

Supplementary Information

A Ligand-Induced Homojunction between Aluminum-based Superatomic Clusters

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Supplementary Table 1. Energies of HOMO and LUMO levels, adiabatic ionization energy, and HOMO-LUMO gap (in eV). The gross charge on Al₁₃ and PAl₁₂ in Al₁₃(EP) and PAl₁₂(EP) are given by the Hirshfeld charge analysis.

Cluster	HOMO (eV)	LUMO (eV)	AIE (eV)	HL gap	Hirshfeld Charges (e ⁻)	Dipole Moment (Debye)
Al ₁₃	-5.108	-4.700	6.13	0.408		
PAl ₁₂	-3.724	-3.156	5.10	0.568		
Al ₁₃ (EP)	-4.407	-3.697	5.08	0.710	-0.369	14.16
PAl ₁₂ (EP)	-3.134	-2.517	4.36	0.617	-0.349	13.91

PAl ₁₂ (Ge ¹ _B)			CH ₃ CH ₃ GeCH ₃ CH ₃		
1	P	-0.1325	1	H	0.0334
2	Al	0.0227	2	H	0.0333
3	Al	0.0193	3	H	0.0337
4	Al	<i>0.1342</i>	4	H	0.0335
5	Al	0.0205	5	H	0.0336
6	Al	0.0276	6	H	0.0336
7	Al	0.0197	7	H	0.0335
8	Al	0.0200	8	H	0.0334
9	Al	-0.0247	9	H	0.0335
10	Al	0.0196	10	H	0.0336
11	Al	0.0241	11	H	0.0336
12	Al	0.0190	12	H	0.0337
13	Al	0.0182	13	C	-0.1961
14	H	0.0332	14	C	-0.1964
15	H	0.0335	15	C	-0.1963
16	H	0.0205	16	C	-0.1960
17	H	0.0234	17	Ge	0.3825
18	H	0.0234	Charges in bold-italic text are for the atoms in Al-C connecting bond in PAl₁₂[Ge¹_B].		
19	H	0.0334			
20	H	0.0197			
21	H	0.0331			
22	H	0.0325			
23	H	0.0324			
24	H	0.0322			
25	C	-0.1973			
26	C	-0.1970			
27	C	<i>-0.2863</i>			
28	C	-0.1976			
29	Ge	0.3696			

Supplementary Table 2. Hirshfeld Charge Analysis of PAl₁₂Ge¹_B and Ge-linker (CH₃CH₃GeCH₃CH₃).

Supplementary Table 3. Hirshfeld Charge Analysis of $\text{PAI}_{12}\text{Ge}^{\text{I}}_{\text{B}}$ and Ge-linker ($\text{CH}_3\text{CH}_3\text{GeCH}_3\text{CH}_3$).

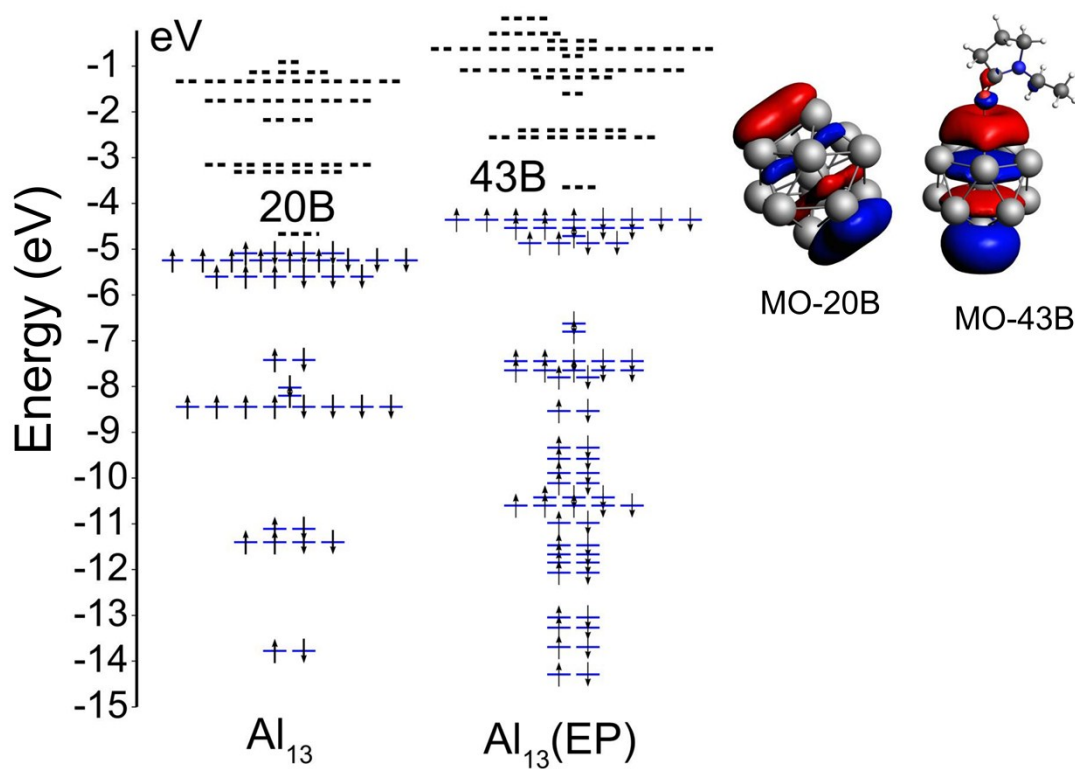
$(\text{EP})_n\text{PAI}_{12}\text{Ge}^2_{\text{B}}\text{PAI}_{12}$		Hirshfeld-charge			
No. of EP (n)	EP	Left- PAI_{12} (ligated)	Net Ligated	Ge^2_{B}	Right- PAI_{12} (non-ligated)
0	0	0.184	+0.1836	-0.367	0.181
1	0.346	-0.12	+0.2300	-0.399	0.168
2	0.615	-0.359	+0.2554	-0.407	0.147
3	0.825	-0.537	+0.288	-0.418	0.129
4	0.947	-0.632	+0.315	-0.431	0.124

Supplementary Table 4. The HOMO, LUMO, and HOMO-LUMO Gap of $(\text{EP})_n\text{PAI}_{12}[\text{Ge}^{\text{I}}_{\text{B}}]$, $n=0-4$.

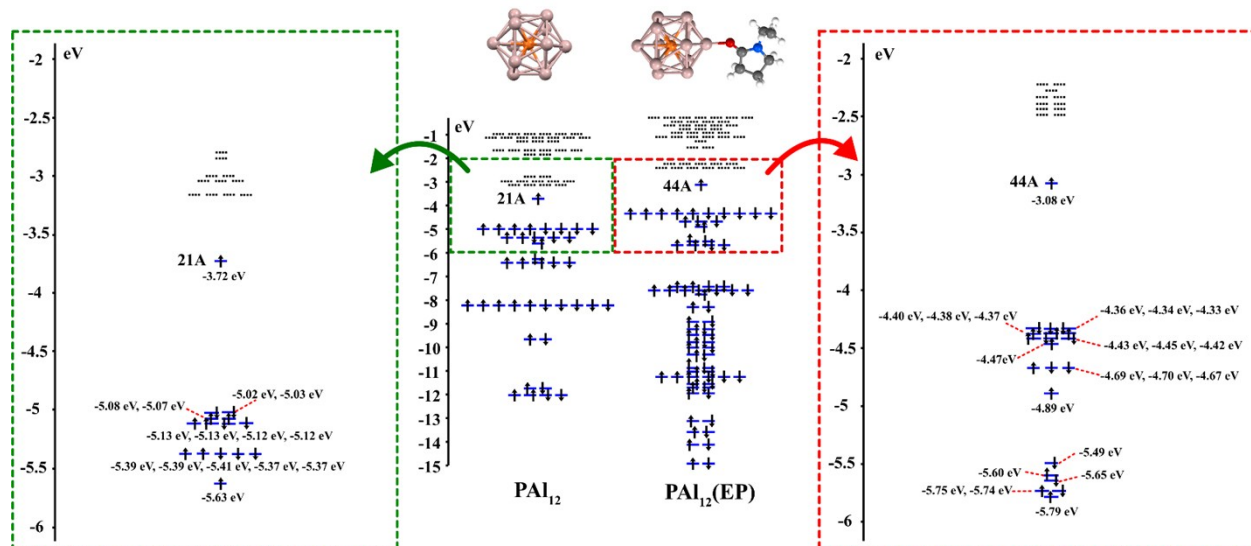
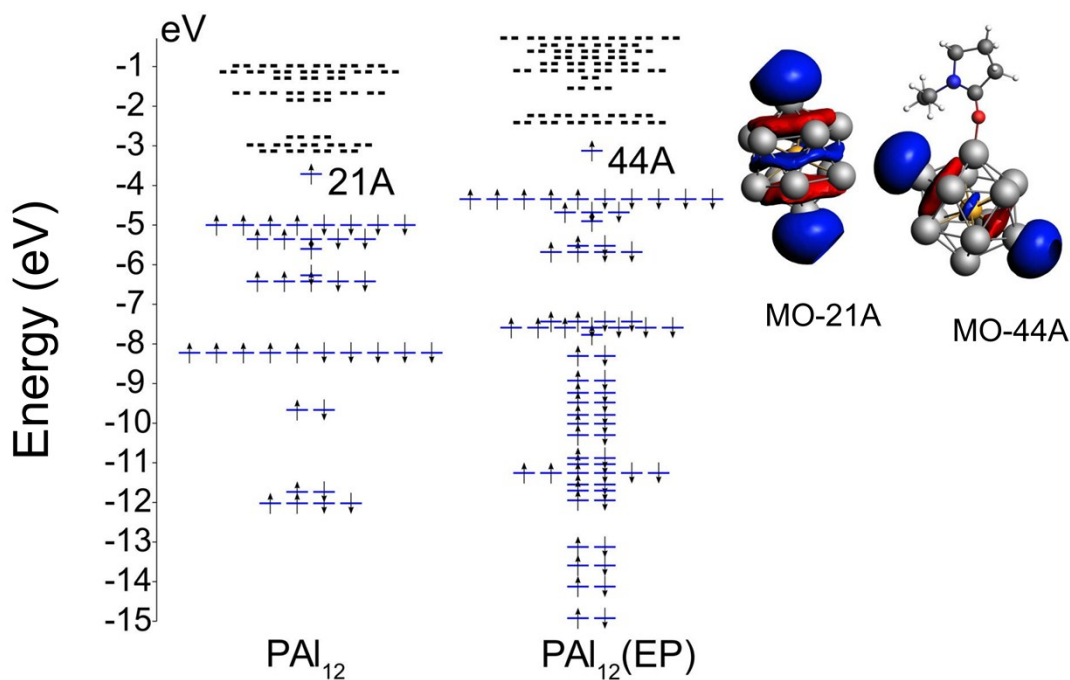
$(\text{EP})_n\text{PAI}_{12}[\text{Ge}^{\text{I}}_{\text{B}}]$	HOMO (eV)	LUMO (eV)	GAP (eV)
0	-4.775	-3.13	1.645
1	-4.15	-2.526	1.624
2	-3.597	-1.986	1.611
3	-3.098	-1.65	1.448
4	-2.811	-1.43	1.381

Supplementary Table 5. The 4 lowest energy absorption processes are shown for (EP)PAI₁₂Ge²BPAI₁₂. The 79a is the HOMO, and 80a

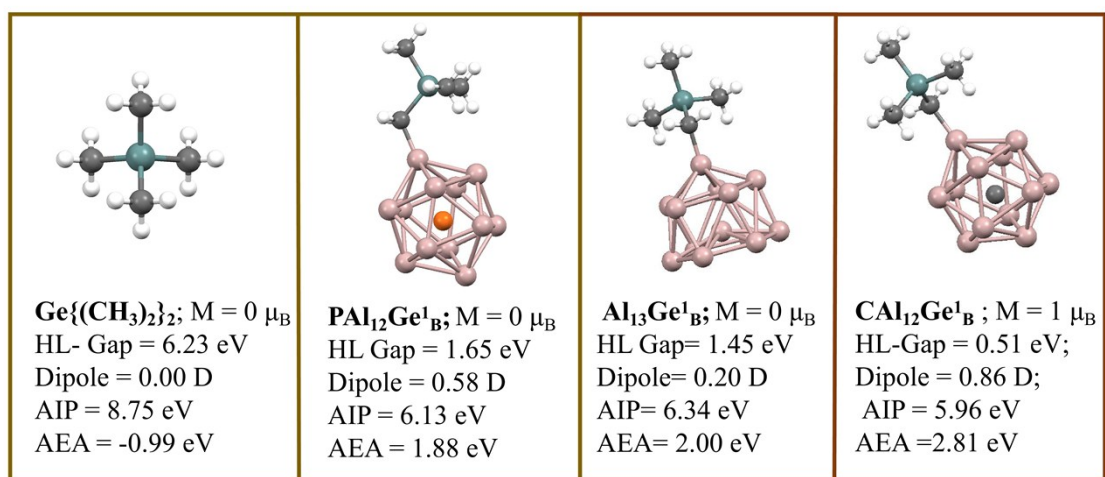
Transitions			Weight (sum=1)	contributions to transition dipole moment			E/eV	Oscillator strengths (f)
				x	y	z		
H O M O	->	80a	0.9998	0.0051	0.0155	-0.0179	1.12694	6.953E-07
79a	->	81a	0.9998	0.0105	-0.0069	0.0061	1.13039	4.057E-07
79a	->	82a	0.9879	0.0564	0.2081	0.1706	1.24892	0.0006201
79a	->	83a	0.9879	0.2267	-0.031	-0.1127	1.25286	0.0005652



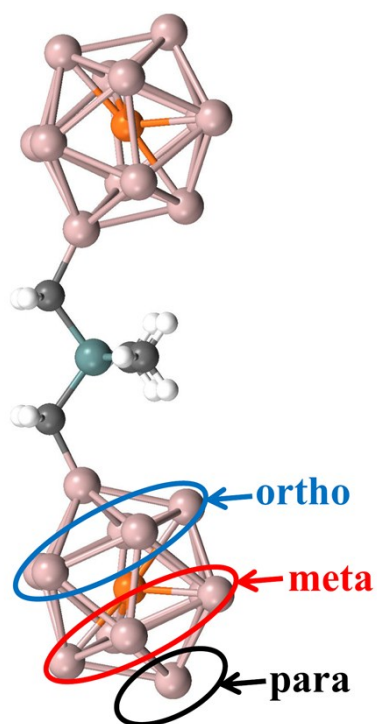
Supplementary Figure 1. One-electron energy levels of Al_{13} and $\text{Al}_{13}(\text{EP})$. Molecular orbital surfaces of LUMO in Al_{13} and $\text{Al}_{13}(\text{EP})$ are shown.



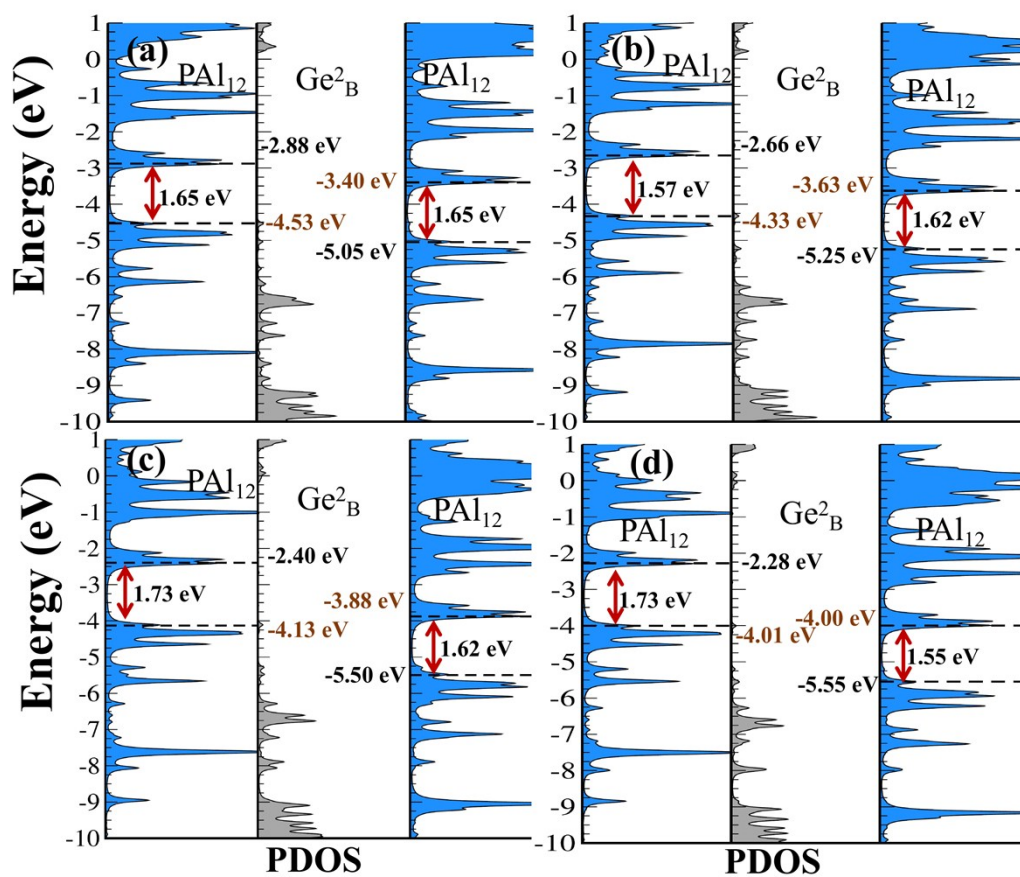
Supplementary Figure 2. One-electron energy levels of PAI₁₂ and PAI₁₂(EP). Molecular orbital surfaces of HOMO in PAI₁₂ and PAI₁₂(EP) are shown. A blown up version of the levels is shown below.



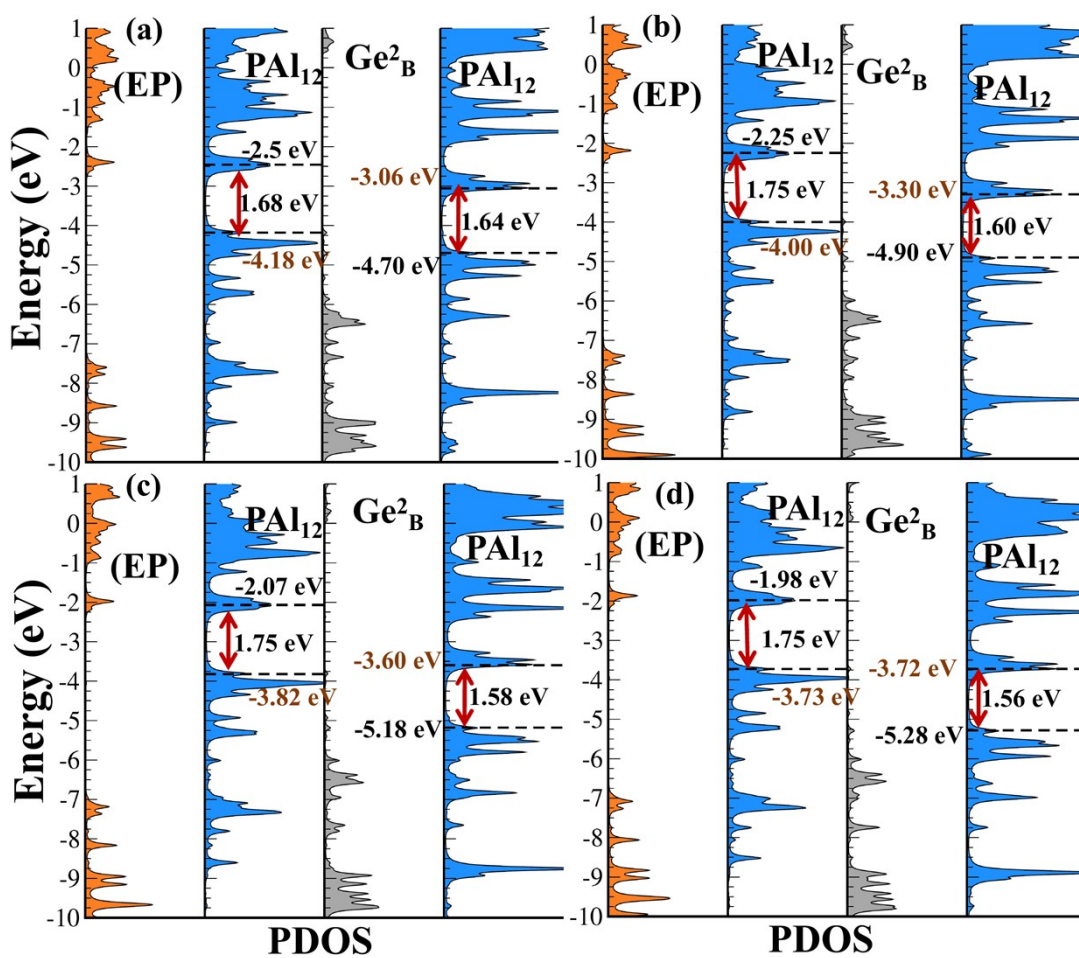
Supplementary Figure 3. Optimized ground state structure of tetramethyl germane CH₃CH₃GeCH₃CH₃ (=Ge-linker), PAl₁₂Ge^IB, Al₁₃Ge^IB, and CAl₁₂Ge^IB respectively. Their electronic properties, total magnetic moment (in μ_B), and dipole moments in Debye(D) are also given.



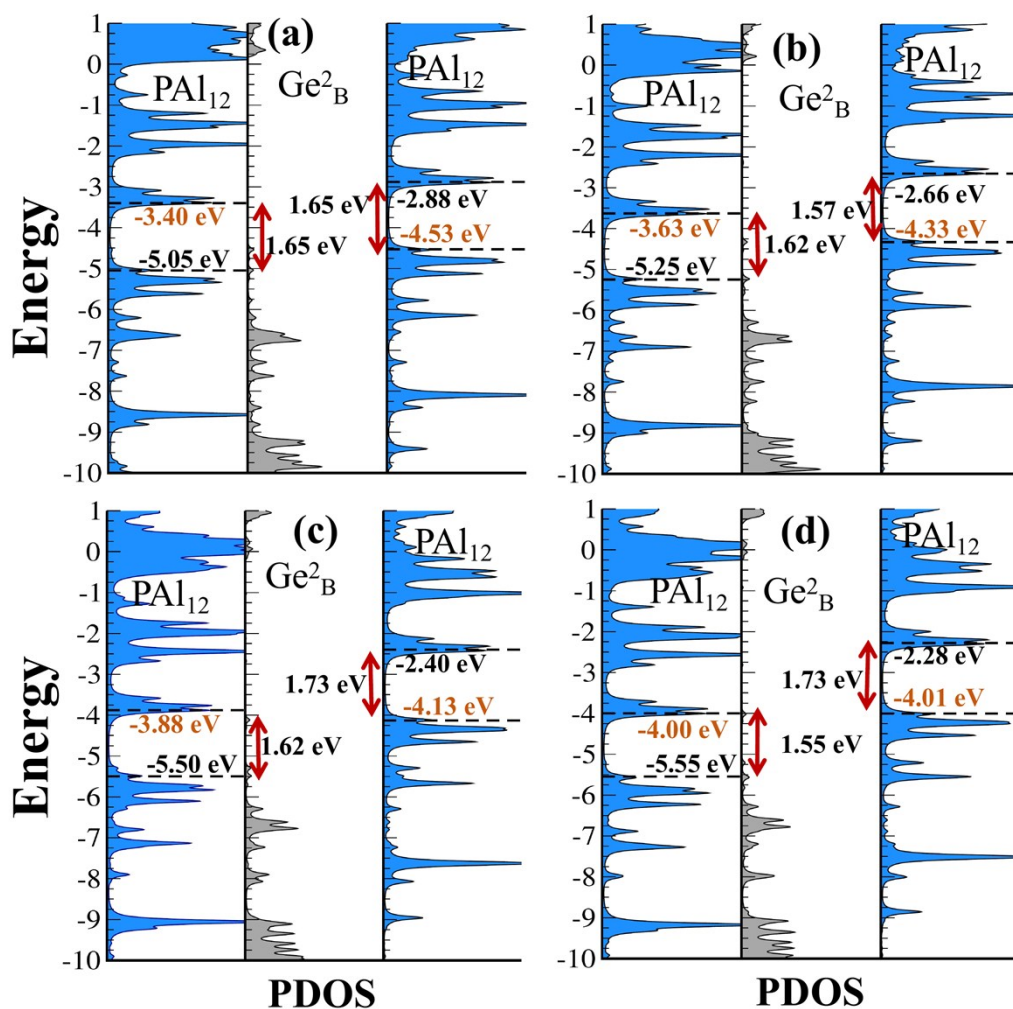
Supplementary Figure 4. Depiction of *Ortho*-, *Meta*-, and *Para*-Al sites for attaching EP (= $\text{C}_6\text{H}_{11}\text{NO}$) ligand in $\text{PAl}_{12}\text{Ge}^2_{\text{B}}\text{PAl}_{12}$.



Supplementary Figure 5. Partial density of states for $\text{PAI}_{12}[\text{Ge}_2\text{B}]\text{PAI}_{12}$ molecule in the presence of applied homogenous electric fields: (a) -0.001 a.u. , (b) -0.002 a.u. , (c) -0.003 a.u., and (d) -0.0036 a.u.



Supplementary Figure 6. Partial density of states for (EP)PAI₁₂[Ge₂B]PAI₁₂ molecule in the presence of applied homogenous electric fields: **(a)** -0.000 a.u., **(b)** -0.001 a.u., **(c)** -0.002 a.u., and **(d)** -0.0026 a.u.



Supplementary Figure 7. Partial density of states for PAI₁₂[Ge₂B]PAI₁₂ molecule in the presence of applied homogenous electric fields: (a) 0.001 a.u., (b) 0.002 a.u., (c) 0.003 a.u., and (d) 0.0036 a.u.

Cartesian co-ordinates of optimized ground state structures of (EP)_nPAI₁₂Ge²_BPAI₁₂, for n= 0, 1, 2, 3, and respectively.

PAI₁₂Ge²_BPAI₁₂

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XYZ

P -0.043747 0.292629 -6.228118
 Al -2.201637 0.199426 -4.675824
 Al -1.581587 2.377416 -6.342846
 Al 0.065293 -1.01401 -3.476046
 Al -1.231905 -2.048675 -5.789868
 Al -0.122933 1.776992 -4.026275
 Al -2.293853 -0.066465 -7.469431
 Al 1.199779 2.560266 -6.370641
 Al -0.148297 1.462896 -8.681599
 Al 1.448348 -1.871577 -5.818045
 Al 2.135598 0.486291 -4.717151
 Al 0.0484 -1.38302 -8.204109
 Al 2.204139 0.232578 -7.512329
 Al -1.159481 -2.23582 5.672729
 Al 1.518059 -2.031043 5.672877
 Al 0.100445 -1.102459 3.379542
 Al 0.142279 -1.642087 8.090886
 Al -2.163178 0.040659 4.649532
 Al 2.170462 0.370353 4.650553
 P 0.010186 0.101407 6.178327
 Al -2.219948 -0.322926 7.432874
 Al 2.275007 0.016595 7.432374
 Al -0.10827 1.664664 4.032379
 Al -0.074207 1.182806 8.673498
 Al -1.544797 2.164711 6.385833
 Al 1.23538 2.374463 6.388298
 H -2.517518 -0.427149 -0.034114
 C -1.677058 0.277377 -0.021449
 H -0.662609 -2.670613 1.504259
 H -1.741922 0.89212 0.884915
 H -1.744084 0.927205 -0.902755
 H -0.653273 -2.63966 -1.631371
 C 0.168118 -1.952085 1.593069
 Ge 0.070661 -0.746282 -0.042486
 C 0.164765 -1.905512 -1.711294
 H 1.102972 -2.528913 1.505163
 H 1.109065 -2.470431 -1.649614

C 1.629167 0.546922 -0.025941
 H 1.596287 1.163959 0.880612
 H 1.588455 1.198807 -0.907308
 H 2.572789 -0.011979 -0.040915

(EP)PAI₁₂Ge²_BPAI₁₂

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XYZ

P 0.5245 1.538 -5.37507
 Al -1.35569 1.15659 -3.54
 Al -1.04413 3.53517 -5.03134
 Al 1.02013 -0.08812 -2.80903
 Al -0.67027 -1.01125 -4.96505
 Al 0.76167 2.7451 -3.06002
 Al -1.88926 1.17961 -6.24448
 Al 1.7577 3.86859 -5.51717
 Al 0.02624 2.84941 -7.64387
 Al 1.9553 -0.70622 -5.34941
 Al 2.86852 1.54936 -4.20737
 Al 0.26952 -0.03943 -7.42243
 Al 2.52697 1.52321 -6.97658
 Al -0.61908 -2.4123 5.86302
 Al 1.92793 -1.79931 6.44694
 Al 0.8522 -0.85098 3.97406
 Al 0.05502 -1.89895 8.54447
 Al -1.78162 -0.22015 4.82853
 Al 2.33447 0.7723 5.77436
 P 0. 0. 6.78593
 Al -2.32142 -0.89626 7.49955
 Al 1.95464 0.13223 8.4827
 Al 0.03718 1.75867 4.7897
 Al -0.75948 0.77495 9.2815
 Al -1.90033 1.76694 6.81351
 Al 0.74495 2.39983 7.42336

H -1.49847 -0.2648 0.59047
 C -0.78365 0.5638 0.67669
 H 0.8126 -2.37033 1.9205
 H -0.96325 1.08951 1.62212
 H -0.94091 1.25672 -0.15923
 H 0.75402 -2.01867 -1.11753
 C 1.38247 -1.45997 2.16823
 Ge 1.11109 -0.15821 0.61778
 C 1.39448 -1.1216 -1.14703
 H 2.44862 -1.73754 2.16751
 H 2.4389 -1.47239 -1.16
 C 2.42262 1.37082 0.8183
 H 2.24593 1.89427 1.76664
 H 2.30519 2.07827 -0.01106
 H 3.44879 0.98231 0.81144
 H -1.33147 -5.67296 -6.79346
 C -1.76052 -6.32204 -6.01905

H -2.6652 -6.79748 -6.42012
 H -1.0351 -7.11584 -5.79827
 H -5.11666 -3.33001 -6.61224
 H -4.67114 -5.50383 -5.74906
 C -2.04989 -5.52742 -4.74763
 H -3.77546 -1.49074 -5.80449
 O -1.51141 -2.7398 -4.82426
 N -3.01543 -4.45098 -4.95563
 C -2.70053 -3.15151 -4.95425
 C -5.01641 -3.32913 -5.5192
 C -4.46163 -4.6868 -5.04675
 H -1.13352 -5.05801 -4.36883
 C -3.94363 -2.31339 -5.09474
 H -2.44741 -6.18286 -3.95774
 H -6.00184 -3.11876 -5.09105
 H -4.84588 -4.98071 -4.05538
 H -4.14826 -1.84365 -4.11893

(EP)₂PAI₁₂Ge²_BPAI₁₂

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XYZ

P -0.30793 1.01073 -5.2215
 Al -2.29994 1.04636 -3.52505
 Al -1.52272 3.23899 -5.09541
 Al -0.17476 -0.44869 -2.51503
 Al -1.80486 -1.28046 -4.73506
 Al 0.02227 2.29116 -2.96004
 Al -2.70688 0.95945 -6.32794
 Al 1.30579 3.10304 -5.34755
 Al -0.37821 2.20692 -7.56603
 Al 0.8704 -1.35096 -4.87768
 Al 2.0666 0.79328 -3.80154

Al -0.56466 -0.6745 -7.14333
 Al 1.83783 0.61131 -6.56664
 Al -1.16552 -2.31516 6.63808
 Al 1.50198 -2.07253 6.51937
 Al -0.03801 -1.01819 4.35044
 Al 0.24944 -1.85725 9.02841
 Al -2.24441 0.00403 5.81459
 Al 2.06959 0.39987 5.62413
 P 0.000 0.000 7.24151
 Al -2.15907 -0.53899 8.57023
 Al 2.32573 -0.12845 8.37057
 Al -0.24981 1.69629 5.20578
 Al 0.02739 0.92004 9.80139
 Al -1.5711 2.02064 7.65433
 Al 1.20044 2.27517 7.53596
 H -2.56265 0.22434 1.11683
 C -1.63656 0.81249 1.09703
 H -0.97941 -2.35365 2.39043
 H -1.57397 1.40681 2.01783
 H -1.66221 1.4854 0.23124
 H -1.00892 -2.10985 -0.72765
 C -0.07152 -1.74165 2.51595
 Ge -0.04349 -0.42982 0.9459
 C -0.11602 -1.46557 -0.78963
 H 0.78891 -2.41573 2.37607
 H 0.75898 -2.13604 -0.79395
 C 1.66918 0.65639 1.03634
 H 1.68541 1.27095 1.94515
 H 1.73216 1.3066 0.15407
 H 2.53155 -0.02234 1.04567
 H -2.97921 -5.86457 -6.30785
 C -3.63623 -6.39031 -5.60335
 H -4.53634 -6.71741 -6.14192
 H -3.11263 -7.28801 -5.24953
 H -6.33452 -2.93661 -6.78616
 H -6.40303 -5.08676 -5.76509
 C -3.9791 -5.49367 -4.41504
 H -4.78748 -1.30396 -5.89583
 O -2.93083 -2.85835 -4.5637
 N -4.69804 -4.28329 -4.80331
 C -4.14899 -3.06156 -4.82833
 C -6.37072 -2.87336 -5.69047
 C -6.13787 -4.26919 -5.08032
 H -3.06565 -5.16925 -3.90218

C -5.1908 -2.03411 -5.17762
 H -4.60445 -6.0327 -3.68648
 H -7.34616 -2.46208 -5.40992
 H -6.69306 -4.4191 -4.13911
 H -5.42549 -1.46386 -4.26422
 H 5.57079 1.56989 1.16347
 C 5.57329 2.05869 0.18059
 H 4.60277 2.55234 0.04465
 H 6.36183 2.82329 0.18766
 C 5.80388 1.01462 -0.90977
 H 4.99559 0.27217 -0.90624
 H 6.75602 0.48481 -0.75154
 N 5.83383 1.59247 -2.25086
 O 3.7859 0.8231 -2.90107
 H 7.3739 3.03039 -2.05125
 C 4.85393 1.45226 -3.1509
 C 7.0003 2.30481 -2.78498
 H 6.14199 3.99579 -3.84573
 H 7.80801 1.58165 -2.99125
 C 6.45853 2.96822 -4.06592
 C 5.23514 2.11876 -4.44495
 H 4.38152 2.68402 -4.84865
 H 7.2149 3.01168 -4.85647
 H 5.45973 1.33052 -5.18219

(EP)₃PAI₁₂Ge²_BPAI₁₂

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XYZ

P -0.06833 0.26195 -5.08497
 Al -2.26331 0.488 -3.68549
 Al -1.18557 2.53616 -5.19953
 Al -0.42983 -0.99608 -2.30281
 Al -1.68511 -1.89273 -4.731
 Al -0.06318 1.74914 -2.75644
 Al -2.25844 0.24573 -6.51746
 Al 1.61152 2.32479 -4.97166
 Al 0.2955 1.37862 -7.41479
 Al 0.96097 -2.04591 -4.39782
 Al 1.99045 0.13644 -3.21872

Al	-0.02936	-1.51012	-7.00457	H	-5.65566	-5.68967	-3.81048
Al	2.26598	-0.20535	-5.98005	H	-4.56249	-5.06025	-8.46987
Al	-0.73946	-2.54131	7.09549	H	-5.86876	-5.51054	-6.48131
Al	1.6937	-1.75679	6.2844	H	-3.96116	-3.02308	-7.2371
Al	-0.51874	-1.21631	4.56427	H	5.50065	-0.04703	2.04992
Al	1.0864	-1.63457	9.0265	C	5.67172	0.49909	1.11305
Al	-2.46951	-0.56964	6.54001	H	4.93104	1.30759	1.05098
Al	1.47346	0.70841	5.23702	H	6.6751	0.94391	1.16321
P	0.000	0.000	7.3342	C	5.5279	-0.45502	-0.06999
Al	2.50302	0.44405	7.83728	H	4.51615	-0.87854	-0.10053
Al	-1.10373	1.44138	5.39342	H	6.24417	-1.28729	0.01278
Al	0.45875	1.09065	9.78621	N	5.74373	0.19287	-1.35964
Al	-1.82226	1.67707	8.09546	O	3.57262	0.07121	-2.05896
Al	0.7072	2.49315	7.27032	H	7.64953	1.08095	-1.10517
H	-2.92905	0.24698	1.22422	C	4.77704	0.37756	-2.27417
C	-1.91372	0.65849	1.17133	C	7.07673	0.53375	-1.8654
H	-1.88567	-2.38596	2.74163	H	6.78022	2.44356	-2.85717
H	-1.74206	1.30563	2.0426	H	7.62604	-0.3941	-2.10352
H	-1.80998	1.246	0.25168	C	6.77784	1.37728	-3.11879
H	-1.73913	-2.36885	-0.53968	C	5.36441	0.94459	-3.53763
C	-0.84736	-2.02128	2.79458	H	4.72622	1.74434	-3.93935
Ge	-0.55341	-0.84493	1.14113	H	7.52589	1.22372	-3.90471
C	-0.72664	-1.93293	-0.54771	H	5.35563	0.14543	-4.29818
H	-0.1922	-2.90019	2.67134	H	-2.04562	6.43364	-2.98285
H	-0.0165	-2.77145	-0.45828	H	0.50091	6.11653	-3.51719
C	1.305	-0.02893	1.25699	H	-2.98236	3.67693	-1.74285
H	1.35238	0.68557	2.09029	C	0.70165	5.60205	-2.56609
H	1.5341	0.49226	0.31832	H	1.13126	4.62275	-2.82135
H	2.04674	-0.82008	1.42079	C	-1.67228	6.34252	-1.94916
H	-2.79027	-6.78815	-3.45612	N	-0.58694	5.35728	-1.92191
C	-3.88284	-6.89621	-3.4388	C	-0.96708	4.17812	-1.41416
H	-4.16277	-7.73543	-4.08987	H	-3.74572	5.97602	-1.32233
H	-4.18449	-7.15232	-2.41492	C	-2.41044	4.24633	-0.98784
H	-3.1549	-5.91969	-7.82044	O	-0.23516	3.14808	-1.36923
H	-4.75256	-6.89282	-6.34866	C	-2.72583	5.74848	-0.99582
C	-4.55943	-5.59433	-3.86321	H	-1.30596	7.32778	-1.62947
H	-2.3417	-3.69832	-7.3106	C	1.65545	6.41346	-1.692
O	-2.88412	-3.43242	-4.61213	H	2.597	6.57737	-2.23362
N	-4.21138	-5.18614	-5.22002	H	-2.564	3.74627	-0.02396
C	-3.4354	-4.12984	-5.50747	H	1.24181	7.39868	-1.43422
C	-3.96362	-5.22162	-7.56752	H	-2.59186	6.16555	0.01158
C	-4.80496	-5.7978	-6.41332	H	1.8836	5.87774	-0.76216
H	-4.25868	-4.77147	-3.20233	Al	-1.58198	-0.86896	9.19234
C	-3.37196	-3.92313	-6.99606				

(EP)₄PAI₁₂Ge²_BPAI₁₂

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XYZ

P 0.07604 0.16039 -3.80904
Al -1.96791 0.27727 -2.26234
Al -1.25411 2.39489 -3.91826
Al 0.18646 -1.13003 -1.18241
Al -1.34599 -2.0973 -3.35102
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