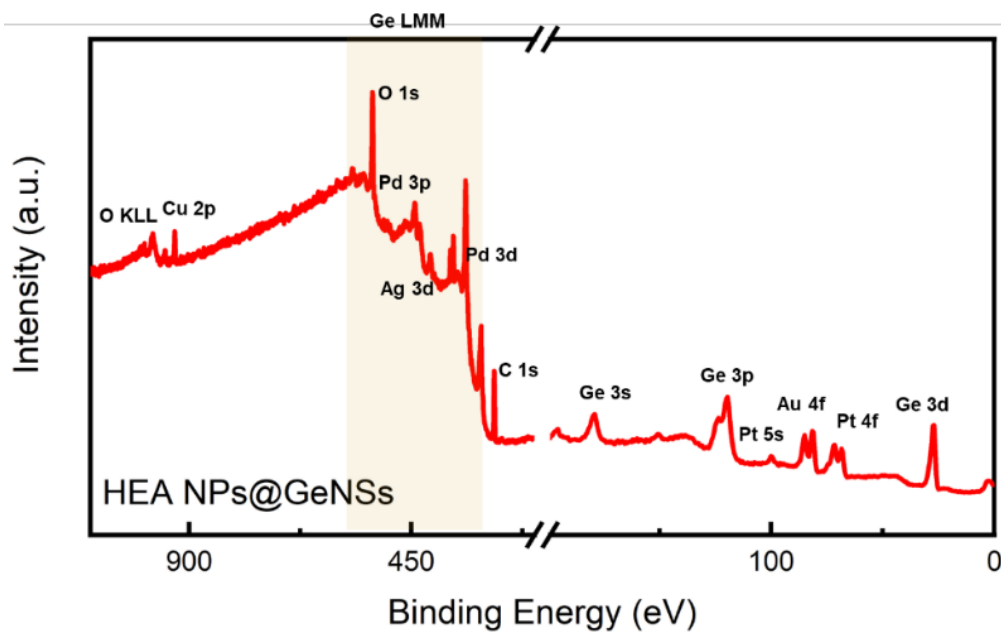


Figure S6. Representative survey XPS spectrum of HEA NPs@GeNSs.

Table S1. Summary of XPS data for HEA NPs@GeNSs

	Ge 3d	Au 4f	Ag 3d	Cu 2p	Pd 3d	Pt 4f
Emission (eV)	29.8	83.9	367.9	932.5	335.2	71.0
Reference emission (eV) ^a	29.8	84.0	368.2	933.0	335.0	71.0
Atomic percentage (%)	20.7	1.94	2.03	2.16	2.17	1.99

^a Reference metal emissions are from NIST X-ray Photoelectron Spectroscopy Database.¹

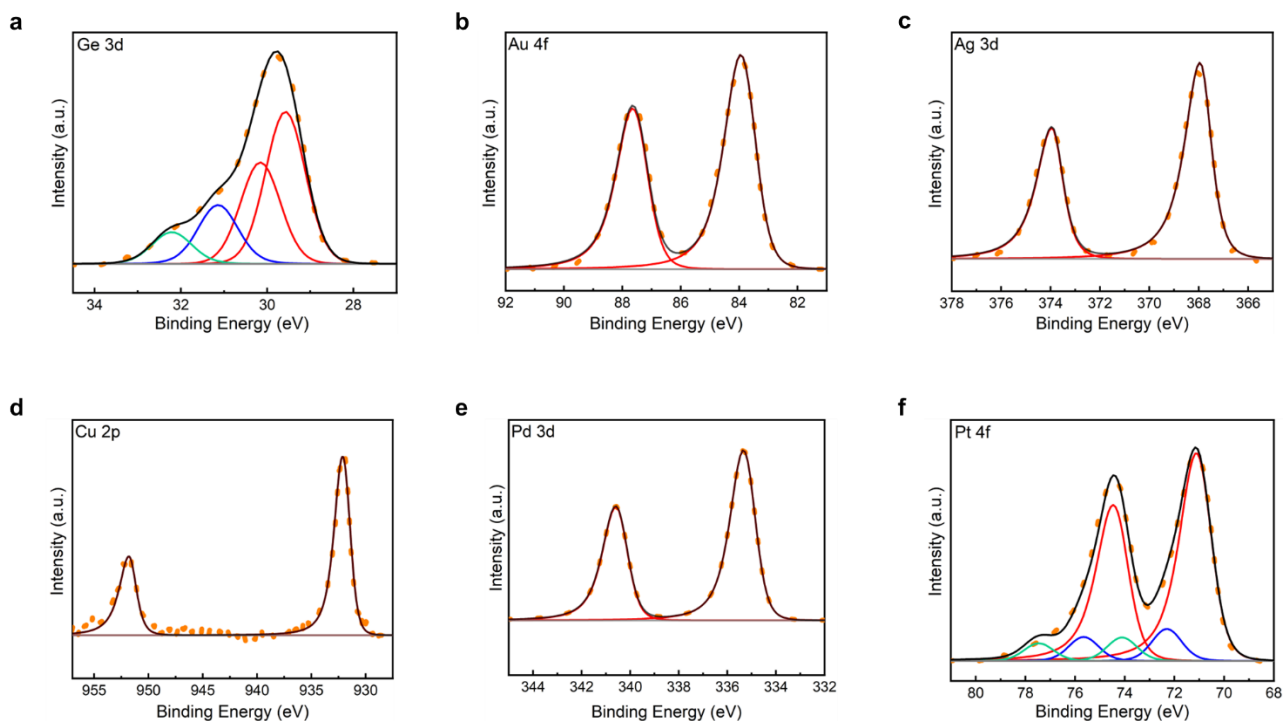


Figure S7. Representative high-resolution XP spectra of HEA NPs@GeNSs: (a) Ge 3d, (b) Au 4f, (c) Ag 3d, (d) Cu 3d, (e) Pd 3d and (f) Pt 4f regions.

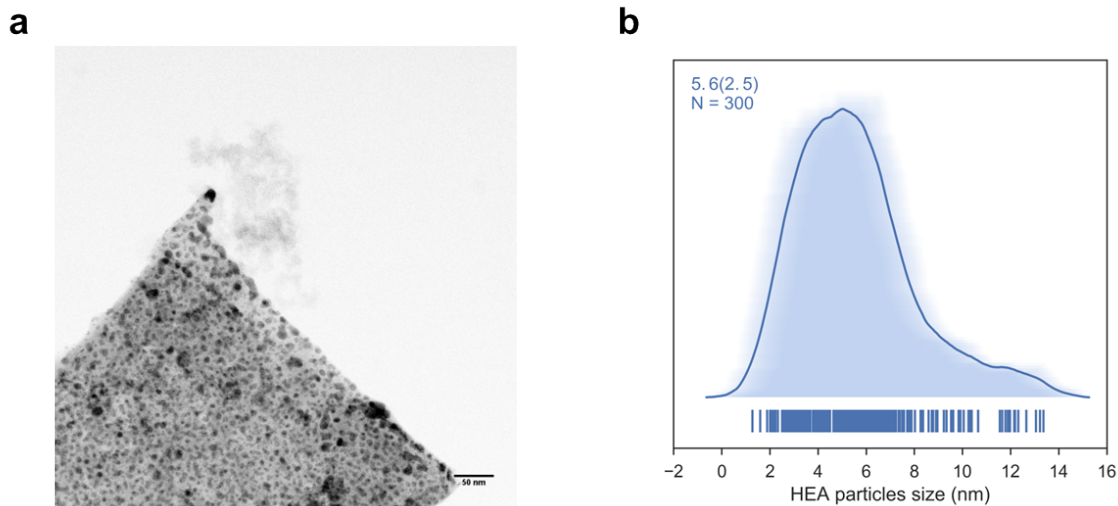


Figure S8. Representative (a) brightfield TEM image of HEA NPs@GeNSs and the associated (b) average shifted histogram for HEA particles on GeNSs.

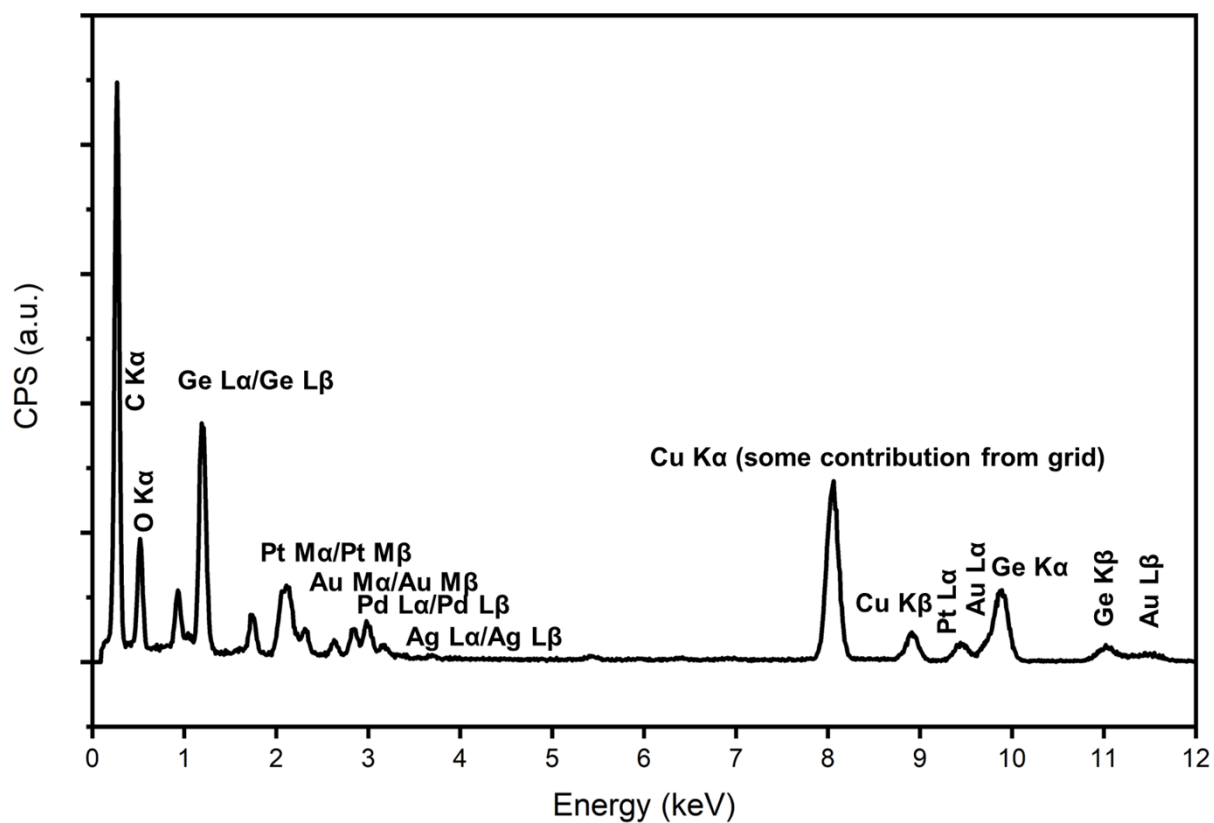


Figure S9. Representative EDX spectrum for HEA NPs@GeNSs.

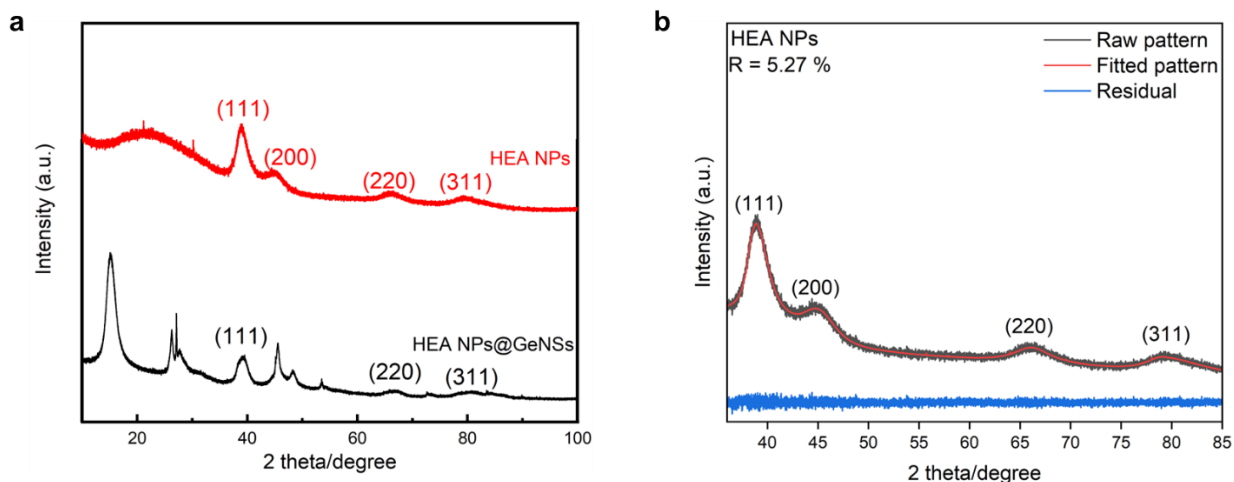


Figure S10. (a) Laboratory XRD patterns of liberated HEA NPs (red trace) and corresponding HEA NPs@GeNSs (black trace). (b) Fitting results of the (111) reflection in the laboratory-based X-ray diffraction pattern for liberated HEA NPs corresponding to an HEA nanocrystal domain size of 6.1 nm.

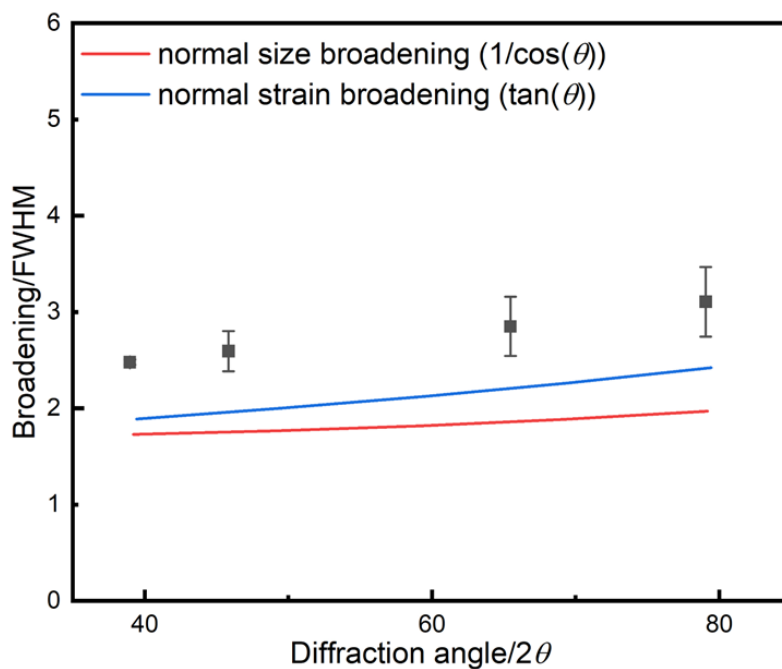


Figure S11. XRD peak broadening distribution for liberated HEA NPs.

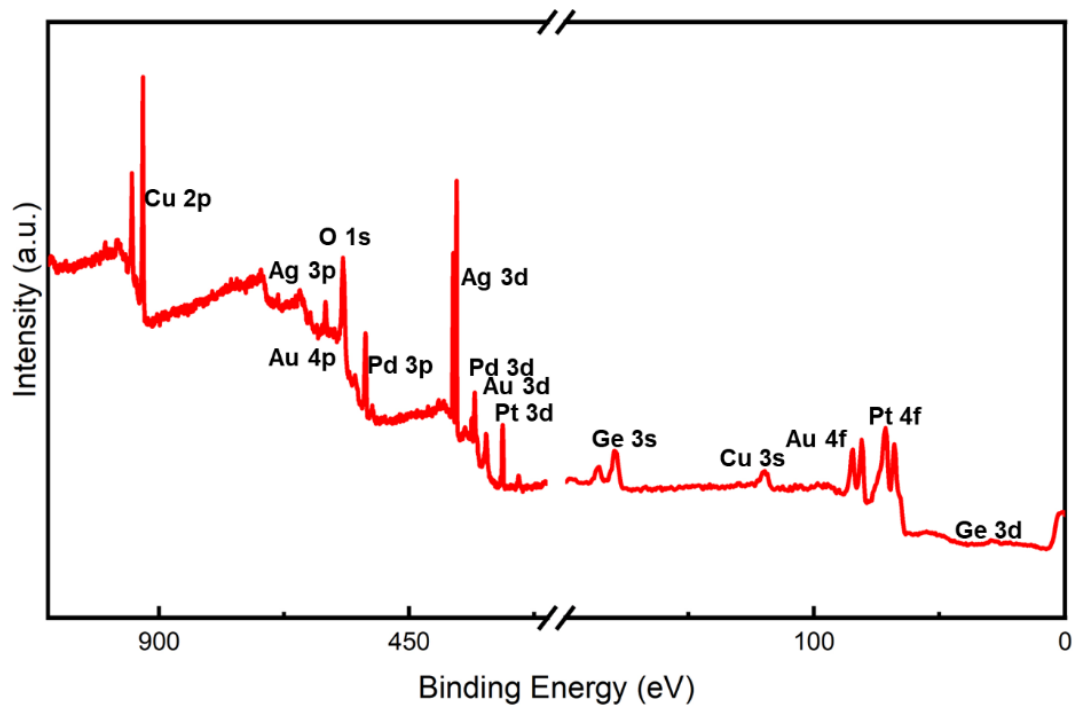


Figure S12. Representative survey XP spectrum of liberated HEA NPs.

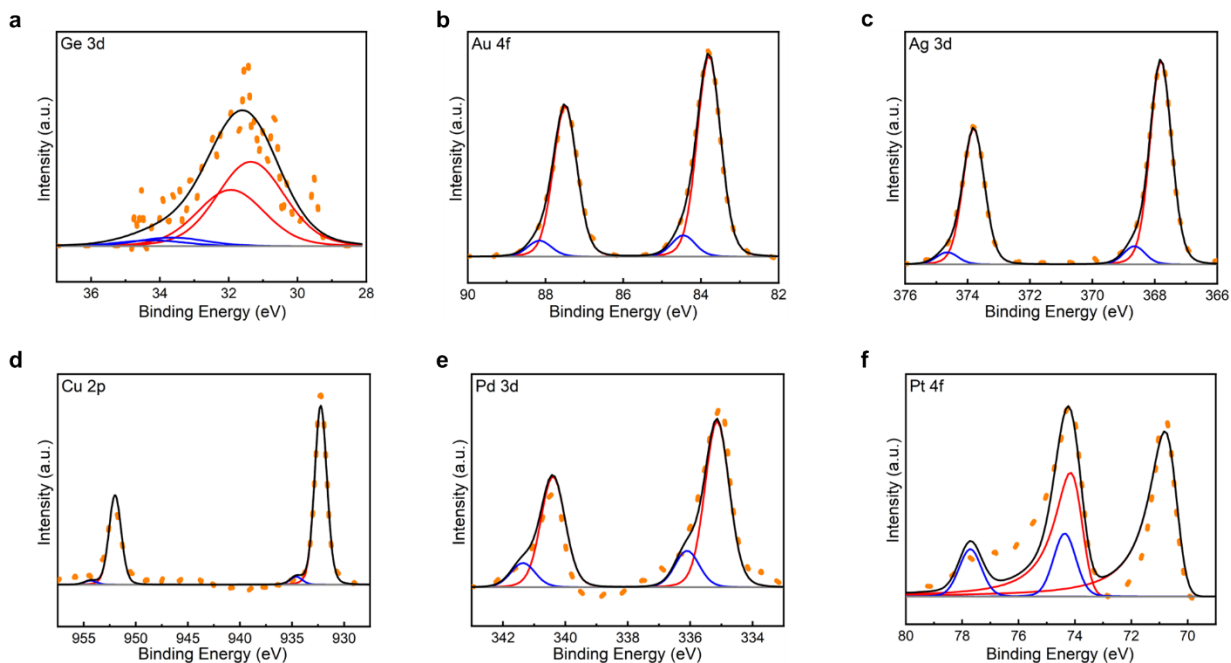


Figure S13. Representative high-resolution XP spectra of liberated HEA NPs: (a) Ge 3d, (b) Au 4f, (c) Ag 3d, (d) Cu 3d, (e) Pd 3d and (f) Pt 4f regions.

Table S2. Summary of XPS data for liberated HEA NPs.

	Ge 3d	Au 4f	Ag 3d	Cu 2p	Pd 3d	Pt 4f
Emission (eV)	31.3	83.7	367.8	932.4	335.1	70.9
Reference emission (eV) ^a	29.8	84.0	368.2	933.0	335.0	71.0
Atomic percentage (%)	1.72	14.35	13.99	14.27	13.51	14.86

^a Reference metal emissions are from NIST X-ray Photoelectron Spectroscopy Database.¹

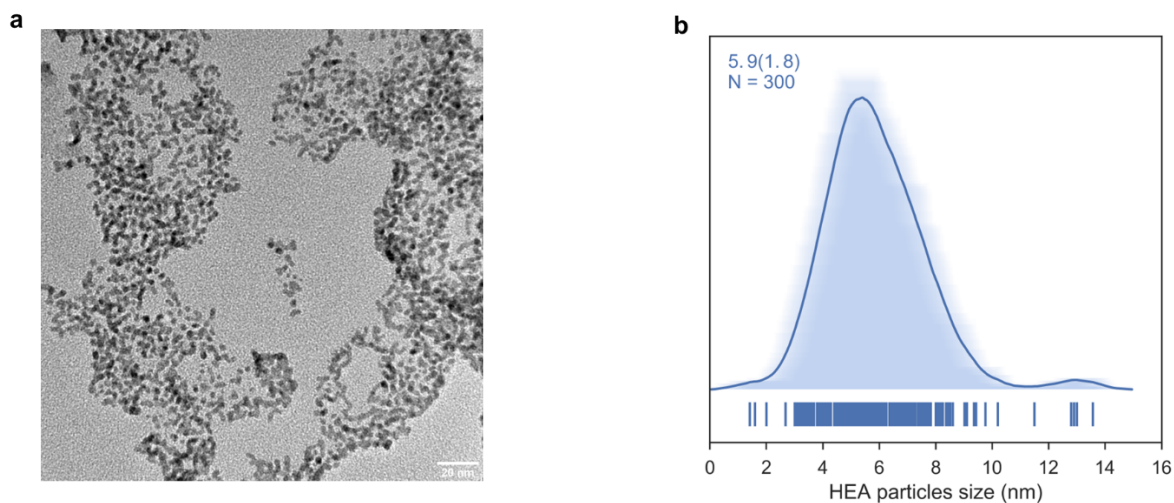


Figure S14. Representative (a) brightfield TEM image of HEA NPs and the associated (b) average shifted histogram.

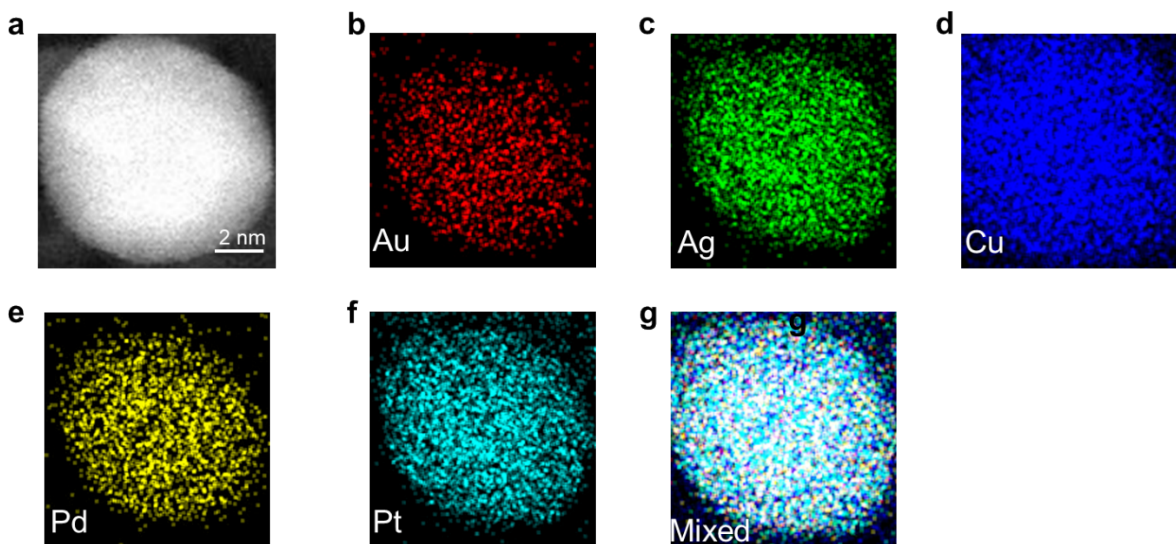


Figure S15. Representative HAADF-STEM images and EDX mapping of liberated HEA NPs.

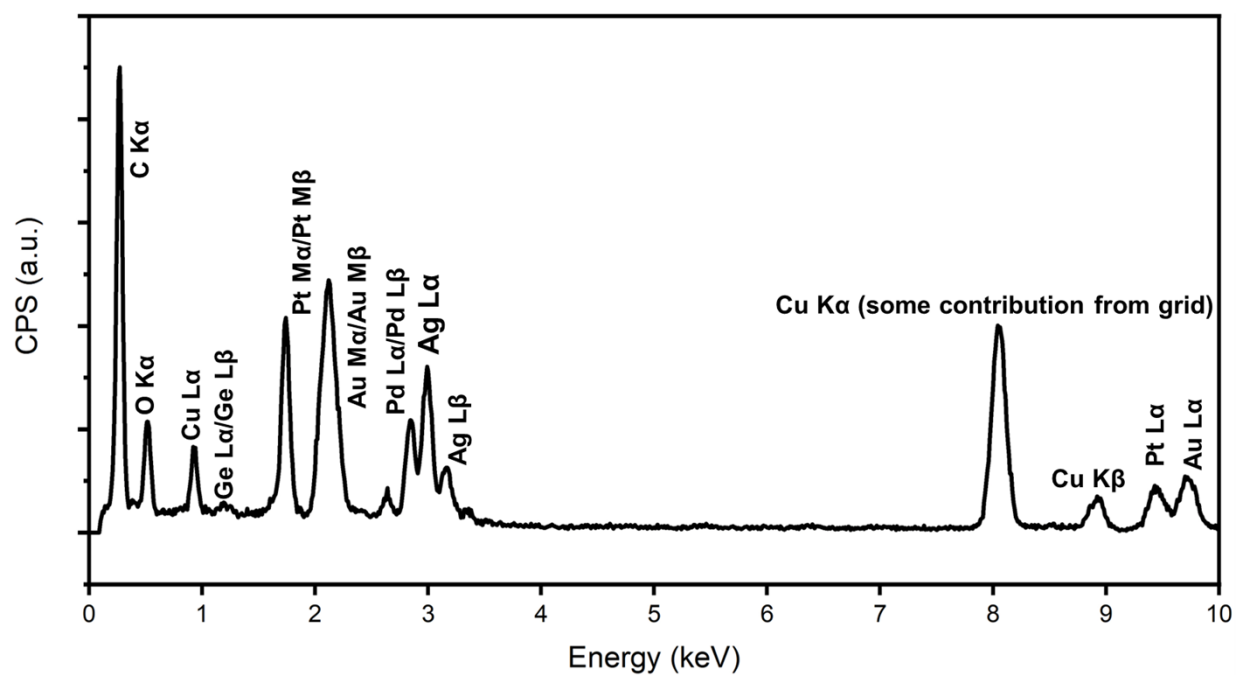


Figure S16. Representative EDX spectrum for HEA NPs liberated from GeNSs.

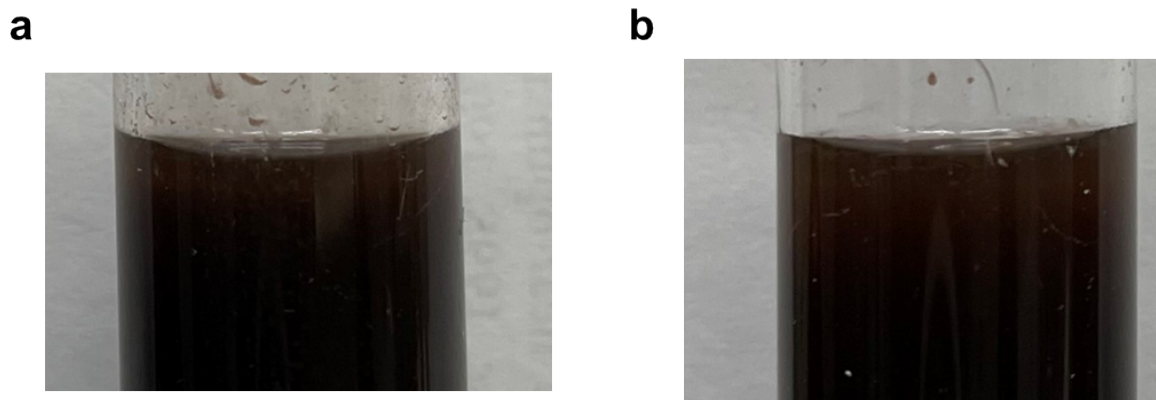


Figure S17. Photography of the HEA NPs@GeNPs (a) before and (b) after the addition of the mixed metal ions solution.

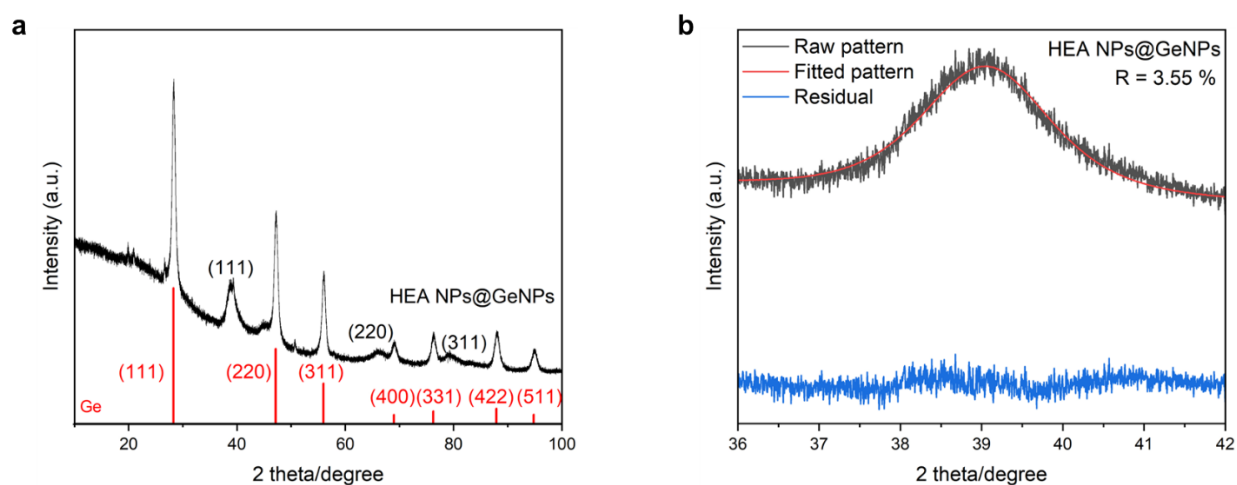


Figure S18. (a) Laboratory XRD pattern of HEA NPs@GeNPs (black trace). Characteristic reflections for bulk Ge (PDF# 79-0001) are provided for reference. (b) Fitting results of the (111) reflection in the laboratory-based X-ray diffraction pattern for HEA NPs@GeNPs corresponding to an HEA nanocrystal domain size of 7.2 nm.

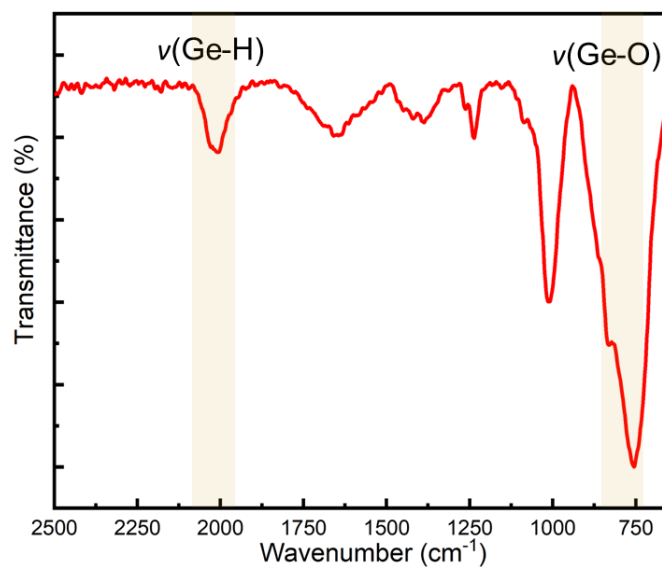


Figure S19. Representative FTIR spectrum of HEA NPs@GeNPs.

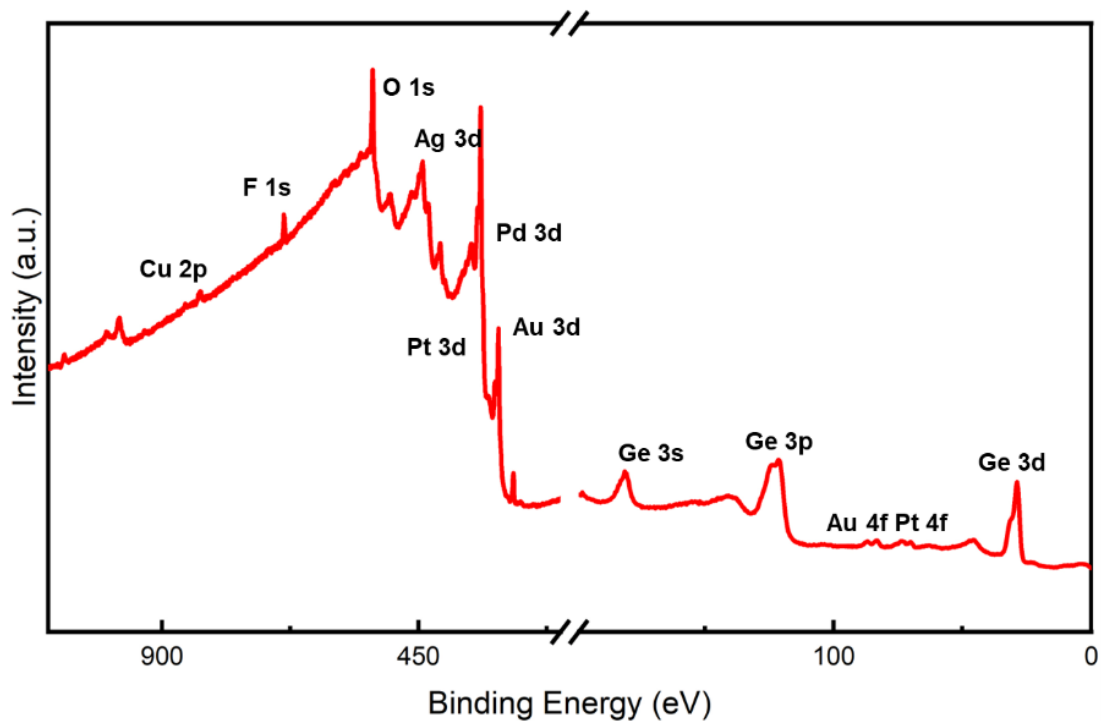


Figure S20. Representative survey XPS spectrum of HEA NPs@GeNPs.

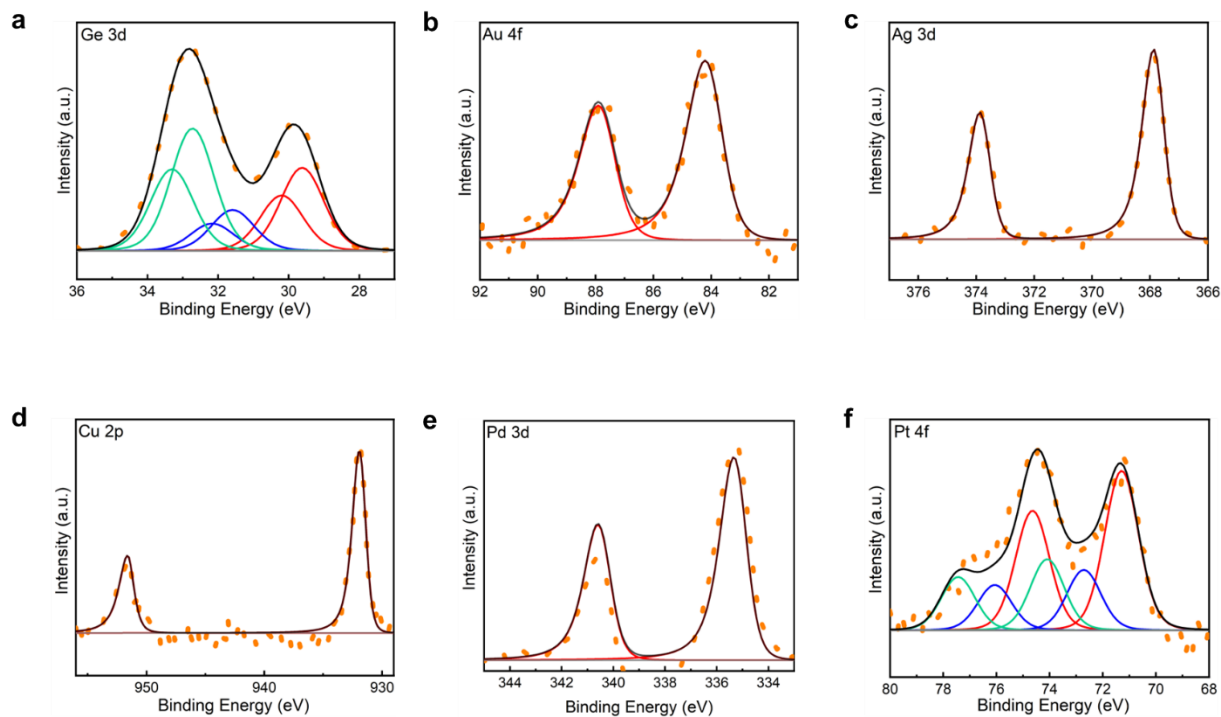


Figure S21. Representative high-resolution XPS spectra of HEA NPs@GeNPs: (a) Ge 3d, (b) Au 4f, (c) Ag 3d, (d) Cu 3d, (e) Pd 3d and (f) Pt 4f regions.

Table S3. Summary of XPS data for HEA NPs@GeNPs.

	Ge 3d	Au 4f	Ag 3d	Cu 2p	Pd 3d	Pt 4f
Emission (eV)	29.6	84.0	367.9	932.3	335.1	71.0
Reference emission (eV) ^a	29.6	84.0	368.2	933.0	335.0	71.0
Atomic percentage (%)	24.6	0.86	1.01	0.96	0.87	0.99

^a Reference metal emissions are from NIST X-ray Photoelectron Spectroscopy Database.¹

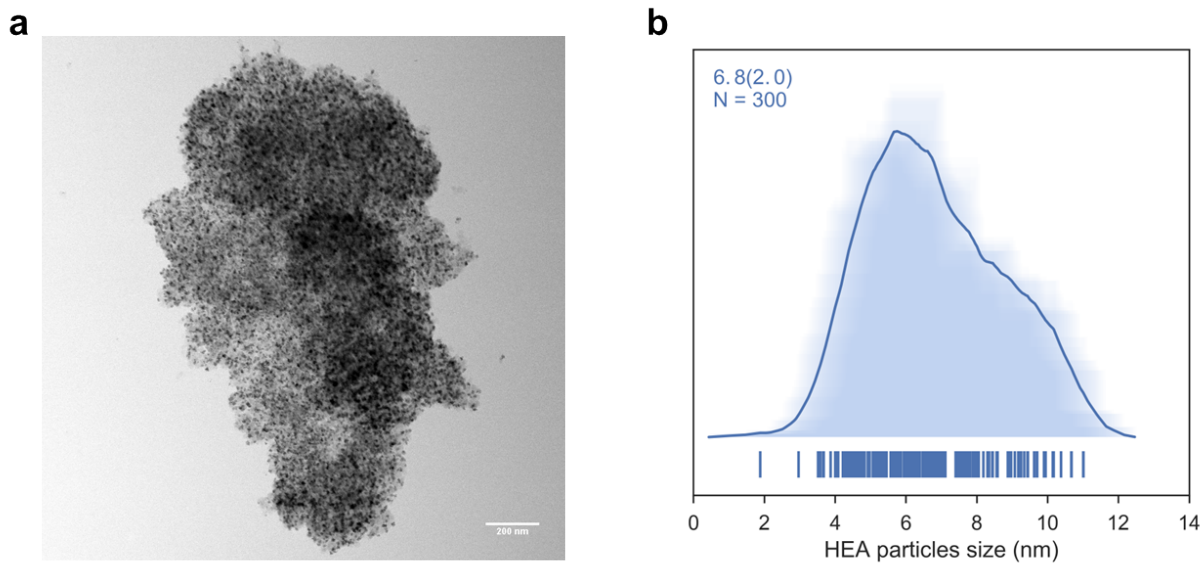


Figure S22. Representative (a) brightfield TEM image of HEA NPs@GeNPs and (b) average shifted histogram for HEA particles on GeNPs.

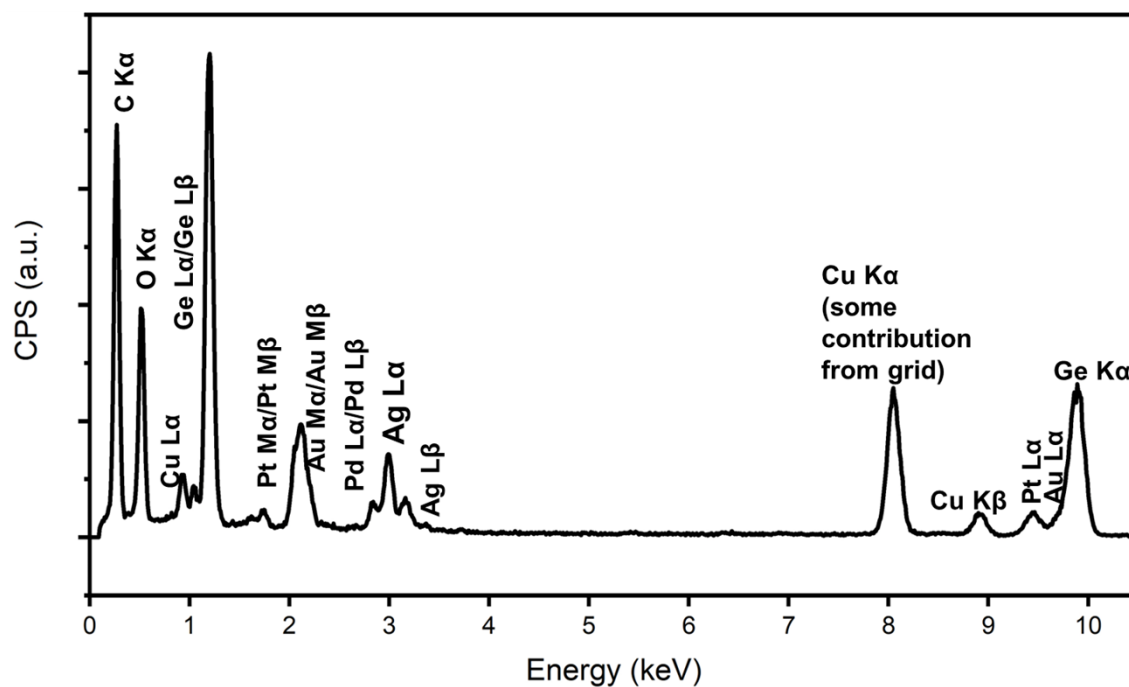


Figure S23. Representative EDX spectrum for HEA NPs@GeNPs.

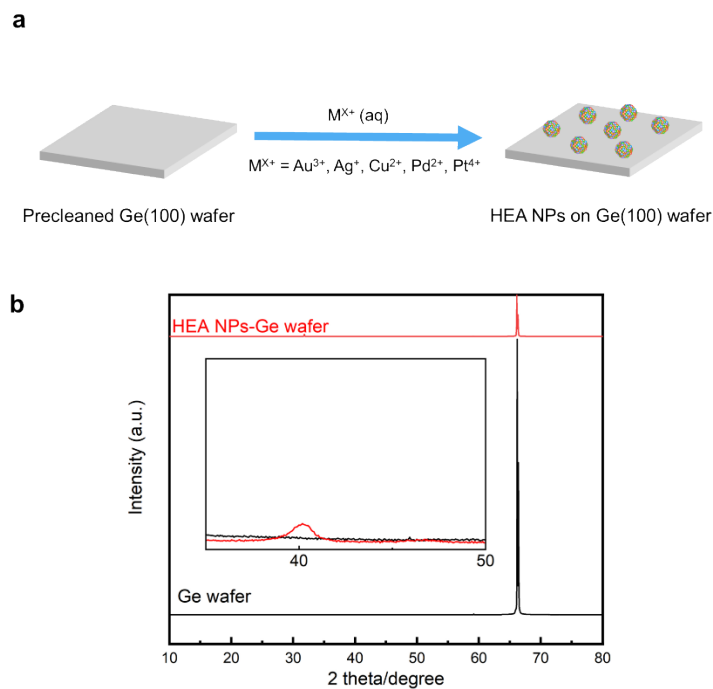


Figure S24. (a) Schematic illustration of the deposition of the HEA NPs on Ge(100) wafer. (b) XRD patterns of HEA NPs-Ge wafer and Ge(100) wafer.

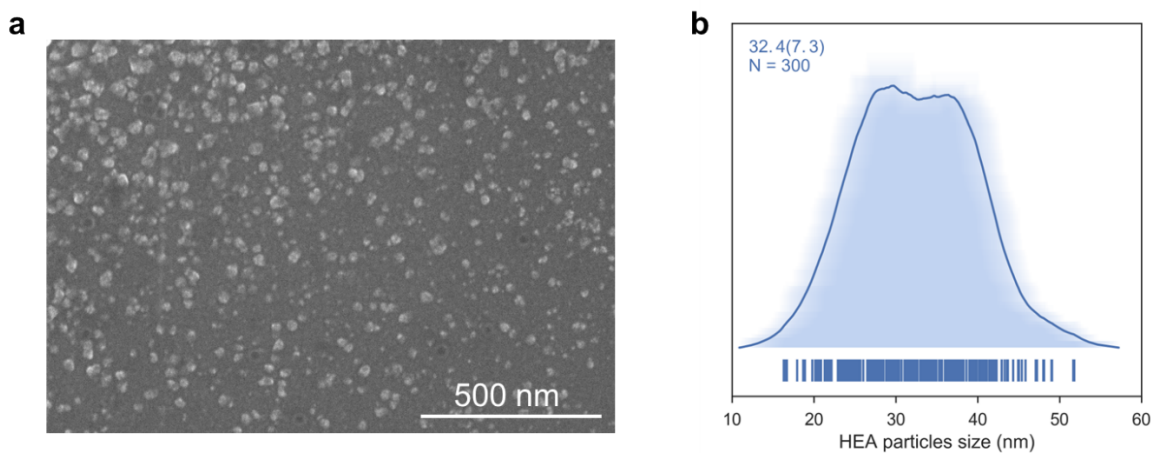


Figure S25. Representative (a) SEM image of HEA NPs-Ge wafer and (b) average shifted histogram for HEA NPs.

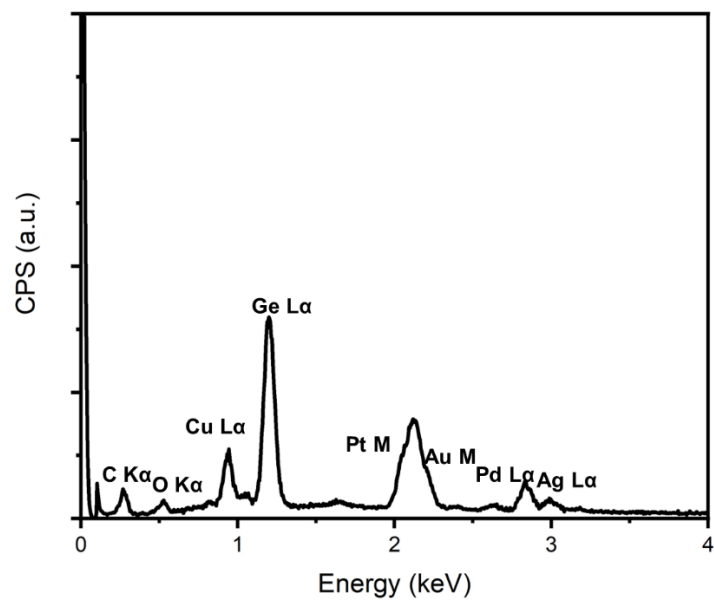


Figure S26. Representative SEM/EDX spectrum for HEA NPs-Ge wafer.

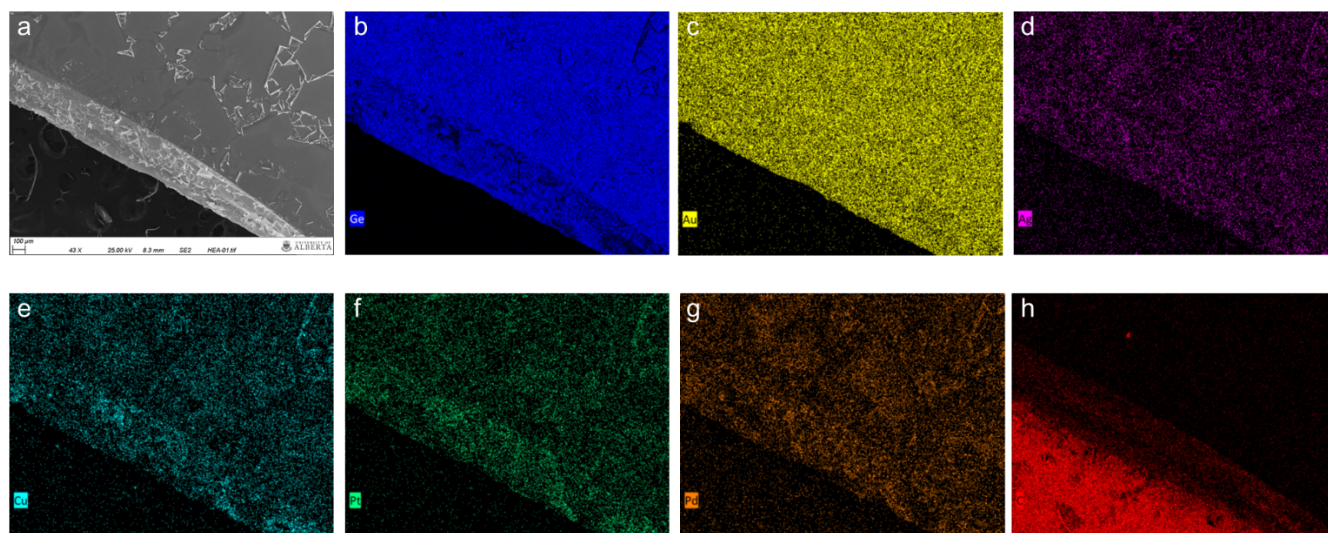


Figure S27. (a) Representative SEM image and (b-h) EDX mapping for HEA NPs-Ge wafer.

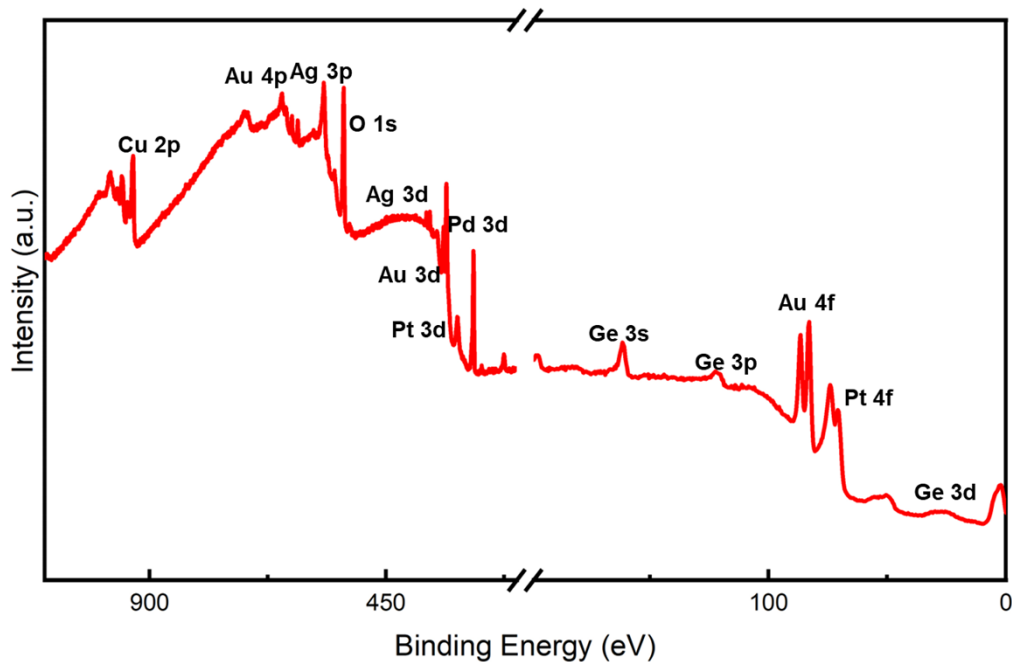


Figure S28. Representative survey XP spectrum of HEA NPs-Ge wafer.

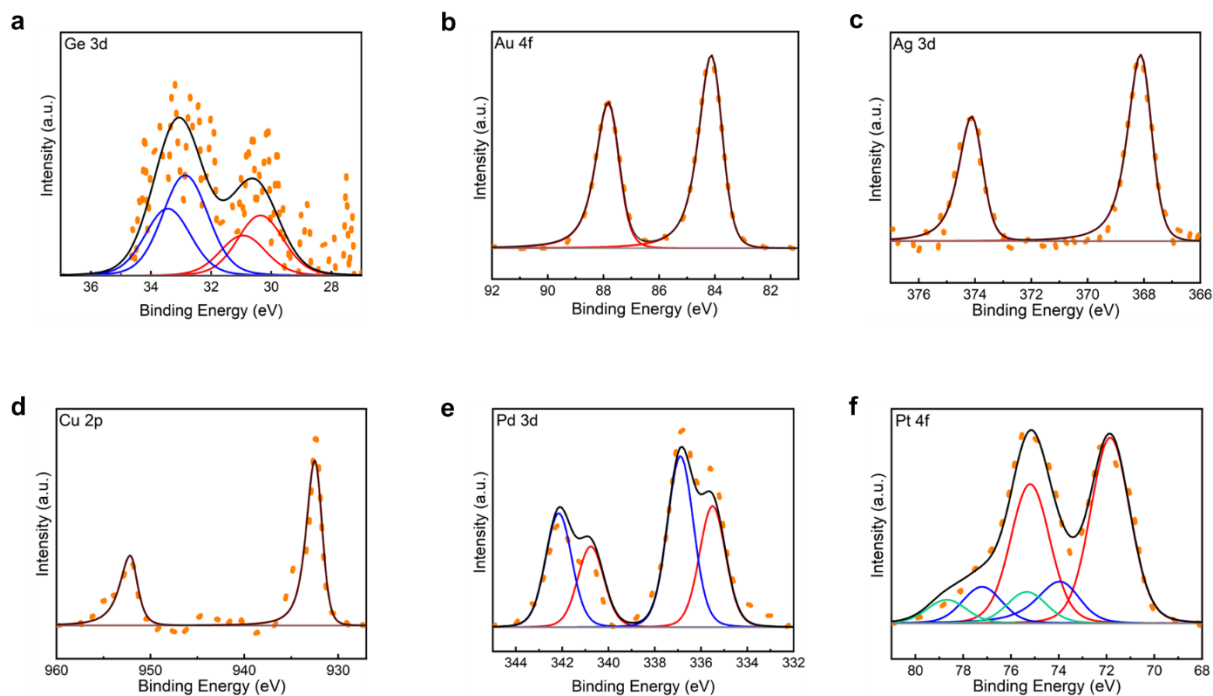


Figure S29. Representative high-resolution XP spectra of HEA NPs-Ge wafer: (a) Ge 3d, (b) Au 4f, (c) Ag 3d, (d) Cu 3d, (e) Pd 3d and (f) Pt 4f regions.

Table S4. Summary of XPS data for HEA NPs-Ge wafer

	Ge 3d	Au 4f	Ag 3d	Cu 2p	Pd 3d	Pt 4f
Emission (eV)	31.3	83.7	368.0	932.4	335.5	70.8
Reference emission (eV) ^a	29.8	84.0	368.2	933.0	335.0	71.0
Atomic percentage (%)	9.27	6.53	4.97	5.39	5.79	5.64

^a Reference metal emissions are from NIST X-ray Photoelectron Spectroscopy Database.¹

References

1. NIST X-ray Photoelectron Spectroscopy Database, NIST Standard Reference Database Number 20, National Institute of Standards and Technology, Gaithersburg MD, 20899 (2000)