Tetrahedron xxx (xxxx) xxx

Contents lists available at ScienceDirect

Tetrahedron

journal homepage: www.elsevier.com/locate/tet

Aromatization-driven Grob-fragmentation approach toward polyazaacenes. Synthesis and amination of multi-functionalized diazapentacenes

Teh-Chang Chou [a, b, *], Ju-Fang Cheng [b], Atul R. Gholap [b], Jim Jing-Kai Huang [b], Jyun-Chang Chen [b], Jing-Kai Huang [a], Jui-Chang Tseng [b]

[a] Department of Chemistry and Biochemistry, National Chung Cheng University, Minsyong, Chiayi, 62102, Taiwan
[b] Department of Applied Chemistry, Chaoyang University of Technology, Wufong, Taichung, 41369, Taiwan

ARTICLE INFO

Article history:
Received 17 August 2019
Received in revised form
8 October 2019
Accepted 12 October 2019
Available online xxx

Keywords:
Polyazaacenes
Diazapentacenes
Acenes
Heteroacenes
Quinoxalines
ipso-Amination
Grob-fragmentation

ABSTRACT

A general approach toward the synthesis of multi-functionalized diazapentacene derivatives **1**, using 1,2,3,4-tetrachloro-5,5-dimethoxycyclopentadiene (TDCp, **2**), a substituted benzene-1,2-diamine (ADA, **6**), and a naphthalene-1,4-dione (BQ, **3**) as the building units, is described. The synthesis basically entails three operations: (i) oxidation of the dichloroetheno-bridge in the Diels-Alder cycloadduct **4** of TDCp and **3**, (ii) condensation of the 1,2-diketone **5** thus generated with an ADA to give quinoxaline-fused polycyclic compounds **7**, followed by (iii) an one-pot, three-reaction process keyed upon the base- or acid-catalyzed aromatization-driven Grob-type fragmentation to produce quinoxaline ring-embedded diazapentaceneesters **1**. The diazapentacene derivative **1a** underwent the nucleophilic aromatic *ipso*-amination with primary and secondary amines to afford the amino-substituted derivatives **12**, which tend to self-assemble in solid state driven by the cofacial π-stacking interactions, demonstrated by the crystal packing structures of **12a** and **12f**.

1. Introduction

Acenes ("carbo-acenes") are a class of polycyclic aromatic hydrocarbons (PAHs) composed of linearly fused benzene rings. The noteworthy features of extended planar structure, high rigidity, and the narrow gap between the HOMO and LUMO energy levels have promoted acenes to be attractive organic materials for use in molecular electronic devices [1]. Among them, pentacene proves to exhibit most outstanding properties in the fabrication of semiconductor devices and is most widely utilized to date. In conjunction with the promising properties and application, synthetic endeavors in quest of the applicable precursors and derivatives related to pentacene and higher acenes continues [2].

Concurrently, study on *N*-embedded heteroacenes (polyazaacenes) for the development of high-performance electronic materials has also been actively undertaken, both synthetically [3] and theoretically at a variety of levels [4]. Compared to carbo-acene analogues, which are p-type semiconductors in the solid state, *N*-heteroacenes are expected to be good candidates for n-type (electron-transporter) semiconducting material, since they generally have substantial less electron deficiency and higher electron affinity [4,5]. They also display other properties of significant interest. For example, they are more likely to form a cofacial π-stacking structure in favor of efficient orbital overlap and charge carrier transport than their non-aza-substituted analogues [6].

Even though the polyazaacenes show promise in various applications, there are only a few reports regarding their synthesis [3]. In particular, there is no general approach for the synthesis multi-functionalized derivatives, which could not only serve as proper precursors toward polyazaacenes but also allow appropriate elaboration of molecular structures at the periphery to provide accesses to a diversity of targeted molecules of interest and applications. In this context, we have developed a general synthetic approach toward the multi-functionalized polyazaacene derivatives having the generic structure **A** and preliminarily reported the representing synthesis and electronic properties of diazapentacenes (**1**: n = m = 1, Fig. 1) [7]. Molecules of **A** are composed of three basic

* Corresponding author. Department of Chemistry and Biochemistry, National Chung Cheng University, Minsyong, Chiayi, 62102, Taiwan.
E-mail address: chetcc@ccu.edu.tw (T.-C. Chou).

https://doi.org/10.1016/j.tet.2019.130689
0040-4020/

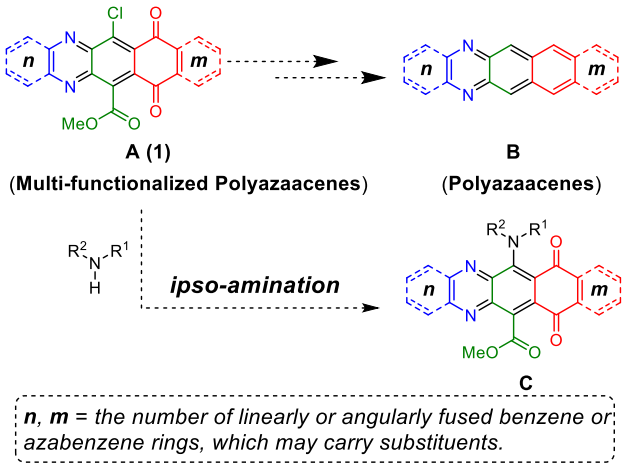
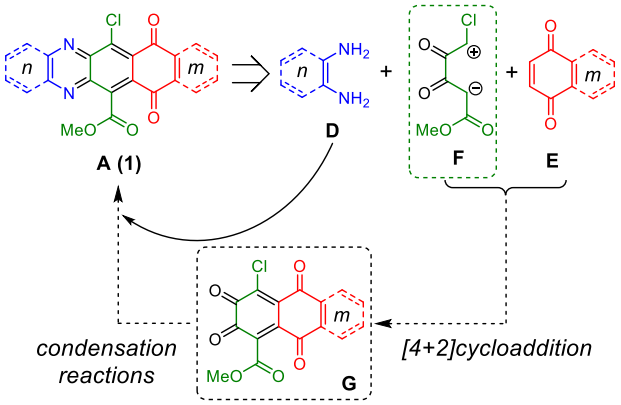


Fig. 1. The polyazaacene derivatives having the generic structure **A** that can be synthesized by the methodology of this study.



Scheme 1. Retro-synthetic analysis of the polyazaacene derivatives **A**.

aromatic ring systems of electron-accepting nature, namely pyrazine, 1,4-benzoquinone, and benzene with electron-withdrawing methoxycarbonyl and chloro substituents. The synthetic approach could potentially allow both pyrazine and 1,4-quinone ring systems to be polycyclically fused and peripherally incorporated with substituents. The inherent peripheral functional groups (−CO_2Me, −Cl, and =O) in **A** could be removed en route to the corresponding polyazaacenes **B** or be changed to modify the periphery of molecules. Because of the electron-withdrawing nature of functional groups, they are expected to have an electronic structure exhibiting high electron affinity.

It is well known that aromatic rings equipped with electron-withdrawing substituents could undergo nucleophilic aromatic substitution (S_NAr) in the presence of a variety of nucleophiles at the electrophilic carbon on which a good leaving group is attached—*ipso*-substitution [8]. Owing to the electron-withdrawing nature of the peripheral functional groups (−CO_2Me, −Cl, and =O), besides the imine (C=N) groups of pyrazine ring, polyazaacene derivatives **A** are expected to have an electronic structure exhibiting high electrophilicity and be able to undergo metal-free aromatic nucleophilic *ipso*-substitution reaction (S_NAr) at aryl carbon bearing chlorine atom. We thus carried out the *ipso*-amination of **A** with primary and secondary amines as nucleophiles. In this paper, we describe in detail the synthesis of multi-functionalized diazapentacenes (**1**: n = m = 1, Fig. 1) [7] and the results of the *ipso*-amination of **A** (**1**) to form the amino-substituted diazapentacenes **C**.

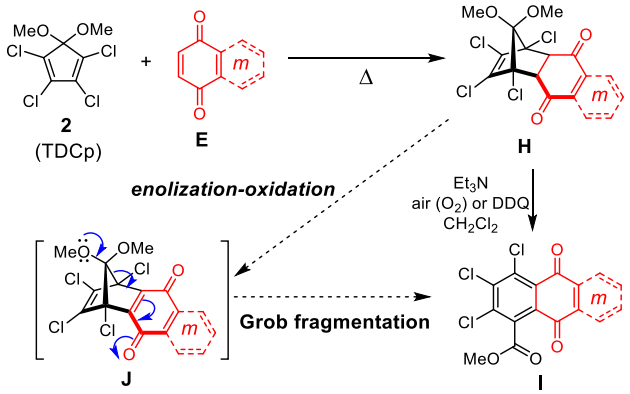
2. Results and discussion

2.1. Synthetic consideration

The approach toward the ring scaffold of polyazaacene **A** was realized conceptually by assembling three fundamental building units via annulation methods as illustrated in Scheme 1. The building units are an arene-1,2-diamine (ADA, **D**), a 1,4-benzoquinone (BQ, **E**), and a four-carbon 1,2-diketonic synthon **F**. Combination of the synthon **F** with a dienophile **E**, via a [4 + 2] cycloaddition with bond-multiplicity correction, would lead to the *para*-quinone-fused *ortho*-quinone **G**. The *ortho*-quinone **G** thus formed could deliver the corresponding polyazaacene **A** via the condensation reaction with **D** (ADA) by its two more electrophilic adjacent C=O groups; a classic, straightforward reaction that remains the most commonly and effective approach to the construction of quinoxaline derivatives [9]. Although 1,2-diketones are commonly obtainable by the oxidation of the corresponding 1,2-diols or α-hydroxyketones [10], the preparation of unsymmetrical 1,2-diketones, acyclic or cyclic, still is not a simple task, largely owing to the difficult accessibility of suitable precursors. Especially is the preparation of corresponding multi-functionalized catechols for making quinone-annulated *ortho*-quinone derivatives like **G** [11]. Obviously a source for an appropriate precursor must be sought.

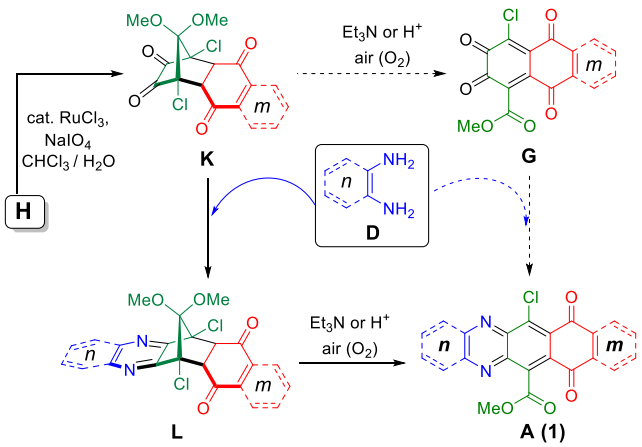
A precursor-in-thought for the diketonic compound **G** was transpired by the observed one-pot conversion shown in Scheme 2 [12,13]. The Diels–Alder cycloadducts **H** obtained from reactions of various BQ (**E**) and 1,2,3,4-tetrachloro-5,5-dimethoxycyclopentadiene (TDCp, **2**) [14] were promoted by triethylamine to yield the corresponding trichlorinated acenoquinone esters **I**. The facile Grob-type fragmentation of unstable intermediates **J**, formed via the triethylamine induced enolization-oxidation of **H**, is evidently driven by the collective effect of ring-strain relief, aromatization, and the proper push-pull setup for electrons to flow from the electron-releasing methoxy to the electron-withdrawing C=O group relayed by the C=C double bond [12,15]. The driving forces for the Grob-type fragmentation of **J** imply that the process could be also promoted under an acidic condition and be facilitated by replacing C(sp^2)–Cl on dichloroethene bridge of **H** with electron-withdrawing groups, such as carbonyl (C=O) or imino (C=N) [16].

As shown in Scheme 3, we envisioned that the cyclic diketonic



Scheme 2. Aromatization-driven Grob-fragmentation of the Diels–Alder cycloadducts **H**.

Please cite this article as: T.-C. Chou et al., Aromatization-driven Grob-fragmentation approach toward polyazaacenes. Synthesis and amination of multi-functionalized diazapentacenes, Tetrahedron, https://doi.org/10.1016/j.tet.2019.130689

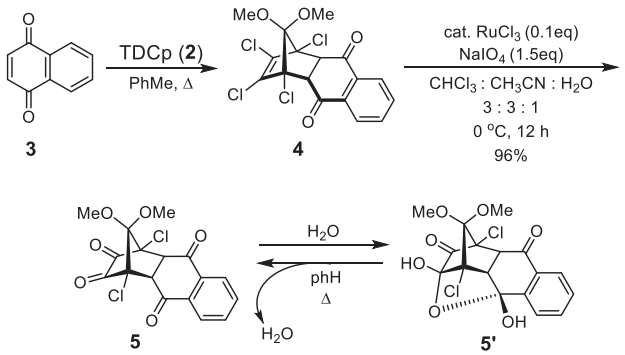


Scheme 3. The synthetic approach of the multi-functionalized diazapentacenes **A** keyed upon the aromatization-driven Grob fragmentation of the quinoxaline-fused polycyclic compounds **L**.

compounds **K**, which were made available from the Diels–Alder adducts **H** by Khan's oxidation protocol [$RuCl_3$(cat.)/$NaIO_4$] [17], might be the source for quinone-annulated *ortho*-quinones **G** via the Grob-type fragmentation promoted by triethylamine or an acid. Once the *ortho*-quinones **G** were in hand, condensation reactions with ADA (**D**) would afford the corresponding polyazaacenes **A** (**1**). However, decision was soon made to take an alternative route, since working with *ortho*-quinones **G** having five conjugated carbonyl groups appears to be disturbing. Thus, we chose to carry out the condensation reactions [18] of 1,2-diketones **K** with ADA (**D**) to obtain the curve-structured, quinoxaline-fused polycyclic compounds **L**, which were then subjected to the base or acid-promoted Grob-type fragmentation. As expected, the three-step transformation (**H** → **K** → **L** → **A**, Scheme 3), keyed upon the aromatization-driven Grob fragmentation, have realized our rational thinking to bestow the quinoxaline ring-embedded polyazaacenes **A**, as demonstrated by the synthesis of diazapentacenes **1**.

2.2. Synthesis of diazapentacenes

The known Diels–Alder cycloadduct **4** (**H**: m = 1) between TDCp (**2**) and naphthalene-1,4-dione (**3**, **E**: m = 1) was utilized as the starting material [12,14,19]. As shown in Scheme 4, when compound **4** was subjected to the modified Khan's oxidation procedure [17] employing $RuCl_3 \cdot 3H_2O/NaIO_4$ in a solvent system of $CHCl_3/CH_3CN/H_2O$ (3:3:1) at 0 °C for 12 h, a product was isolated in 96%,



Scheme 4. The synthesis of 1,2-diketone **5** and its monohydrated derivative **5′**.

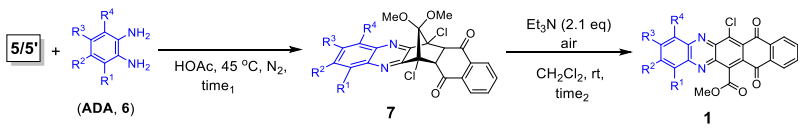
which displayed a rather complex ^{1}H NMR spectrum and an IR spectrum containing absorption bands attributable to hydroxyl and carbonyl groups. Apparently, the product was obtained in the monohydrate form **5′** resulting from transannular hemiacetal formation; a commonly phenomenon observed in the RuO_4 oxidation of structurally similar Diels–Alder adducts [17a,c], as shown in Scheme 4. Dehydration by benzene under azeotropic reflux yielded hygroscopic 1,2- diketone **5** (**K**: m = 1), indicated by the expected simple and symmetry-reflect ^{1}H NMR spectrum [7].

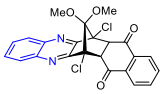
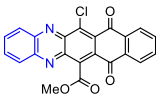
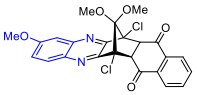
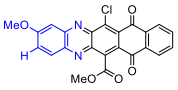
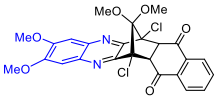
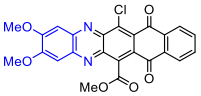
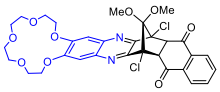
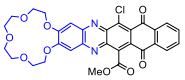
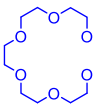
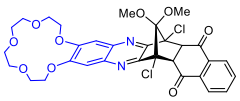
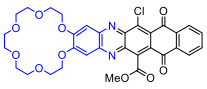
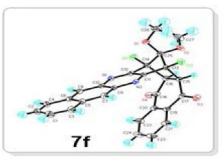
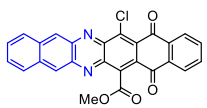
In practice, monohydrated 1,2-diketone **5′** was used directly in the condensation reactions with various ADA [**D**: substituted benzene-1,2-diamines (**6a**–**e**) or naphthalene-2,3-diamine (**6f**)] in AcOH at 45 °C under N_2 atmosphere for a period of time to afford colorless crystals of the corresponding quinoxaline ring-fused derivatives **7a**–**f** isolated in moderate yields of 55–75% by direct filtration. As expected, the successive enolization-oxidation-fragmentation reactions of **7a**–**f** performed under previously employed protocol (Scheme 2) furnished respectively the bright yellow-colored solids of diazapentacene esters **1a**–**f**, albeit the isolated yields were only moderate in the range of 45–75%. The results are summarized in Table 1. It was found necessary to conduct the condensation reactions at 45 °C to minimize AcOH-promoted decomposition of 1,2-diketone **5**/**5′**, which occurred at higher temperature and particularly in the absence of ADA [16,20]. All compounds **7a**–**f** were properly characterized and the general structures of **7** was supported by the single-crystal X-ray analysis of **7f** (Insert, Table 1). Compound **1f** (reddish solids) derived from **7f** is a diazahexacene derivative, considered here for descriptive convenience to be a benzodiazapentacene derivative. All diazapentacene esters **1a**–**f** were properly characterized by spectral analyses, and among them **1a**, **1b-*a***, and **1f** had been reported earlier (Table 1, entries 1, 2, and 6) [7]. A case merits attention (entry 2). Quinoxaline ring-fused compound **7b**, unlike others, is asymmetrical and was expected to render two isomeric fragmentation products, in which the methoxy group is anti (**1b-*a***) or syn (**1b-*s***) to the methoxycarbonyl group. However, only one regioisomer was found, which was identified by X-ray crystallography to be the anti-isomer **1b-*a*** [7].

The two-step synthesis of diazapentacene derivatives **1** form 1,2-diketone **5**/**5′** resulted in low overall yields (<40%) of desired products (Table 1) [21]. With the expectation that the successive enolization-oxidation-fragmentation transformation of quinoxaline ring-fused compound **7** to diazapentacenes **1** could be promoted under acidic conditions, we decided to amend the synthetic method by a one-pot operation without isolation of the condensation products **7** as shown in Table 2. Thus, a solution of equal molar of 1,2-diketone **5**/**5′** and an ADA (**6a**–**c**, **6f**, **6g**, and **6h**) in AcOH was heated at 45 °C under N_2 atmosphere for 3 h; the same procedure (Table 1) used previously to ensure the complete conversion of **5**/**5′** to the condensation product **7**. The reaction mixture was then heated at refluxing temperature for 24–48 h under air atmosphere, followed by removal of solvent AcOH under reduced pressure to give a dark-colored solid residue, which was water-rinsed and subsequently subjected to stirring at room temperature with 5% aq. NaOH in CH_2Cl_2 under air atmosphere for 2 h [22]. The corresponding bright yellow-colored diazapentacene derivatives **1a**–**c** and **1f**–**h** were obtained in much improved overall yields ranging from about 70% to 90%. It is interesting to note that both anti- and syn-regioisomers were observed in diazapentacene derivatives **1** derived from unsymmetrical ADA (**6b**, **6g**, and **6h**). The ratios of anti-to syn-isomer for **1b**-*a*:**1b**-*s*, **1g**-*a*:**1g**-*s*, and **1h**-*a*:**1h**-*s* were 2.3:1, 1.3:1, and 1:1.9, respectively, determined by ^{1}H NMR spectral analysis. It is also interesting to recall that only one regioisomer (**1b-*a***) was observed previously (Table 1, entry 2) [7]. The observations suggest that the Grob-type fragmentation

Please cite this article as: T.-C. Chou et al., Aromatization-driven Grob-fragmentation approach toward polyazaacenes. Synthesis and amination of multi-functionalized diazapentacenes, Tetrahedron, https://doi.org/10.1016/j.tet.2019.130689

Table 1
Two-step synthesis of diazapentacene derivatives **1a**–**f** from 1,2-diketone **5**/**5'** via the condensation products **7a**–**f** followed by the consecutive enolization-oxidation-fragmentation reactions of **7a**–**f** promoted by triethylamine.

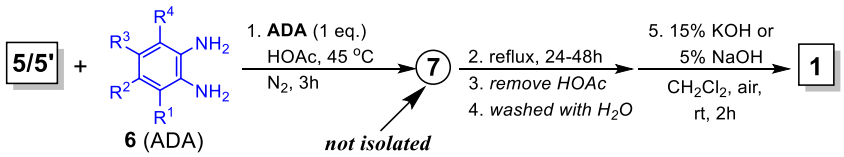


entry		6					7		1
		R^1	R^2	R^3	R^4		(time$_1$, yield) [a,b]		(time$_2$, yield) [a,b]
1	**6a**	H	H	H	H	**7a**		**1a**	
							(2 h, 71%)		(24 h, 52%)
2	**6b**	H	H	OMe	H	**7b**		**1b-*a***	
							(4 h, 76%)		(18 h, 49%)
3	**6c**	H	OMe	OMe	H	**7c**		**1c**	
							(3 h, 54%)		(30 h, 76%)
4	**6d**	H			H	**7d**		**1d**	
							(0.5 h, 59%)		(30 h, 65%)
5	**6e**	H			H	**7e**		**1e**	
							(0.5 h, 56%)		(30 h, 68%)
6	**6f**	H			H	**7f**		**1f**	
							(3 h, 76%) [c]		(24 h, 48%)

[a] The progress of reaction (the reaction time) was monitored by TLC or ^{1}H NMR spectroscopy.
[b] The yields are for the isolated products after purification via flash chromatography or recrystallization.
[c] The structure of compound **7f** is supported and shown in the Table by its X-ray crystal structure.

Please cite this article as: T.-C. Chou et al., Aromatization-driven Grob-fragmentation approach toward polyazaacenes. Synthesis and amination of multi-functionalized diazapentacenes, Tetrahedron, https://doi.org/10.1016/j.tet.2019.130689

Table 2
The synthesis of diazapentacenes **1** from 1,2-diketone **5**/**5′** and arene-1,2-diamine (ADA) by a one-pot operation without isolation of the intermediate quinoxaline ring-fused compounds **7**.



entry	ADA	R^1	R^2	R^3	R^4	Product (1)	Yield (%)[a]
1	**6a**	H	H	H	H	**1a**	92
2	**6b**	H	H	OMe	H	**1b-*a*** 2.2 : 1 **1b-*s***	74
3	**6c**	H	OMe	OMe	H	**1c**	79
4	**6f**	H	benzo		H	**1f**	89
5	**6g**	NO_2	H	H	H	**1g-*a*** 1.3 : 1 **1g-*s***	83
6	**6h**	H	H	NO_2	H	**1h-*a*** 1 : 1.9 **1h-*s***	82

[a] Isolated yields of one-pot operation.

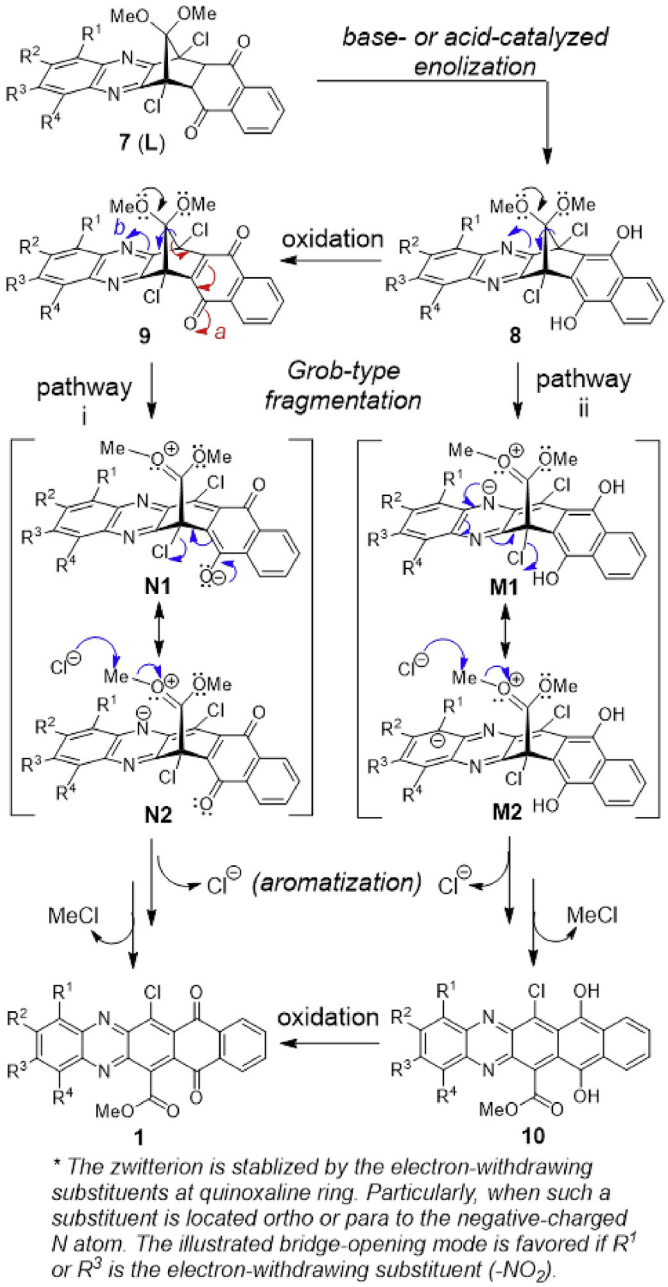
pathways for **7** leading to the regioisomeric diazapentacenes **1** could be directed by the electronic nature and the location of substituent at quinoxaline ring. We discuss this point in the next section.

2.3. Mechanistic consideration

The synthesis of the flat diazapentacene carboxylates **1** (**A**) is keyed upon the aromatization-driven Grob fragmentation of quinoxaline-fused, bridged polycyclic compounds **7** (**L**) (Scheme 3). Scheme 5 illustrates two plausible pathways for the fragmentation of **7** which involve the unstable hydroquinone **8** and benzoquinone **9** as key intermediates. As shown for the bridge-opening of benzoquinone **9** (pathway i), the fragmentation is driven by, besides the relief of ring strain and aromatization, the push−pull setup for electrons to flow from −OMe to C═O group (a) relayed by the enone C═C bond [12,15] or (b) directly to the nitrogen atom of properly situated C═N group [16] to form a zwitterion having a structure of **N1** or **N2**, respectively. Structures **N1** and **N2** are in fact mesomeric. In contrast, the bridge-opening of hydroquinone **8** (pathway ii), lacking the electron-withdrawing enone moiety, involves only electron-flow from −OMe directly to C═N group, forming a zwitterion with mesomeric structures **M1** and **M2**. Both fragmentation pathways are expected to be accelerated by the acid catalyst, which forms complex with carbonyl oxygen or imine nitrogen and hence increases electron pull ability of aromatic rings in hydroquinone **8** and benzoquinone **9**. The intermediate zwitterions **M** and **N** thus generated expel chloride ion to achieve aromatization followed by elimination of methyl group in form of CH_3Cl to yield diazapentacene derivatives **1** and the antecedent non-oxidized hydroquinone esters **10**, respectively.

Both fragmentation pathways proposed in Scheme 5 would be additionally facilitated by the presence of electron-withdrawing substituents at quinoxaline ring. Particularly, when such an electron-withdrawing substituent is located ortho or para to the imine group that accepts the electrons flowing from the adjacent bridge C−C bond being ruptured, because the zwitterions thus formed would gain more stabilization. The preference of one

Please cite this article as: T.-C. Chou et al., Aromatization-driven Grob-fragmentation approach toward polyazaacenes. Synthesis and amination of multi-functionalized diazapentacenes, Tetrahedron, https://doi.org/10.1016/j.tet.2019.130689



Scheme 5. Two plausible pathways for the Grob-fragmentation of the quinoxaline ring-fused compounds **7**.

bridge-opening mode over the other is consequently expected to be dictated by the electronic nature and location of substituent at quinoxaline ring. For example, if R^1 (or R^3) is an electron-withdrawing substituent, such as $-NO_2$, the bridge-opening mode illustrated in Scheme 5 would be favored, leading to the formation of more anti-regioisomer (or syn-regioisomer) in the final product mixture of **1**. The mechanistic rationale is supported by the experimental results. As shown in Table 2, the fragmentation of **7g** ($R^1 = NO_2$) in AcOH resulted in the formation of a mixture of regioisomeric **1g** in favor of anti-regioisomer **1g-*a*** by a ratio of 1.3:1, whereas the fragmentation of **7h** ($R^3 = NO_2$) gave a mixture of **1h-*a*** and **1h-*s*** in a ratio of 1:1.9. Exchanging NO_2 group by an electron-releasing substituent, the AcOH-catalyzed fragmentation of **7b** ($R^3 = OMe$) at refluxing temperature led to the formation of a mixture of **1b-*a*** and **1b-*s*** in a ratio of 2.2:1, the opposite regioselectivity displayed by **7h** ($R^3 = NO_2$). Incidentally, the regioselectivity was much enhanced in the Et_3N-promoted fragmentation of **7b** in CH_2Cl_2 at lower temperature (rt), which gave only the anti-isomeric **1b-*a*** (Table 1) [7].

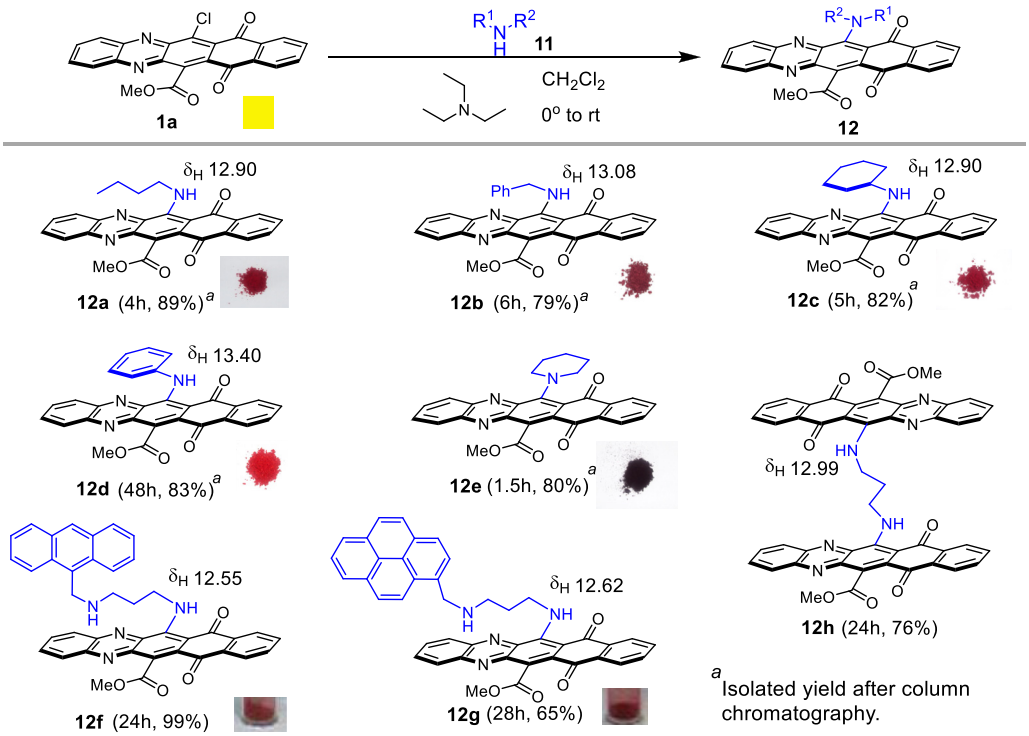
2.4. Amination of Diazapentacene 1a

In all the cases, the aromatic nucleophilic *ipso*-substitution [8] of **1a** at the aryl carbon bearing chlorine atom to produce the amino-substituted diazapentacene derivatives **12** were performed in dichloromethane using triethylamine as HCl-scavenger. The results of the *ipso*-amination reactions of **1a** are outlined in Scheme 6. Thus, a primary amine [butan-1-amine (**11a**), phenylmethanamine (**11b**), cyclohexanamine (**11c**), aniline (**11d**)] or a secondary amine [piperidine (**11e**)] was dissolved in CH_2Cl_2 and added in dropwise manner to an ice-water cooled CH_2Cl_2 solution containing **1a** and molar equivalent of Et_3N. A change of solution color from pale yellow to pink or dark purple was instantly noticed [23]. After the addition of amine was complete (<30 min), the reaction mixture was allowed to warm to room temperature and stirred for a period of time, thereby affording the dark colored solids of amino-substituted diazapentacenes **12a-e** in yields ranging from 80% to 90%. Under similar condition, *ipso*-amination of **1a** to render amino-substituted diazapentacenes **12f** and **12g** was realized in yields of 99% and 65%, respectively, via reactions with the corresponding hydrochloride salts of N^1-(arylmethyl)propane-1,3-diamines **11f** [24] and **11g**. When a CH_2Cl_2 solution containing **1a** and Et_3N was treated under similar condition with 0.5 molar equivalent of propane-1,3-diamine (**11h**) as an aminating agent, a binary amination occurred to furnish the corresponding 1,5-diazapentandiyl-tethered diazapentacene **12h** in 76% yield.

In the ^1H and ^{13}C NMR spectra of diazapentacene derivatives **12a-h**, besides the signals and pattern inherited from **1a**, signals assignable to the corresponding hydrogen and carbon atoms of the appending alkylamino-substituent were observed (see Supplementary data). Particularly worthy of attention is the observed diagnostic *N*—H proton signal at extra lower field ($\delta \sim 13$ ppm, Scheme 6) in the ^1H NMR spectra of compounds **12a-d/f-h** derived from the *ipso*-amination with primary amines (**11a-d/f-h**). The low-field signal is attributable to the intramolecular hydrogen bonding between the *N*—H and nearby oxygen atom of naphthoquinone C═O group, which is also revealed in the X-ray crystal structures of **12a** and **12f**.

Single crystals of **12a** and **12f** were grown by slow evaporation of $CHCl_2$ or $CHCl_3$/*n*-Hex solution. The ORTEP plots of their X-ray crystal structures are depicted in Fig. 2. The tables for crystal data/structure refinement are provided in the Supplementary Data. The *n*-butylamino-appended diazapentacene **12a** displayed two molecular structures in the crystal, different in the conformation of *n*-butyl chain. Two conformational isomers exhibited the N—H•••O hydrogen bonding of different distance and angle (Fig. 2A). Compound **12f** (Fig. 2B) consists of electron-accepting diazapentacene and electron-releasing naphthalene rings, connected by a 1,5-diazahexandiyl linker. An intramolecular hydrogen bonding between N—H and C═O groups was also observed. Resembling the previous reported crystal structure of **1b-*a*** [7], the plane of diazapentacene ring of **12a** and **12f** is slightly twisted (ca. 6°/10°) and aligns in a nearly perpendicular manner (ca. 101°/93°) with the plane of the appending methoxycarbonyl (—COOMe) group.

The electron-deficient aromatic rings tend to self-assemble in the solid state by the cofacial packing arrangement driven by π-stacking interactions [25]. As illustrated in Fig. 3, single crystals of **12a** and **12f** (cf. **1a** and **1b-*a***) [7] evidently implement π-stacking motifs in mode of either direct face-to-face or parallel-displaced



Scheme 6. Amination of Diazapentacene **1a**.

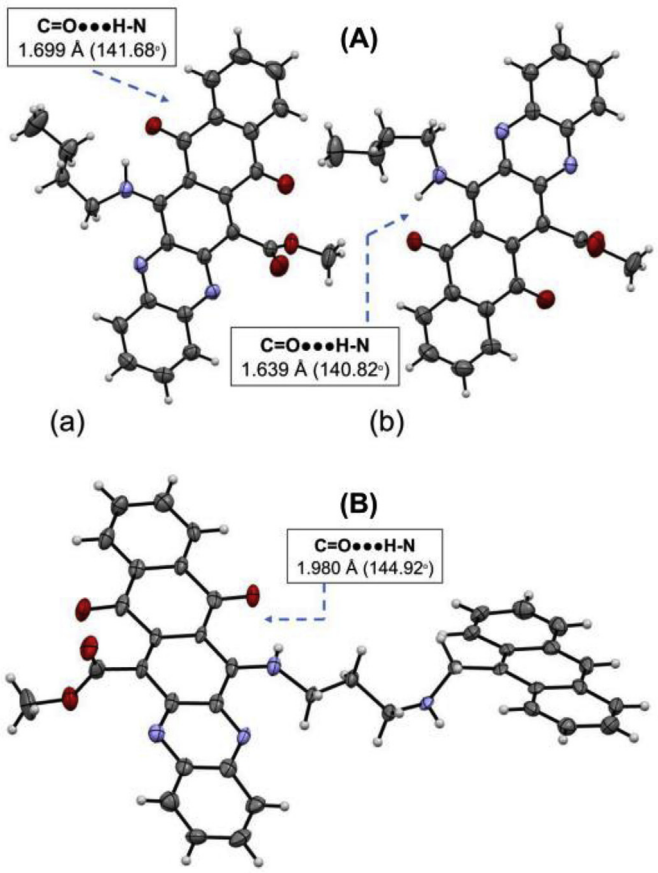


Fig. 2. ORTEP plots of amino-substituted diazapentacenes: (A) Two observed. conformers of **12a** and (B) **12f.**

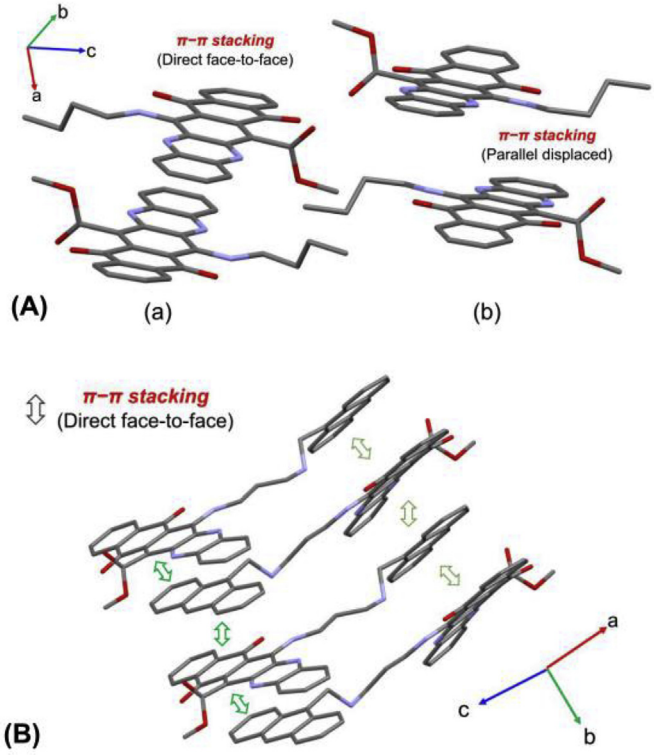


Fig. 3. The crystal packing diagrams showing cofacial π−π stacking structures: (A) **12a** and (B) **12f**. Hydrogen atoms in the crystal packing diagrams are hidden for clarity. Two conformers of **12a** show different π−π stacking modes independently. Compound **12f** displays π−π stacking arrangement of the electron-rich naphthalene ring against the electron-deficient diazapentacene ring and the solvate ($CHCl_3$) molecules in the crystal are hidden.

Please cite this article as: T.-C. Chou et al., Aromatization-driven Grob-fragmentation approach toward polyazaacenes. Synthesis and amination of multi-functionalized diazapentacenes, Tetrahedron, https://doi.org/10.1016/j.tet.2019.130689

geometry [26] between aromatic rings as pivotal crystal packing motifs. The π-stacked column has regular alternating intermolecular distances forming cofacial π-stacks of π-dimers. As shown in Fig. 3A, each of conformational isomeric molecules of **12a** independently stacks against identical molecules on both sides in a head-to-tail style via cofacial π-stacking interactions, alternatively in mode of face-to-face and parallel-displaced geometry, leading to the formation of ribbon-like packing structures along crystallographic *ac*-plane. The most prominent feature displayed in the crystal packing structure of **12f** is the head-to-tail, face-to-face π−π stacking arrangement of the electron-rich naphthalene and the electron-deficient diazapentacene rings (Fig. 3B), which well demonstrates an electron donor−acceptor driven π−π stacking [27], forming deck-like packing structures along crystallographic *ab*-plane.

3. Conclusion

We have developed a general synthetic approach (Schemes 1 and 3) toward the multi-functionalized polyazaacene derivatives having the generic structure **A** by demonstrating the synthesis of quinoxaline ring-embedded diazapentacene esters **1** (Tables 1 and 2). The synthetic strategy utilizes three fundamental building units: 1,2,3,4-tetrachloro-5,5-dimethoxycyclopentadiene (TDCp, **2**), a naphthalene-1,4-dione (BQ, **3**), and an arene-1,2-diamines (ADA, **6**). The synthetic approach basically consists of three operations: (i) oxidation of the dichloroetheno-bridge in the Diels-Alder cycloadduct **4** derived from BQ and TDCp, (ii) condensation of the 1,2-diketone **5** thus generated with an ADA to give curved quinoxaline-fused polycyclic compounds **7**, followed by (iii) an one-pot, three-reaction process keyed upon the base- or acid-catalyzed aromatization-driven Grob-type fragmentation to produce planar quinoxaline ring-embedded diazapentacene esters **1**. We have also taken advantage of the electron affinity nature of diazapentacene ring bestowed by the electron-withdrawing functional groups to examine the *ipso*-amination of **1a** with electron-donating primary and secondary amines as nucleophiles (Scheme 6), paving the way for exploring prospective application of synthesizing the D−π−A molecules (push−pull systems) [28]. The present synthetic strategy appears flexible and feasible as manifested by the occurrence of two changeable building units: BQ (**3**) and ADA (**6**), and the amendable functional groups. We envisage the synthetic approach could be further exploited to make analogous polyazaacene systems of interest and applications.

4. Experimental section

4.1. General

Melting points were determined in capillaries and are uncorrected. ^{1}H and ^{13}C NMR spectra were recorded at ambient temperature. Chemical shift (δ) and coupling constant (J) were expressed in unit of ppm and Hz, respectively. The chemical shift of $CHCl_3$ was calibrated at δ 7.26 ppm in ^{1}H NMR spectra and δ 77.0 ppm in ^{13}C NMR spectra. Multiplicities of splitting pattern in ^{1}H NMR spectra were abbreviated: s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet) and br (broad). All ^{13}C NMR spectra were recorded with the protons completely decoupled. The number of attached hydrogen on the carbon atom was determined by the Distortionless Enhancement by Polarization Transfer (DEPT) analysis. Infrared (IR) spectra were obtained using samples suspended in a KBr disk. The spectral data were recorded in unit of wavenumber (cm^{-1}). Mass spectral (MS) analysis, both low and high resolution (HRMS), was performed with a double focusing mass spectrometer. Electron-Impact (EI) mass spectra were obtained at an electron beam energy of 70 eV, unless otherwise specified. Fast atom bombardment (FAB) mass spectra were obtained with a resolution of 8000 and 3000 for HR and LR FAB-mass spectra, respectively. The source accelerating voltage was operated at 10 kV with Xe gun for FAB-mass spectra, using 3-nitrobenzyl alcohol as matrix. Low resolution MS spectral data were reported at *m/z*, and the relative intensities (%) were expressed in parenthesis, where the base peak was calibrated to be 100. The X-ray crystallographic data were recorded with a Bruker AXS SMART APEX CCD X-ray diffractometer. Graphite monochromatized Mo Kα radiation [λ = 0.71073 Å] and temperature of 298 (2) K were used. The CCD data were processed with SAINT and the structures were solved by direct method (SHELXS-97) and refined on F^2 by full-matrix least-squares techniques (SHELXL-97). Thin-layer chromatography (TLC) was performed on E. Merck silica gel 60 F_{254} plate (0.20 mm). The developed TLC sheets were examined under UV light. 1,4-Naphthoquinone (**3**) was commercially available and was purified by recrystallization. Unless otherwise stated, all other reagents, such as 1,2-diaminoarenes (**6**) and amines (**11**) were purchased from Merck or Aldrich, and used without further purification; solvents were used without further distillation.

4.2. Synthesis

4.2.1. Ruthenium-promoted $NaIO_4$-oxidation of Diels-Alder cycloadduct 4. preparation of 1,2-diketone 5

A solution of $RuCl_3 \cdot 3H_2O$ (49 mg, 0.24 mmol) in water (16 mL) was added in portions to a suspension of **4** (1000 mg, 2.37 mmol) and $NaIO_4$ (760 mg, 3.55 mmol) in a mixture of $CHCl_3$ (48 mL) and CH_3CN (48 mL), cooled with an ice-water bath at 0 °C. The progress of reaction was monitored by TLC or ^{1}H NMR spectroscopy. After the reaction was completed (~12 h), the lower organic layer (pale yellow colored) of the resulting reaction mixture was separated from the top aqueous layer (red brownish colored) and filtered through a pad of Celite to give 1,2-diketone **5** in monohydrate form **5'** (910 mg, 96%) after removal of solvent. 1,2-Diketonic monohydrate **5′** could be dehydrated to hygroscopic 1,2-diketone **5** by benzene under azeotropic reflux with a Dean-Stark apparatus.

5': colorless solids; mp 142−148 °C (dehydrated); IR (cm^{-1}) 3545, 3320 (br), 1788, 1677, 1597, 1278, 1225; ^{1}H NMR (200 MHz, $CDCl_3$) δ 3.68 (s, 3 H), 3.70 (s, 2 H), 3.76 (s, 3 H), 7.48−7.56 (m, 1 H), 7.66−7.73 (m, 1 H), 7.92−8.00 (m, 2 H); MS (FAB) *m/z* (%) 403 ($M^+ + 2$, 11.5), 401 (M^+, 15.5), 383 ($M^+ - H_2O$, 8.2), 333 (28.0), 307 (68.2), 301 (32.5), 289 (49.7). HRMS (FAB) Calcd for $C_{17}H_{15}Cl_2O_7$ ($M^+ + H$): 401.0189; Found: 401.0209.

5: colorless solids; mp 267 °C (decomp.); IR (cm^{-1}) 1798, 1770, 1690, 1590, 1289, 1220; ^{1}H NMR (200 MHz, $CDCl_3$) δ 3.61 (s, 3 H), 3.83 (s, 3 H), 4.03 (s, 2 H), 7.77 (dd, J = 3.2, 6.0 Hz, 2H), 7.92 (dd, J = 3.3, 5.9 Hz, 2H). HRMS (FAB) Calcd for $C_{17}H_{13}Cl_2O_6$ ($M^+ + H$): 383.0084; Found: 383.0090.

4.2.2. General procedure for the preparation of quinoxaline-fused polycyclic compounds 7

Into a solution of 1,2-diketone monohydrate **5′** or **5** (1.00 mmol) in acetic acid (8 mL) was added arene-1,2-diamine (1.10 mmol) [*o*-phenylenediamine (**6a**), 4-methoxybenzene-1,2-diamine (**6b**), 4,5-dimethoxybenzene-1,2-diamine (**6c**), 3,4-diaminobenzo-15-crown-5-ether (**6d**), 3,4-diaminobenzo-18-crown-6-ether (**6e**), or naphthalene-2,3-diamine (**6f**)]. The reaction mixture was stirred at 45 °C under N_2 atmosphere for a period of time (~3 h), and the progress of reaction was monitored by TLC or ^{1}H NMR spectroscopy. After the reaction was complete, the reaction mixture was cooled to room temperature. The resulting solid residue of quinoxaline product was collected by filtration, washed with acetic acid (~2 mL) and then with water (~10 mL). The filtrate was added water to

Please cite this article as: T.-C. Chou et al., Aromatization-driven Grob-fragmentation approach toward polyazaacenes. Synthesis and amination of multi-functionalized diazapentacenes, Tetrahedron, https://doi.org/10.1016/j.tet.2019.130689

precipitate the second crop of crude product, collected by filtration. The combined crude product was purified via recrystallization from EtOH/$CHCl_3$ (3/2 by vol.) to afford the corresponding pure quinoxaline-fused polycyclic compounds **7a**–**f**.

7a. Reaction time 2 h, yield 71%, colorless crystals; mp 239 °C (decomp.); IR (cm^{-1}) 1686, 1590, 1290, 1248, 1178, 999; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.52 (s, 3H), 3.89 (s, 3H), 4.16 (s, 2H), 7.06 (dd, J = 5.8, 3.3 Hz, 2H), 7.41 (dd, J = 5.8, 3.3 Hz, 2H), 7.62 (dd, J = 6.2, 3.2 Hz, 2H), 7.91 (dd, J = 6.2, 3.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.6 (C), 150.5 (C), 142.1 (C), 134.7 (C), 133.4 (CH), 130.2 (CH), 129.0 (CH), 126.1 (CH), 110.9 (C), 73.9 (C), 54.1 (CH), 52.8 (CH_3), 52.6 (CH_3); MS (FAB) *m/z* (%) 457 (M^+ + H + 2, 80.6), 456 (M^+ + H + 1, 54.9), 455 (M^+ + H, 93.5), 454 (M^+, 21.3), 307 (59.7), 289 (51.7). HRMS (FAB) Calcd for $C_{23}H_{17}Cl_2N_2O_4$ (M^+ + H): 455.0560; Found: 455.0553. Anal Calcd for $C_{23}H_{16}Cl_2N_2O_4$: C, 60.67; H, 3.54; N, 6.15; O, 14.06; found: C, 60.72; H, 3.55; N, 5.94; O, 14.18.

7b. Reaction time 4 h, yield 76%, green solids; mp 250 °C (decomp.); IR (cm^{-1}) 1711, 1692, 1660, 1624, 1590, 1487; ^{1}H NMR (500 MHz, CD_2Cl_2) δ 3.53 (s, 3 H), 3.91 (s, 3 H), 3.93 (s, 3 H), 4.15 (s, 2 H), 7.16–7.18 (m, 2H), 7.26 (d, J = 2.5 Hz, 1H), 7.31 (dd, J = 9, 2.5 Hz, 1H), 7.41–7.44 (m, 2 H), 7.78 (d, J = 9 Hz, 1H); ^{13}C NMR (125 MHz, CD_2Cl_2) δ 191.1 (C), 191.0 (C), 161.4 (C), 150.6 (C), 148.0 (C), 144.2 (C), 138.2 (C), 135.0 (2 × C), 133.8 (CH), 133.7 (CH) (CH), 130.0 (C) (CH), 126.2 (C) (CH), 123.1 (C) (CH), 111.3 (C), 107.4 (CH), 74.5 (C), 74.3 (C), 56.2 (CH) (CH_3), 54.6 (2 × CH), 53.0 (CH_3), 52.8 (CH_3); MS (EI) *m/z* (%) 484 (M^+, 63), 449 (M^+ − Cl, 33), 413 (M^+ − 2Cl, 100), 317 (55). HRMS (EI) Calcd for $C_{24}H_{18}Cl_2N_2O_5$ (M^+): 484.0593; Found: 484.0591. Anal Calcd for $C_{24}H_{18}Cl_2N_2O_5$: C, 59.40; H, 3.74; N, 5.77; O, 16.48; found: C, 59.28; H, 3.70; N, 5.68; O, 16.25.

7c. Reaction time 3 h, yield 54%, colorless crystals; mp 277–278 °C; IR (cm^{-1}) 2952 (w), 2930 (w), 2857 (w), 1684 (s), 1591 (w), 1467 (m), 1294 (w), 1237 (s), 1192 (m), 734 (m); ^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 7.48 (dd, J = 5.8, 3.3 Hz, 2 H), 7.23 (s, 2 H), 7.15 (dd, J = 5.8, 3.3 Hz, 2 H), 4.15 (s, 2 H), 3.95 (s, 6 H), 3.88 (s, 3 H), 3.51 (s, 3 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 190.9 (C), 152.7 (C), 147.7 (C), 139.3 (C), 134.8 (C), 133.4 (CH), 126.2 (CH), 111.3 (C), 106.9 (CH), 74.1 (C), 56.4 (CH_3), 54.4 (CH), 52.7 (CH_3), 52.5 (CH_3); MS (EI, 70 eV) *m/z* (%) 516 (M^+ + 2, 15), 514 (M^+, 22), 479 (M^+ − Cl, 21), 443 (M^+ − 2Cl − H, 100); HRMS (EI, 70 eV) Calcd for $C_{25}H_{20}Cl_2N_2O_6$ (M^+): 514.0698; Found: 514.0692; Anal. Calcd for $C_{25}H_{20}Cl_2N_2O_6$: C, 58.27; H, 3.91; N, 5.44; O, 18.63; Found: C, 58.14; H, 3.80; N, 5.43; O, 18.55.

7d. Reaction time 0.5 h, yield 59%, colorless crystals; mp 246–250 °C; IR (cm^{-1}) 2950 (w), 2873 (w), 1688 (s), 1592 (w), 1447 (m), 1292 (m), 1246 (s), 1190 (s), 1129 (s), 752 (m); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43 (dd, J = 5.8, 3.3 Hz, 2 H), 7.15 (dd, J = 5.8, 3.3 Hz, 2 H), 7.13 (s, 2 H), 4.15–4.11 (m, 6 H), 3.92–3.91 (m, 4 H), 3.86 (s, 3 H), 3.80–3.72 (m, 8 H), 3.49 (s, 3 H); ^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 190.8 (C), 152.3 (C), 147.4 (C), 139.2 (C), 134.6 (C), 133.5 (CH), 126.0 (CH), 111.2 (C), 107.3 (CH), 74.0 (C), 70.9 (CH_2), 69.7 (CH_2), 68.6 (CH_2), 68.2 (CH_2), 54.3 (CH), 52.6 (CH_3), 52.4 (CH_3); MS (EI, 70 eV) *m/z* (%) 646 (M^+ + 2, 21), 644 (M^+, 30), 608 (M^+ − HCl, 22), 573 (M^+ − 2Cl − H, 100); HRMS (EI, 70 eV) Calcd for $C_{31}H_{30}Cl_2N_2O_9$ (M^+): 644.1328; Found: 644.1335; Anal. Calcd for $C_{31}H_{30}Cl_2N_2O_9$: C, 57.68; H, 4.68; N, 4.34; O, 22.31; Found: C, 57.80; H, 4.28; N, 4.19; O, 22.50.

7e. Reaction time 0.5 h, yield 58%, colorless crystals; mp 242–246 °C; IR (cm^{-1}) 2949 (w), 2818 (w), 1687 (s), 1590 (w), 1444 (m), 1290 (m), 1240 (s), 1189 (s), 732 (w); ^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 7.45 (dd, J = 5.3, 3.3 Hz, 2 H), 7.18 (dd, J = 5.8, 3.3 Hz, 2 H), 7.16 (s, 2 H), 4.20–4.13 (m, 6 H), 3.99–3.90 (m, 4 H), 3.87 (s, 3 H), 3.77–3.68 (m, 12 H), 3.50 (s, 3 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 190.9 (C), 152.3 (C), 147.5 (C), 139.2 (C), 134.7 (C), 133.7 (CH), 126.1 (CH), 111.3 (C), 107.4 (CH), 74.1 (C), 70.8 (CH_2), 70.6 (CH_2), 70.3 (CH_2), 68.9 (CH_2), 68.8 (CH_2), 54.4 (CH), 52.7 (CH_3), 52.5 (CH_3); MS (EI, 70 eV) *m/z* (%) 690 (M^+ + 2, 63), 688 (M^+, 90), 652 (M^+ − HCl, 52), 617 (M^+ − 2Cl − H, 100); HRMS (EI, 70 eV) Calcd for $C_{33}H_{34}Cl_2N_2O_{10}$ (M^+): 688.1591; Found: 688.1599.

7f. Reaction time 3 h, yield 76%, dark green solids; mp 224 °C (decomp.); IR (cm^{-1}) 1687, 1590, 1295, 1182, 999; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.55 (s, 3 H), 3.92 (s, 3 H), 4.20 (s, 2 H), 6.95 (dd, J = 5.8, 3.3 Hz, 2H), 7.47 (dd, J = 5.8, 3.3 Hz, 2H), 7.58 (dd, J = 6.5, 3.2 Hz, 2H), 8.02 (dd, J = 6.5, 3.2 Hz, 2H), 8.50 (s, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.6 (C), 151.3 (C), 138.2 (C), 134.7 (C), 133.6 (C), 133.5 (CH), 128.4 (CH), 127.8 (CH), 127.3 (CH), 126.2 (CH), 110.0 (C), 74.0 (C), 53.9 (CH), 52.8 (CH_3), 52.6 (CH_3); MS (FAB) *m/z* (%) 507 (M^+ + H + 2, 54.8), 506 (M^+ + 2, 41.9), 505 (M^+ + H, 65.3), 504 (M^+, 26.1), 433 (22.4), 337 (23.7), 289 (29.9). HRMS (FAB) Calcd for $C_{27}H_{19}Cl_2N_2O_4$ (M^+ + H): 505.0716; Found: 505.0714. Anal Calcd for $C_{27}H_{18}Cl_2N_2O_4$: C, 64.17; H, 3.59; N, 5.54; O, 12.66; found: C, 64.05; H, 3.81; N, 5.36; O, 12.77.

4.2.3. General procedure for the synthesis of diazapentacene esters 1 from 7

Triethylamine (2.12 mmol) was added into an uncapped reaction bottle containing a stirring solution of quinoxaline-fused polycyclic compounds **7** (1.00 mmol) in dichloromethane (30 mL) at room temperature. The progress of reaction was monitored by TLC or ^{1}H NMR spectroscopy. After the compound **7** completely disappeared, the reaction mixture was cooled with an ice-water bath and quenched by the addition of saturated aqueous ammonium chloride solution (25 mL). The organic layer was separated, washed sequentially with water (50 mL × 3) and brine (50 mL × 3). The organic layer was dried over anhydrous magnesium sulfate and filtered, and the filtrate was concentrated in vacuo. The colored solid residue thus obtained was purified via flash chromatography and recrystallization ($CHCl_3$/EtOH) to afford the corresponding pure diazapentacene esters **1a**–**f**.

1a. Reaction time 24 h, yield 52%, bright yellow crystallines; mp 319–321 °C (decomp.); IR (cm^{-1}) 1736, 1680, 1590, 1560, 1505, 1405, 1244, 1009; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.29 (s, 3 H), 7.85–7.90 (m, 2 H), 8.01–8.03 (m, 2 H), 8.32–8.34 (m, 2 H), 8.39–8.42 (m, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 181.6 (C), 181.3 (C), 168.0 (C) 145.2 (C), 145.1 (C), 141.9 (C), 141.4 (C), 139.5 (C), 136.1 (C), 135.6 (C), 135.5 (CH), 134.7 (CH), 133.8 (CH), 133.7 (CH), 133.1 (C), 130.6 (CH), 130.5 (CH), 129.7 (C), 128.8 (C), 128.3 (CH), 127.8 (CH), 53.6 (CH_3); MS (EI) *m/z* (%) 404 (M^+, 11.8), 402 (M^+, 34.6), 373 (34.4), 372 (32.0), 371 (M^+ − OMe, 100), 252 (24.6). HRMS (EI) Calcd for $C_{22}H_{11}ClN_2O_4$ (M^+): 402.0407; Found: 402.0399. Anal Calcd for $C_{22}H_{11}ClN_2O_4$: C, 65.60; H, 2.75; N, 6.95; O, 15.89; found: C, 65.60; H, 2.92; N, 6.89; O, 15.53.

1b. Reaction time 18 h, yield 49%. bright yellow crystallines; mp 250–251 °C; sparsely soluble in $CHCl_3$ and CH_2Cl_2, IR (cm^{-1}) 1734, 1678, 1622, 1471, 1409, 1297, 1239, 1202, 1004; ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.10 (s, 3 H), 4.28 (s, 3H), 7.59 (d, J = 2.5 Hz, 1H), 7.66 (dd, J = 9.5, 2.5 Hz, 1 H), 7.84–7.91 (m, 2 H), 8.18 (d, J = 9.5 Hz, 1 H), 8.33 (d, J = 7.5 Hz, 1H), 8.40 (d, J = 7.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 181.6, 181.1, 168.1, 164.0, 146.9, 142.7, 141.9, 139.5, 138.0, 135.9, 135.4, 135.2, 134.4, 132.8, 131.4, 129.9, 128.7, 128.2, 128.0, 127.5, 104.9, 56.6, 53.3; MS (FAB) *m/z* (%) 432 (M^+, 49), 401 (M^+ − OMe, 100), HRMS (EI) Calcd for $C_{23}H_{13}ClN_2O_5$ (M^+): 432.0513; Found: 432.0518. Anal Calcd for $C_{23}H_{13}ClN_2O_5$: C, 63.83; H, 3.03; N, 6.47; O, 18.48; found: C, 63.60; H, 2.98; N, 6.15; O, 18.45.

1c. Reaction time 30 h, yield 76%, bright yellow crystallines; mp > 325 °C (decomp.); IR (cm^{-1}) 3022 (w), 2953 (w), 2923 (w), 2850 (w), 1738 (m), 1681 (m), 1553 (w), 1414 (m), 1295 (s), 1230 (s), 1198 (m), 724 (w); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.39 (d, J = 7.5 Hz, 1 H), 8.22 (d, J = 7.0 Hz, 1 H), 7.88 (t, J = 6.8 Hz, 1 H), 7.83 (t, J = 7.0 Hz, 1 H), 7.55 (s, 1 H), 7.44 (s, 1 H), 4.28 (s, 3 H), 4.16 (d, J = 5.5 Hz, 6 H); ^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 181.6 (C), 181.3

Please cite this article as: T.-C. Chou et al., Aromatization-driven Grob-fragmentation approach toward polyazaacenes. Synthesis and amination of multi-functionalized diazapentacenes, Tetrahedron, https://doi.org/10.1016/j.tet.2019.130689

(C), 168.4 (C), 157.2 (C), 157.1 (C), 144.2 (C), 144.1 (C), 140.6 (C), 140.0 (C), 138.1 (C), 135.4 (C), 135.1 (CH), 135.1 (C), 134.2 (CH), 132.8 (C), 128.5 (C), 128.0 (CH), 127.6 (C), 127.4 (CH), 105.7 (CH), 105.6 (CH), 57.1 (CH_3), 57.0 (CH_3), 53.3 (CH_3); MS (EI, 70 eV) *m/z* (%) 464 ($M^+ + 2$, 20), 462 (M^+, 57), 431 ($M^+ -$ OMe, 100); HRMS (EI, 70 eV) Calcd for $C_{24}H_{15}ClN_2O_6$ (M^+): 462.0619; Found: 462.0617; Anal. Calcd for $C_{24}H_{15}ClN_2O_6$: C, 62.28; H, 3.27; N, 6.05; O, 20.74; Found: C, 61.96; H, 3.40; N, 5.79; O, 20.57.

1d. Reaction time 30 h, yield 65%, bright yellow crystallines; mp > 316–318 °C (decomp.); IR (cm^{-1}) 2941 (w), 2875 (w), 1736 (m), 1678 (m), 1561 (w), 1449 (m), 1296 (s), 1227 (m), 1198 (m), 728 (w); ^1H NMR (500 MHz, $CDCl_3$) δ 8.39 (d, $J = 7.5$ Hz, 1 H), 8.32 (d, $J = 8.0$ Hz, 1 H), 7.88 (t, $J = 7.0$ Hz, 1 H), 7.83 (t, $J = 7.5$ Hz, 1H), 7.42 (s, 1 H), 7.34 (s, 1 H), 4.37 (d, $J = 3.0$ Hz, 4 H), 4.28 (s, 3 H), 4.00 (s, 4 H), 3.77 (dd, $J_1 = 7.1$ $J_2 = 4.8$ Hz, 8 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 181.5 (C), 181.3 (C), 168.4 (C), 156.7 (C), 156.5 (C), 144.1 (C), 144.0 (C), 140.4 (C), 140.0 (C), 138.0 (C), 135.4 (C), 135.0 (CH), 135.0 (C), 134.2 (CH), 132.9 (C), 128.3 (C), 127.9 (CH), 127.4 (CH), 127.3 (C), 105.8 (d, 2 C), 71.1 (CH_2), 69.8 (CH_2), 69.0 (CH_2), 68.9 (CH_2), 68.5 (CH_2), 53.2 (CH_3); MS (EI, 70 eV) *m/z* (%) 594 ($M^+ + 2$, 19), 592 (M^+, 47), 563 ($M^+ + 2 -$ OMe, 2), 561 ($M^+ -$ OMe, 6), 559 ($M^+ + 2 -$ Cl, 3), 557 ($M^+ -$ Cl, 3), 533 ($M^+ -$ CO_2Me, 17), 429 ($M^+ - C_6H_{12}O_3 -$ OMe, 100); HRMS (EI, 70 eV) Calcd for $C_{30}H_{25}ClN_2O_9$ (M^+): 592.1249; Found: 592.1238; Anal. Calcd for $C_{30}H_{25}ClN_2O_9$: C, 60.76; H, 4.25; N, 4.72; O, 24.28; Found: C, 60.58; H, 4.37; N, 4.67; O, 24.20.

1e. Reaction time 30 h, yield 68%, bright yellow crystallines; mp 298–300 °C (decomp.); IR (cm^{-1}) 2958 (w), 2919 (w), 2874 (w), 1731 (m), 1678 (m), 1556 (w), 1481 (m), 1295 (s), 1225 (s), 1196 (s), 1117 (s), 725 (w); ^1H NMR (500 MHz, $CDCl_3$) δ 8.38 (d, $J = 7.5$ Hz, 1 H), 8.31 (d, $J = 7.0$ Hz, 1 H), 7.88 (t, $J = 7.5$ Hz, 1 H), 7.83 (t, $J = 7.3$ Hz, 1H), 7.49 (s, 1 H), 7.38 (s, 1 H), 4.42 (d, $J = 0.5$ Hz, 4 H), 4.27 (s, 3 H), 4.05 (s, 4 H), 3.81 (d, $J = 4.5$ Hz, 4 H), 3.76–3.72 (m, 8 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 181.6 (C), 181.3 (C), 168.4 (C), 156.8 (C), 156.6 (C), 144.1 (C), 144.0 (C), 140.5 (C), 139.9 (C), 138.0 (C), 135.4 (C), 135.0 (CH), 135.0 (C), 134.2 (CH), 132.8 (C), 128.3 (C), 127.9 (CH), 127.4 (C), 127.4 (CH), 105.9 (CH), 105.8 (CH), 71.1 (CH_2), 70.7 (CH_2), 70.5 (CH_2), 69.8 (CH_2), 69.6 (CH_2), 68.7 (CH_2), 53.3 (CH_3); MS (EI, 70 eV) *m/z* (%) 638 ($M^+ + 2$, 34), 636 (M^+, 86), 607 ($M^+ + 2 -$ OMe, 3), 605 ($M^+ -$ OMe, 9), 603 ($M^+ + 2 -$ Cl, 8), 601 ($M^+ -$ Cl, 5), 577 ($M^+ -$ CO_2Me, 26), 429 ($M^+ - C_8H_{16}O_4 -$ OMe, 100); HRMS (EI, 70 eV) Calcd for $C_{32}H_{29}ClN_2O_{10}$ (M^+): 636.1511; Found: 636.1516.

1f. Reaction time 24 h, yield 48%. Deep reddish solids; mp 324–329 °C (decomp.); IR (cm^{-1}) 1731, 1678, 1589, 1395, 1280, 1252, 1011; ^1H NMR (400 MHz, $CDCl_3$) δ 4.34 (s, 3 H), 7.56–7.59 (m, 2 H), 7.86–7.92 (m, 2 H), 8.14–8.15 (m, 2 H), 8.35 (d, $J = 7.1$ Hz, 1H), 8.42 (d, $J = 7.4$ Hz, 1H), 9.00 (s, 1 H), 9.09 (s, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 181.3 (C), 181.0 (C), 167.8 (C), 141.6 (C), 141.4 (C), 140.6 (C), 140.4 (C), 139.7 (C), 136.5 (C), 136.4 (C), 136.3 (C), 135.5 (C), 135.3 (CH), 134.5 (CH), 132.9 (C), 129.1 (C), 129.0 (CH), 128.9 (CH), 128.8 (CH), 128.5 (CH), 128.5 (CH), 128.2 (C), 128.1 (CH), 127.6 (CH), 53.4 (CH_3); MS (FAB) *m/z* (%) 454 (M^+, 38.0), 452 (M^+, 100), 423 (41.0), 422 (50.9), 421 ($M^+ -$ OMe, 95.5), 394 (17.0), 302 (37.3), 142 (24.3). HRMS (EI) Calcd for $C_{26}H_{13}ClN_2O_4$ (M^+): 452.0564; Found: 452.0569. Anal Calcd for $C_{26}H_{13}ClN_2O_4$: C, 68.96; H, 2.89; N, 6.19; O, 14.13; O; found: C, 68.95; H, 3.03; N, 5.95; O, 14.08.

4.2.4. General procedure for the one-pot synthesis of diazapentacene esters 1 from 5

A solution of 1,2-diketone monohydrate **5′** or **5** (1.00 mmol) in AcOH (8 mL) containing arene-1,2-diamine (1.10 mmol) [*o*-phenylenediamine (**6a**), 4-methoxybenzene-1,2-diamine (**6b**), 4,5-dimethoxybenzene-1,2-diamine (**6c**), naphthalene-2,3-diamine (**6f**), 3-nitrobenzene-1,2-diamine (**6g**), or 5-nitrobenzene-1,2-diamine (**6h**)] was stirred at 45 °C under N_2 atmosphere for 3 h. After the reaction mixture was subsequently heated in the open air under reflux for 24–48 h, the solvent (AcOH) was removed under reduced pressure. The resulting dark-colored residue (containing compounds **1** and **10**, analyzed by ^1H NMR spectroscopy) was rinsed with water and dissolved in dichlomethane. An aqueous solution of NaOH (5%) or KOH (15%) was then added and the reaction mixture was stirred at room temperature for a period of time. The progress of reaction was monitored by TLC or ^1H NMR spectroscopy or color changing from brown to yellow. After the reaction was completed (<2 h), the lower organic layer of the resulting reaction mixture was separated, washed with water, filtered through a pad of Celite, and concentrated under reduced pressure. The solid residue thus obtained was purified via flash chromatography or recrystallization to afford the corresponding pure colored diazapentacene esters **1a** (92%), **1b** (74%), **1c** (79%), **1f** (89%), **1g** (83%), and **1h** (82%).

1g-*a* + **1g-*s***. yellow crystals; mp 270–275 °C (decomp.); ^1H NMR (500 MHz, $CDCl_3$) δ 8.70 (d, $J = 9$ Hz, 1 H), 8.59 (d, $J = 9$ Hz, 1 H), 8.53 (d, $J = 7.5$ Hz, 1 H), 8.45 (d, $J = 7.5$ Hz, 1 H), 8.41 (d, $J = 7$ Hz, 1 H), 8.35 (dd, $J = 6$ Hz, 2 H), 8.10 (m, 2 H), 7.93 (dd, $J = 7.5$ Hz, 2 H), 7.88 (dd, $J = 7$ Hz, 2 H), 4.28 (s, 6 H).

1h-*a* + **1h-*s***. yellow crystals; mp 256–260 °C (decomp.); ^1H NMR (500 MHz, $CDCl_3$) δ 9.39 (d, $J = 2$ Hz, 1 H), 9.28 (d, $J = 2$ Hz, 1 H), 8.64 (dt, $J = 9.5$, 2 Hz, 2 H), 8.63 (d, $J = 9.5$ Hz, 1 H), 8.53 (d, $J = 9.5$ Hz, 1 H), 8.42 (d, $J = 7.5$ Hz, 2 H), 8.36 (d, $J = 7.5$ Hz, 2 H), 7.94 (dd, $J = 7.5$ Hz, 2 H), 7.89 (dd, $J = 7$ Hz, 2 H), 4.31 (s, 3H), 4.29 (s, 3H).

4.2.5. tert-butyl 3-(pyren-1-ylmethylamino)propylcarbamate (11g•Boc)

The procedure for the preparation of the Boc-protected *N* [1]-(anthracen-9-ylmethyl)propane-1,3-diamine (**11f**) was generally followed.[29] A solution of pyrene-1-carbaldehyde (2.06 g, 8.9 mmol) in MeOH/CH_2Cl_2 (20 mL, 1:3 by vol.) was added under N_2 atmosphere into a stirred solution of mono-Boc-protected 1,3-diamine (1.95 g, 11 mmol) in MeOH/CH_2Cl_2 (20 mL, 1:3 by vol.). The mixture was stirred at room temperature for 20 h and then cooled to 0 °C with an ice-water bath. $NaBH_4$ (22 mmol) was added in small portions to the solution and the mixture was stirred at room temperature for 18 h. The solvent was removed in vacuo. The solid residue thereby obtained was dissolved in CH_2Cl_2 (40 mL) and washed with aqueous Na_2CO_3 solution (10%, 30 mL × 3). The organic layer was dried over anhydrous Na_2SO_4 and filtered, and the solvent was removed in vacuo to give an oily residue. The oil was purified by flash column chromatography (3% MeOH/$CHCl_3$) to yield **11g•Boc** as a thick oil (82%): IR (cm^{-1}) 3366 (m), 2913 (s), 2849 (s), 1698 (s), 1364 (s), 1249 (m), 1169 (s); ^1H NMR (500 MHz, $CDCl_3$) δ 1.42 (s, 9 H), 1.6–1.8 (m, 2 H), 2.85 (t, $J = 6.6$ Hz, 2 H), 3.25 (m, 2 H), 4.46 (s, 2 H), 5.10–5.38 (br, 1 H), 8.00 (t, $J = 7.5$ 2 H), 8.04 (s, 2 H), 8.10–8.15 (m, 2 H), 8.15–8.21 (m, 2 H), 8.37 (d, $J = 9.5$ Hz, 1 H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 28.4 (CH_3), 29.9 (CH_2), 39.4 (CH_2), 48.0 (CH_2), 51.9 (CH_2), 78.9 (CH), 123.1 (CH), 124.6 (CH), 124.9 (C), 125.0 (CH), 125.0 (C), 125.0 (CH), 125.8 (CH), 127.0 (CH), 127.0 (CH), 127.4 (CH), 127.6 (CH), 129.0 (C), 130.6 (C), 130.8 (C), 131.3 (C), 133.7 (C), 156.1 (C); MS (EI, 70 eV) 388 (M^+, 2), 331 (15), 230 (44), 215 (100), 201 (6). HRMS (EI, 70 eV) *m/z* (%) Calcd for $C_{25}H_{28}N_2O_2$ (M^+): 388.2151; Found: 388.2155; Anal. Calcd for $C_{25}H_{28}N_2O_2$: C, 77.29; H, 7.26; N, 7.21; O, 8.24; Found: C, 77.60; H, 7.42; N, 7.35; O, 8.29.

4.2.6. General procedure for amination of diazapentacene 1a. Synthesis of compounds 12a–h

Into a stirring solution of compound **1a** (1 mmol) and Et_3N (1.1 mmol) in DCM (20 mL) was added in dropwise manner at 0 °C a DCM (5 mL) solution of amine (1.1 mmol) [butan-1-amine (**11a**), phenylmethanamine (**11b**), cyclohexanamine (**11c**), aniline (**11d**), piperidine (**11e**), N^1-(anthracen-9-ylmethyl)propane-1,3-diamine (**11f**), N^1-(pyren-1-ylmethyl)propane-1,3-diamine (**11g**), or

Please cite this article as: T.-C. Chou et al., Aromatization-driven Grob-fragmentation approach toward polyazaacenes. Synthesis and amination of multi-functionalized diazapentacenes, Tetrahedron, https://doi.org/10.1016/j.tet.2019.130689

propane-1,3-diamine (**11h**, 0.5 mmol)]. The hydrochloride salts of **11f** and **11g** were used which were generated in situ from the corresponding Boc-protected precursors (**11f•Boc** and **11g•Boc**) by treatment in absolute ethanol with a 4 N HCl solution. After addition of amine was completed, the reaction mixture was allowed to warm to room temperature and stirred for a period of time (1.5–48 h). The progress of reaction was monitored by TLC. After the completion of reaction, water was added to reaction mixture and stirred for a few min. The organic layer was separated, concentrated, and purified by flash chromatography using DCM as eluant.

12a: Reaction time 4 h, yield 89%, burgundy wine color crystals; mp 225–227 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.06 (t, J = 7.5 Hz, 3H), 1.63–1.67 (m, 2H), 1.93 (quin, J = 7.5 Hz, 3H), 4.21 (s, 3H), 4.58 (m, 2H), 7.69–7.72 (m, 1H), 7.79–7.85 (m, 2H), 7.88–7.91 (m, 1H), 8.16 (d, J = 8 Hz, 1H), 8.20 (d, J = 8 Hz, 1H), 8.26 (d, J = 7.5 Hz, 1H), 8.37 (d, J = 7.5 Hz, 1H), 12.90 (br, 1H); ^{13}CNMR (125 MHz, $CDCl_3$) δ 13.9, 20.3, 32.7, 48.3, 52.9, 105.5, 123.1, 126.8, 127.1, 129.90, 129.95, 130.6, 131.1, 132.6, 132.71, 132.77, 134.6, 135.8, 139.3, 140.7, 143.7, 143.9, 153.7, 169.5, 182.2, 183.0; HRMS calcd for $C_{26}H_{21}N_3O_4$: 439.1532. Found 439.1541.

12b: Reaction time 6 h, yield 79%, reddish brown color crystals; mp > 300 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.21 (s, 3H), 5.78 (s, 2H), 7.30–7.38 (m, 3H), 7.50–7.52 (m, 2H), 7.71–7.85 (m, 4H), 8.07 (d, J = 8.0 Hz, 1H), 8.18 (d, J = 8.0 Hz, 1H), 8.27 (d, J = 7.2 Hz, 1H), 8.33 (d, J = 7.2 Hz, 1H), 13.08 (br 1H); ^{13}CNMR (125 MHz, $CDCl_3$) δ 52.2, 52.9, 106.1, 123.6, 126.9, 127.2, 127.4, 127.5, 128.9, 129.7, 129.9, 130.5, 131.3, 132.6, 132.7, 132.9, 134.6, 135.6, 138.8, 139.0, 140.7, 143.72, 143.79, 153.1, 169.4, 182.7, 182.9; HRMS calcd for $C_{29}H_{19}N_3O_4$: 473.1376. Found: 473.1371.

12c: Reaction time 5 h, yield 62%, deep plum reddish color crystals; mp 245–247 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.43–2.35 (m, 10H), 4.21 (s, 3H), 5.50 (br, 1H), 7.70 (td, J = 1.1, 7.5 Hz, 1H), 7.81 (td, J = 1.1, 7.5 Hz, 1H), 7.83–7.87 (m, 1H), 7.89–7.92 (m, 1H), 8.13 (d, J = 8.5 Hz, 1H), 8.21 (d, J = 8.5 Hz, 1H), 8.26 (d, J = 8.0 Hz, 1H), 8.38 (d, J = 8.0 Hz, 1H), 12.9 (br, 1H); ^{13}CNMR (125 MHz, $CDCl_3$) δ 25.1, 25.9, 34.4, 53.2, 55.8, 105.7, 123.3, 127.0, 127.4, 130.1, 130.2, 131.1, 131.5, 132.8, 132.9, 134.9, 136.1, 141.0, 144.0, 144.1, 153.1, 169.8, 182.5, 183.3; HRMS calcd for $C_{28}H_{23}N_3O_4$: 465.1689. Found: 465.1679.

12d: Reaction time 48 h, yield 83%, deep orange color crystals; mp 253–255 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.26 (s, 3H), 7.20 (d, J = 7.8, 2H), 7.27–7.30 (m, 1H), 7.33–7.36 (m, 2H), 7.43 (d, J = 8.0, 1H), 7.68 (td, J = 1.2, 7.9 Hz, 1H), 7.76 (td, J = 1.1, 7.4 Hz, 1H), 7.81–7.85 (m, 2H), 8.16 (d, J = 8.3 Hz, 1H), 8.31 (d, J = 7.8 Hz, 1H), 8.38 (d, J = 7.8 Hz, 1H), 13.40 (br 1H); ^{13}CNMR (125 MHz, $CDCl_3$) δ 53.0, 108.6, 124.4, 125.4, 125.5, 127.1, 127.4, 128.5, 129.7, 129.8, 130.0, 131.5, 132.7, 132.8, 133.4, 134.8, 135.3, 137.2, 140.3, 142.4, 143.1, 144.3, 150.5, 169.1, 182.5, 183.5; HRMS calcd for $C_{28}H_{17}N_3O_4$: 459.1219. Found 459.1213.

12e: Reaction time 1.5 h, yield 80%, dark violet color crystals; mp > 300 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.92–1.98 (m, 6H), 3.81 (br, 4H), 4.22 (s, 3H), 7.73 (td, J = 7.3, 1.2 Hz, 1H), 7.81 (td, J = 1.2, 7.5 Hz, 1H), 7.86–7.90 (m, 2H), 8.16–8.18 (m, 1H), 8.21–8.23 (m, 1H), 8.26 (d, J = 8.0 Hz, 1H), 8.31 (d, J = 8.0 Hz, 1H); ^{13}CNMR (125 MHz, $CDCl_3$) δ 24.5, 27.0, 53.0, 56.4, 115.8, 126.2, 127.1, 129.8, 131.5, 132.0, 132.1, 132.7, 132.9, 134.7, 136.5, 141.1, 142.7, 142.9, 143.5, 152.5, 169.3, 179.4, 183.4; HRMS calcd for $C_{27}H_{21}N_3O_4$: 451.1533. Found: 451.1525.

12f: Reaction time 24 h, yield 99%, reddish crystals; mp 208–210 °C (decomp.); IR (cm^{-1}) 3358 (m), 2918 (s), 2849 (s), 1717 (w), 1650 (m), 1541 (m), 1288 (m); ^{1}H NMR (500 MHz, CD_2Cl_2) δ 2.05–2.08 (m, 2 H), 3.14 (t, J = 6.2 Hz, 2 H), 4.17 (s, 3 H), 4.47 (q, J = 5.8 Hz, 2 H), 4.72 (s, 2 H), 7.07 (dd, J = 8.1 Hz, 2H), 7.26 (dd, J = 8.1 Hz, 2H), 7.68 (d, J = 8.1 Hz, 2H), 7.70 (dd, J = 7.6 Hz, 1H), 7.75 (dd, J = 7.6 Hz, 1 H), 7.81 (dd, J = 7.6 Hz, 1H), 7.90 (dd, J = 7.6 Hz, 1H), 7.92 (d, J = 7.6 Hz, 1H), 8.12 (s, 1H), 8.16 (d, J = 7.6 Hz, 1H), 8.17 (d, J = 7.6 Hz, 1H), 8.25 (d, J = 7.3 Hz, 1H), 8.32 (d, J = 8.1 Hz, 2H); ^{13}C NMR (125 MHz, CD_2Cl_2) δ 30.6 (CH_2), 45.0 (CH_2), 45.4 (CH_2), 45.7 (CH_2), 52.11 (CH_3), 104.9 (C), 122.4 (C), 123.8 (CH), 124.1 (CH), 125.1 (CH), 126.3 (C), 126.3 (C), 126.4 (C), 128.3 (CH), 128.9 (CH), 129.4 (CH), 129.7 (C), 130.1 (C), 130.5 (C), 130.7 (C), 131.2 (C), 132.2 (CH), 132.4 (CH), 134.1 (CH), 135.4 (C), 138.6 (C), 140.1 (C), 143.2 (C), 143.3 (C); MS (ESI$^+$) 632 (M^+ + 2, 41), 631 (M^+ + H, 100), 437 (4), 191 (46); HRMS (ESI$^+$) m/z (%) Calcd for $C_{40}H_{31}O_4N_4$ (M + H): 631.2340; Found: 631.2343.

12g: Reaction time 28 h, yield 85%, reddish crystals; mp 190–193 °C; IR (cm^{-1}) 3362 (s), 2918 (s), 2849 (s), 1646 (s), 1541 (s), 1374 (s), 1288 (m); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.093 (m, 2 H), 3.09 (t, J = 6.5 Hz, 2H), 4.23 (s, 3H), 4.44–4.60 (m, 4H), 7.55 (dd, J = 7.5 Hz, 1H), 7.66 (dd, J = 7.5 Hz, 1H), 7.69–7.78 (m, 4H), 7.79–7.97 (m, 8H), 8.03 (d, J = 7.5 Hz, 1H), 8.07 (d, J = 8.5 Hz, 1H), 8.15 (d, J = 7.5 Hz, 1H), 8.20 (d, J = 7.5 Hz, 1H), 8.32 (d, J = 9 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 30.9 (CH_2), 46.0 (CH_2), 46.3 (CH_2), 52.1 (CH_2), 52.9, (CH_3), 105.4(C), 123.0 (C), 23.2 (CH), 124.4 (CH), 124.5 (C), 124.8 (CH), 125.1 (CH), 125.8 (CH), 126.6 (CH), 127.0 (CH), 127.0 (CH), 127.2 (CH), 127.3 (CH), 127.3 (CH), 129.1 (C), 129.7 (CH), 129.7 (CH), 130.4 (C), 130.5 (C), 130.5 (C), 130.9 (CH), 130.9 (C), 132.4 (CH), 132.5 (CH), 132.6 (CH), 133.7 (C), 134.4 (CH), 135.6 (C), 139.0 (C), 140.4 (C), 143.5 (C), 143.7 (C), 153.2 (C), 169.4 (C), 181.9 (C), 182.9 (C); MS (EI, 70 eV) 654 (M^+, 0.01), 352 (16), 231 (52), 215 (100), 201 (34); HRMS (EI, 70 eV) m/z (%) Calcd for $C_{42}H_{30}N_4O_4$ (M^+): 654.2267; Found: 654.2261.

12h: Reaction time 24 h, yield 76%, reddish crystals; mp 266–268 °C (decomp.); IR (cm^{-1}) 3358 (m), 2922 (s), 2852(m), 1731 (w), 1633 (m), 1285 (m); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.63 (t, J = 6 Hz, 2 H), 4.19 (s, 6H), 4.70–5.20 (br, 4H), 7.62–7.69 (m, 6H) 7.79 (dd, J = 7.8 Hz, 2H), 8.03 (d, J = 9.25 Hz, 2H), 8.09 (d, J = 9.25 Hz, 6H), 8.11 (d, J = 8 Hz, 6H), 12.99 (s, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 32.1 (CH_2), 46.3 (CH_2), 52.8 (CH_3), 106.0 (C), 123.5 (C), 126.8 (CH), 127.0 (CH), 129.6 (CH), 130.0 (CH), 130.3 (C), 131.2 (CH), 132.5 (C), 132.6 (CH), 132.8 (CH), 134.6 (CH), 135.4 (C), 139.0 (C), 140.5 (C), 143.7 (C), 153.4 (C), 169.2 (C), 182.5 (C); MS (ESI$^+$) 829 (M + Na, 33), 808 (M^+ + 2, 51), 807 (M^+ + H, 100), 806 (M^+, 15), 437 (14); HRMS (ESI$^+$) m/z (%) Calcd for $C_{47}H_{31}O_8N_6$ (M^+ + H): 807.2198; Found: 807.2161.

Acknowledgments

We are grateful to the Ministry of Science and Technology (MOST) of Taiwan for financial support of this research.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tet.2019.130689.

References

[1] (a) M. Watanabe, K.Y. Chen, Y.J. Chang, T.J. Chow, Acc. Chem. Res. 46 (2013) 1606–1615;
(b) J.E. Anthony, Angew. Chem., Int. Ed. 47 (2008) 452–483;
(c) J.E. Anthony, Chem. Rev. 106 (2006) 5028–5048;
(d) S. Allard, M. Forster, B. Souharce, H. Thiem, U. Scherf, Angew. Chem., Int. Ed. 47 (2008) 4070–4098;
(e) M.L. Tang, A.D. Reichardt, N. Miyaki, R.M. Stoltenberg, Z. Bao, J. Am. Chem. Soc. 130 (2008) 6064–6065;
(f) I. Kaur, W. Jia, R.P. Kopreski, S. Selvarasah, M.R. Dokmeci, C. Pramanik, N.E. McGruer, G.P. Miller, J. Am. Chem. Soc. 130 (2008) 16274–16286;
(g) M. Bendikov, H.M. Duong, K. Starkey, K.N. Houk, E.A. Carter, F. Wudl, J. Am. Chem. Soc. 126 (2004) 7416–7417;
(h) J. Mei, Y. Diao, A.L. Appleton, L. Fang, Z. Bao, J. Am. Chem. Soc. 135 (2013) 6724–6746;
(i) H. Moon, R. Zeis, E.-J. Borkent, C. Besnard, A.J. Lovinger, T. Siegrist, C. Kloc,

Z. Bao, J. Am. Chem. Soc. 126 (2004) 15322–15323;
(j) K.N. Houk, P.S. Lee, M. Nendel, J. Org. Chem. 66 (2001) 5517–5521;
(k) C.D. Dimitrakopoulos, R.L. Malenfant, Adv. Mater. 14 (2002) 99–117;
(l) H.F. Bettinger, Pure Appl. Chem. 82 (2010) 905–915;
(m) D. Jiang, S. Dai, J. Phys. Chem. A 112 (2008) 332–335.

[2] (a) R. Dorel, A.M. Echavarren, Eur. J. Org. Chem. (2017) 14–24;
(b) S.S. Zade, M. Bendikov, Angew. Chem. Int. Ed. 49 (2010) 4012–4015;
(c) R.P. Bula, I.M. Oppel, H.F. Bettinger, J. Org. Chem. 77 (2012) 3538–3542;
(d) S. Katsuta, H. Yamada, T. Okujima, H. Uno, Tetrahedron Lett. 51 (2010) 1397–1400;
(e) H.-H. Huang, H.-H. Hsieh, C.-C. Wu, C.-C. Lin, P.-T. Chou, T.-H. Chuang, Y.-S. Wen, T.J. Chow, Tetrahedron Lett. 49 (2008) 4494–4497;
(f) J. Jiang, B.R. Kaafarani, D.C. Neckers, J. Org. Chem. 71 (2006) 2155–2158;
(g) Q. Ye, C. Chi, Chem. Mater. 26 (2014) 4046–4056.

[3] (a) U.H.F. Bunz, Acc. Chem. Res. 48 (2015) 1676–1686;
(b) W. Yue, S.-L. Suraru, D. Bialas, M. Müller, F. Würthner, Angew. Chem. Int. Ed. 53 (2014) 6159–6162;
(c) U.H.F. Bunz, J.U. Engelhart, B.D. Lindner, M. Schaffroth, Angew. Chem. Int. Ed. 52 (2013) 3810–3821;
(d) G. Li, Y. Wu, J. Gao, C. Wang, J. Li, H. Zhang, Y. Zhao, Y. Zhao, Q. Zhang, J. Am. Chem. Soc. 134 (2012) 20298–20301;
(e) B.D. Lindner, J.U. Engelhart, O. Tverskoy, A.L. Appleton, F. Rominger, A. Peters, H.-J. Himmel, U.H.F. Bunz, Angew. Chem. Int. Ed. 50 (2011) 8588–8591;
(f) C.-L. Song, C.-B. Ma, F. Yang, W.-J. Zeng, H.-L. Zhang, X. Gong, Org. Lett. 13 (2011) 2880–2883;
(g) U.H.F. Bunz, Chem. Eur J. 15 (2009) 6780–6789;
(h) G.J. Richards, J.P. Hill, N.K. Subbaiyan, F. D'Souza, P.A. Karr, M.R.J. Elsegood, S.J. Teat, T. Mori, K. Ariga, J. Org. Chem. 74 (2009) 8914–8923;
(i) S. Miao, A.L. Appleton, N. Berger, S. Barlow, S. Marder, K.I. Hardcastle, U.H.F. Bunz, Chem. Eur J. 15 (2009) 4990–4993;
(j) B. Gao, M. Wang, Y. Cheng, L. Wang, X. Jing, F. Wang, J. Am. Chem. Soc. 130 (2008) 8297–8306;
(k) F. Stöckner, R. Beckert, D. Gleich, E. Birckner, W. Günther, H. Görls, G. Vaughan, Eur. J. Org. Chem. (2007) 1237–1243.

[4] (a) B. Kollmann, Z. Chen, D. Lüftner, O. Siri, P. Puschnig, J. Phys. Chem. C 122 (2018) 6475–6482, 2018, J. Phys. Chem. C;
(b) M. Winkler, K.N. Houk, J. Am. Chem. Soc. 129 (2007) 1805–1815.

[5] (a) Z. Liang, Q. Tang, J. Liu, J. Li, F. Yan, Q. Miao, Chem. Mater. 22 (2010) 6438–6443;
(b) C.-a Di, J. Li, G. Yu, Y. Xiao, Y. Guo, Y. Liu, X. Qian, D. Zhu, Org. Lett. 10 (2008) 3025–3028;
(c) C.J. Tonzola, M.M. Alam, W. Kaminsky, S.A. Jenekhe, J. Am. Chem. Soc. 125 (2003) 13548–13558;
(d) M. Jonforsen, T. Johansson, O. Ingana1, M.R. Andersson, Macromolecules 35 (2002) 1638–1643.

[6] (a) H.-C. Chen, Y.-H. Chen, C.-C. Liu, Y.-C. Chien, S.-W. Chou, P.-T. Chou, Chem. Mater. 24 (2012) 4766–4772;
(b) I. Geronimo, E.C. Lee, N.J. Singh, K.S. Kim, J. *Chem. Theory Comput.* 6 (2010) 1931–1934;
(c) S.-Z. Weng, P. Shukla, M.-Y. Kuo, Y.-C. Chang, H.-S. Sheu, I. Chao, Y.-T. Tao, Appl. Mater. Interfaces 1 (2009) 2071–2079;
(d) G.J. Richards, J.P. Hill, K. Okamoto, A. Shundo, M. Akada, M.R.J. Elsegood, T. Mori, K. Ariga, Langmuir 25 (2009) 8408–8413.

[7] T.-C. Chou, K.-C. Lin, M. Kon-no, C.-C. Lee, T. Shinmyozu, Org. Lett. 13 (2011) 4588–4591.

[8] (a) J.F. Bunnett, R.E. Zahler, Chem. Rev. 49 (1951) 273–412;
(b) P.G. Baraldi, A. Unciti-Broceta, M.J. Pineda-de-las-Infantas, J.J. Diaz-Mochon, A. Espinosa, R. Romagnoli, Tetrahedron 58 (2002) 7607–7611;
(c) G.L. Hamilton, B.J. Backes, Tetrahedron Lett. 47 (2006) 2229–2231;
(d) J.A. Kowalski, S.F. Leonard, G.E. Lee Jr., J. Comb. Chem. 8 (2006) 774–779.

[9] (a) J. Azuaje, A.E. Maatougui, X. García-Mera, E. Sotelo, ACS Comb. Sci. 16 (2014) 403–411;
(b) B. Schmidt, S. Krehl, S. Hauke, J. Org. Chem. 78 (2013) 5427–5435;
(c) J.D. Spence, A.C. Rios, M.A. Frost, C.M. McCutcheon, C.D. Cox, S. Chavez, R. Fernandez, B.F. Gherman, J. Org. Chem. 77 (2012) 10329–10339;
(d) C. Xie, Z. Zhang, B. Yang, G. Song, H. Gao, L. Wen, C. Ma, Tetrahedron 71 (2015) 1831–1837;
(e) W.-X. Guo, H.-L. Jin, J.-X. Chen, F. Chen Ding, JC, H.-Y. Wu, J. Braz. Chem. Soc. 20 (2009) 1674–1679.

[10] (a) M.E. Jung, F. Perez, Org. Lett. 11 (2009) 2165–2167;
(b) O. Onomura, H. Arimoto, Y. Matsumura, Y. Demizu, Tetrahedron Lett. 48 (2007) 8668–8672;
(c) S.L. Jain, V.B. Sharma, B. Sain, Synth. Commun. 35 (2005) 465–469;
(d) J.M. Khurana, B.M. Kandpal, Tetrahedron Lett. 44 (2003) 4909–4912.

[11] (a) C.-C. Liao, R. Peddinti, Acc. Chem. Res. 35 (2002) 856–866;
(b) D. Magdziak, A.A. Rodriguez, R.W. Van De Water, T.R.R. Pettus, Org. Lett. 4 (2002) 285–288.

[12] T.-C. Chou, C.-J. Hsu, J.-Y. Chen, J. Chin. Chem. Soc. 51 (2004) 167–174.

[13] (a) A.P. Marchand, S. Alihodzic, R. Shukla, Synth. Commun. 28 (1998) 541–546;
(b) U. O'Connor, W. Rosen, J. Org. Chem. 45 (1980) 1824–1828.

[14] (a) F.A. Khan, B. Prabhudas, J. Dash, J. Prakt. Chem. 342 (2000) 512–517;
(b) P.G. Gassman, J.L. Marshall, "Organic Syntheses", Collect, vol. V, Wiley, New York, 1973, p. 424;
(c) J.S. Newcomer, E.T. McBee, J. Am. Chem. Soc. 71 (1949) 946–951.

[15] Similar Grob-type fragmentation of suitably substituted dihalonorbornyl ketones: (a) F.A. Khan, S. Choudhury, Eur. J. Org. Chem. 15 (2010) 2954–2970;
(b) F.A. Khan, S. Choudhury, Eur. J. Org. Chem. (2006) 672–676.

[16] (a) F.A. Khan, Ch N. Rao, J. Org. Chem. 76 (2011) 3320–3328;
(b) S.H. Mahadevegowda, F.A. Khan, Eur. J. Org. Chem. 4 (2015) 858–870.

[17] (a) F.A. Khan, B. Prabhudas, J. Dash, N. Sahu, J. Am. Chem. Soc. 122 (2000) 9558–9559;
(b) F.A. Khan, J. Dash, J. Am. Chem. Soc. 124 (2002) 2424–2425;
(c) F.A. Khan, J. Dash, N. Sahu, Ch Sudheer, J. Org. Chem. 67 (2002) 3783–3787;
(d) F.A. Khan, J. Dash, Ch Sudheer, N. Sahu, K. Parasuraman, J. Org. Chem. 70 (2005) 7565–7577.

[18] (a) T.-C. Chou, K.-C. Liao, J.-J. Lin, Org. Lett. 7 (2005) 4843–4846;
(b) T.-C. Chou, K.-C. Lin, C.-A. Wu, Tetrahedron 65 (2009) 10243–10257;
(c) T.-C. Chou, K.-C. Liao, Tetrahedron 67 (2011) 236–249;
(d) T.-C. Chou, J.-K. Huang, S.S. Bahekar, J.-H. Liao, Tetrahedron 70 (2014) 8361–8373;
(e) T.-C. Chou, Y.-J. Li, Tetrahedron 71 (2015) 5620–5633.

[19] (a) P. Kniel, Helv. Chim. Acta (1965) 837–839;
(b) T.-C. Chou, P.-C. Hong, Y.-F. Wu, W.-Y. Chang, C.-T. Lin, K.-J. Lin, Tetrahedron 52 (1996) 6325–6338.

[20] When compound **5**/**5′** was heated in AcOH at 45 °C for 1 day, it gave yellowish fragmentation product, methyl 4-chloro-2,3-dihydroxy-9,10-dioxo-9,10-dihydroanthracene-1-carboxylate in 70% yield (see Supplementary Data).

[21] The sluggish oxidation by air (O_2) at room temperature in the fragmentation process might account for the low overall yields. Recourse to an environmentally less desirable way of using a strong oxidant (CAN or DDQ) resulted in producing a complex product mixture.

[22] The ^{1}H NMR spectral analyses of solid residues prior to the NaOH-treatment indicated that the fragmentations of **7** were complete but the resultant diazapentacene derivatives **1** were in most cases accompanied with various amounts of the non-oxidized polyacenohydroquinone esters **10** (Scheme 5).

[23] The color change is not attributable to the complexation of reactants via hydrogen bonding. Under the same condition, the event of color change was not observed for other nucleophiles having ability of serving as a hydrogen bond donor, such as AcOH and EtOH (see Supplementary Data). Presumably, the color change is attributable to the formation of σ-complexes (Meisenheimer complexes). See: (a) G.A. Artamkina, M.P. Egorov, I.P. Beletskaya, Chem. Rev. 82 (1982) 427–459;
(b) I. Gallardo, G. Guirado, J. Marquet, J. Org. Chem. 67 (2002) 2548–2555.

[24] F. Breitbeil III, N. Kaur, J.G. Delcros, B. Martin, K.A. Abboud, O. Phanstiel IV, J. Med. Chem. ***49*** (2006) 2407–2416.

[25] (a) B.W. Gung, J.C. Amicangelo, J. Org. Chem. 71 (2006) 9261–9270;
(b) D.M. Cho, S.R. Parkin, M.D. Watson, Org. Lett. 7 (2005) 1067–1068;
(c) H. Moon, R. Zeis, E.-J. Borkent, C. Besnard, A.J. Lovinger, T. Siegrist, C. Kloc, Z. Bao, J. Am. Chem. Soc. 126 (2004) 15322–15323;
(d) J.A.R.P. Sarma, G.R. Desiraju, Acc. Chem. Res. 19 (1986) 222–228;
(e) M.Y. Kuo, H.Y. Chen, I. Chao, Chem. Eur J. 13 (2007) 4750–4758.

[26] (a) E.A. Meyer, R.K. Castellano, F. Diederich, Angew. Chem., Int. Ed. 42 (2003) 1210–1250;
(b) L.M. Salonen, M. Ellermann, F. Diederich, Angew. Chem. Int. Ed. 50 (2011) 4808–4842;
(c) Z.-F. Yao, J.-Y. Wang, J. Pei, Cryst. Growth Des. 18 (2018) 7–15.

[27] (a) Y.-C. Chang, Y.-D. Chen, C.-H. Chen, Y.-S. Wen, J.T. Lin, HY, M.-Y. Chen Kuo, I. Chao, J. Org. Chem. 73 (2008) 4608–4614;
(b) Z. Chen, P. Müller, T.M. Swager, Org. Lett. 8 (2006) 273–276;
(c) M.-H. Yoon, A. Facchetti, C.E. Stern, T.J. Marks, J. Am. Chem. Soc. 128 (2006) 5792–5801.

[28] (a) J. Zhang, W. Xu, P. Sheng, G. Zhao, D. Zhu, *Acc. Chem. Res.* 50 (2017) 1654–1662;
(b) T. Ishi-I, Y. Moriyama, Tetrahedron 73 (2017) 1157–1164;
(c) R. Bodapati, M. Sarma, A. Kanakati, S.K. Das, J. Org. Chem. 80 (2015) 12482–12491;
(d) F. Bureś, RSC Adv. 4 (2014) 58826–58851;
(e) P. Singh, A. Baheti, K.R.J. Thomas, J. Org. Chem. 76 (2011) 6134–6145;
(f) K.R.J. Thomas, J.T. Lin, Y.-T. Tao, C.-H. Chuen, Chem. Mater. 14 (2002) 2796–2802.

Please cite this article as: T.-C. Chou et al., Aromatization-driven Grob-fragmentation approach toward polyazaacenes. Synthesis and amination of multi-functionalized diazapentacenes, Tetrahedron, https://doi.org/10.1016/j.tet.2019.130689