Chinese Chemical Letters 37 (2026) 112003

Contents lists available at ScienceDirect

Chinese Chemical Letters

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

Carbonylation of C(sp^3)–H bonds with CO_2: Facile synthesis of 2,4-quinolinediones and related luminescent materials

Xiu-Mei Xie[a,b], Hongyang Zhang[c,d,*], Shao-Xuan Gong[a], Hong-Xia Sun[a], Yu-Ting Liu[a], Xue-Ling Chen[a], Shuming Chen[e], Tian-Yu Gao[b], Wai-Yeung Wong[c,d,*], Zhen Zhang[a,*], Da-Gang Yu[b,*]

[a] Natural Products Chem-Bio Innovation Center & College of Food and Biological Engineering, Chengdu University, Chengdu 610106, China
[b] Key Laboratory of Green Chemistry & Technology of Ministry of Education, College of Chemistry, Sichuan University, Chengdu 610064, China
[c] Department of Applied Biology and Chemical Technology and Research Institute for Smart Energy, The Hong Kong Polytechnic University, Hong Kong 999077, China
[d] The Hong Kong Polytechnic University Shenzhen Research Institute, Shenzhen 518057, China
[e] Department of Electrical and Electronic Engineering, Southern University of Science and Technology, Shenzhen 518055, China

ARTICLE INFO

Article history:
Received 8 July 2025
Revised 13 October 2025
Accepted 21 October 2025
Available online 22 October 2025

Keywords:
Carbon dioxide
Carbonylation
2,4-Quinolinedione
Organic light-emitting diodes
N-Heterocyclic carbene

ABSTRACT

A novel method for carbonylation of tertiary C(sp^3)–H bonds in 2-aminophenyl-alkyl methanones with CO_2 has been developed, enabling the synthesis of 2,4-quinolinediones featuring quaternary carbon centres. Building on this approach, a promising iridium(III) complex involving carbon from CO_2 was designed and synthesized. This complex, exhibiting a high photoluminescent quantum yield, was successfully applied in organic light-emitting diodes (OLEDs), achieving a high maximum luminance up to 12,010 cd/m² and a maximum external quantum efficiency (EQE) of 13.95 %.

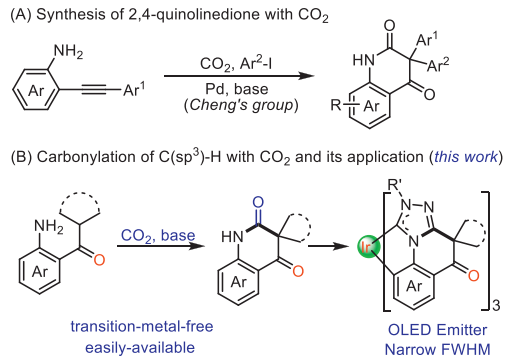
© 2025 Published by Elsevier B.V. on behalf of Chinese Chemical Society and Institute of Materia Medica, Chinese Academy of Medical Sciences.

Carbon dioxide (CO_2), a well-known greenhouse gas driving global warming, has garnered significant worldwide attention for its capture and utilization [1]. In the last decades, chemists have increasingly focused on harnessing CO_2 as an abundant, cost-effective, renewable and environmentally friendly C1 source for the organic synthesis [1–23]. Despite its potential, this endeavor faces significant challenges due to the inherent thermodynamic and kinetic stability of CO_2. As a result, the development of practical and efficient strategies for converting CO_2 into valuable chemicals, particularly carbonyl-containing heterocyclic compounds, has become a prominent focus in contemporary organic synthesis. Encouragingly, the recent progress in the synthesis of carbonyl compounds with CO_2, particularly the carbonylation of C–H bonds, has attained promising outcomes [24–34]. These advancements further highlight that the utilization of CO_2 is not only safe and environmentally friendly but also exhibits favorable atom economy.

The 2,4-quinolinedione framework represents an important class of carbonyl-containing compounds in medicinal and materials chemistry [35–37]. Numerous investigators have explored synthetic methodologies for these compounds [38–40], including the notable contributions from the Cheng group (Scheme 1A) [39]. However, most of these methods suffer from complex reaction conditions or inadequate selectivity. Therefore, it is particularly important to efficiently and selectively synthesize such compounds in simple systems. Building on our persistent interest in the carbonylation of C–H bonds with CO_2 [24,25], we sought to investigate whether CO_2 could be employed in the carbonylation of tertiary C(sp^3)–H bonds in 2-aminophenyl-alkyl methanones to synthesize such compounds (Scheme 1B). In addition, considering the significance of organic light-emitting diode (OLED) development and the widespread application of carbene ligands in OLEDs [41–46], 2,4-quinolinedione framework is ideally suited for synthesizing rigid, carbonyl-containing triazole carbene ligands. We aim to make use of these ligands in the development of organometallic luminescent materials, thereby providing valuable insights into the applications of carbonylation reactions with CO_2. However, this scenario presents two primary challenges. First, the thermodynamic stability and kinetic inertness of CO_2 impede efficient transformations,

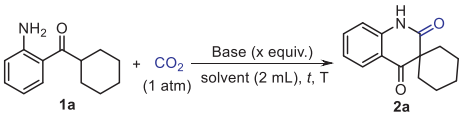
* Corresponding authors.
E-mail addresses: hongyang.zhang@polyu.edu.hk (H. Zhang), wai-yeung.wong@polyu.edu.hk (W.-Y. Wong), zhangzhen1@cdu.edu.cn (Z. Zhang), dgyu@scu.edu.cn (D.-G. Yu).

https://doi.org/10.1016/j.cclet.2025.112003
1001-8417/© 2025 Published by Elsevier B.V. on behalf of Chinese Chemical Society and Institute of Materia Medica, Chinese Academy of Medical Sciences.



Scheme 1. Generation of 2,4-quinolinedione and the application in OLEDs.

Table 1
Screening of the reaction parameters.[a]



Entry	Base (x)	Solvent	*t* (h)	T (°C)	Yield[b] (%)
1	LiO^{t}Bu (4.5)	DMF/*o*-Xylene (1/1)	24	110	89
2	NaO^{t}Bu (4.5)	DMF/*o*-Xylene (1/1)	24	110	81
3	KO^{t}Bu (4.5)	DMF/*o*-Xylene (1/1)	24	110	68
4	LiO^{t}Bu (4.5)	DMF	24	110	48
5	LiO^{t}Bu (4.5)	*o*-Xylene	24	110	13
6	LiO^{t}Bu (4.5)	DMAc/*o*-Xylene (1/1)	24	110	n.d.
7	LiO^{t}Bu (4.5)	Diglyme/*o*-Xylene (1/1)	24	110	46
8	LiO^{t}Bu (4.0)	DMF/*o*-Xylene (1/1)	24	110	77
9	LiO^{t}Bu (3.0)	DMF/*o*-Xylene (1/1)	24	110	26
10	LiO^{t}Bu (4.5)	DMF/*o*-Xylene (1/1)	16	110	80
11	LiO^{t}Bu (4.5)	DMF/*o*-Xylene (1/1)	12	110	73
12	LiO^{t}Bu (4.5)	DMF/*o*-Xylene (1/1)	24	40	n.d.
13	LiO^{t}Bu (4.5)	DMF/*o*-Xylene (1/1)	24	60	n.d.
14	LiO^{t}Bu (4.5)	DMF/*o*-Xylene (1/1)	24	80	34
15	LiO^{t}Bu (4.5)	DMF/*o*-Xylene (1/1)	24	100	74
16	LiO^{t}Bu (4.5)	DMF/*o*-Xylene (1/1)	24	120	98
17	–	DMF/*o*-Xylene (1/1)	24	120	n.d.
18[c]	LiO^{t}Bu (4.5)	DMF/*o*-Xylene (1/1)	24	120	n.d.

n.d. = not detected, DMF = *N*,*N*-dimethylformamide, DMAc = *N*,*N*-dimethylacetamide, *o*-Xylene = *o*-dimethylbenzene, Diglyme = diethylene glycol dimethyl ether.

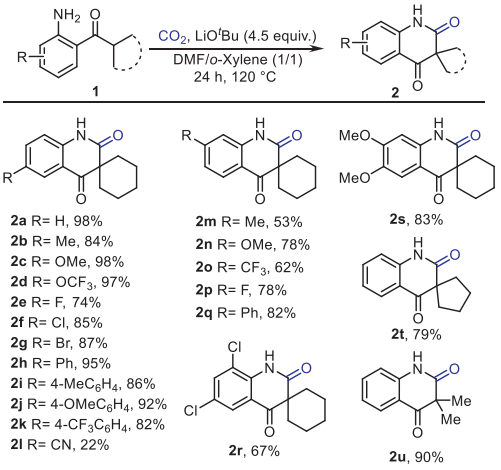
[a] Reaction conditions: **1a** (0.2 mmol), CO_2 (1 atm), solvent (2 mL), LiO^{t}Bu (x equiv.), T °C, *t* h.

[b] Isolated yield.

[c] Under Ar.

specifically under low-pressure conditions; second, the considerable steric hindrance from tertiary C(sp^3) centres might considerably obstruct carbonylation of C(sp^3)–H bonds using CO_2, consequently affecting the overall efficiency of carbonylation reaction.

In light of the observed challenges and our previous findings, we investigated a reaction using (2-aminophenyl)(cyclohexyl)methanone **1a** as the substrate under 1 atm of CO_2 (Table 1). We successfully synthesized the target compound **2a** with a yield of 89% using LiO^{t}Bu as the base in a mixture of dimethylformamide (DMF)/*o*-xylene *via* heating at 110 °C for 24 h (Table 1, entry 1) [47]. The use of NaO^{t}Bu or KO^{t}Bu decreased the yield of **2a** (Table 1, entries 2 and 3). Moreover, using solvents such as DMF or *o*-xylene alone resulted in diminished yields of **2a** (Table 1, entries 4 and 5), which might be explained by our earlier observations that the resultant product tended to disperse in the less basic *o*-xylene, mitigating further degradation. Alternative solvent combinations, such as DMAc/*o*-xylene or diglyme/*o*-xylene, also resulted in lower yields of **2a** (Table 1, entries 6 and 7). Notably, decreasing the amount of LiO^{t}Bu from 4.0 equiv. to 3.0 equiv. considerably decreased the product yield. Building upon prior mechanistic studies [31], LiO^{t}Bu appears to fulfill multiple

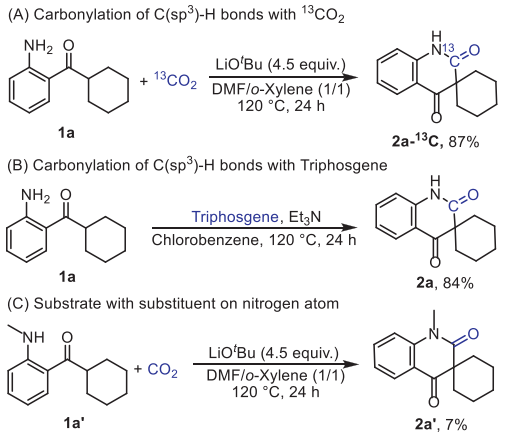


Scheme 2. Substrate scope. **1** (0.2 mmol), CO_2 (1 atm), LiO^{t}Bu (4.5 equiv., 0.9 mmol), DMF/*o*-Xylene (2 mL, v/v = 1/1), 120 °C, 24 h. Isolated yields are shown.

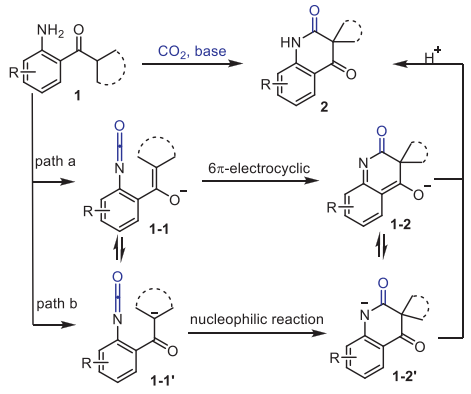
functions beyond simple base mediation, including (i) CO_2 activation through chemical fixation and (ii) direct involvement in intermediate generation. This multifunctional nature consequently renders the base stoichiometry a critical parameter for reaction optimization (Table 1, entries 8 and 9). Next, we investigated the effects of varying the reaction durations and temperatures on the product yield. Decreasing the reaction duration to 16 or 12 h resulted in a lower yield (Table 1, entries 10 and 11). However, temperature had a substantial effect: increasing the temperature markedly increased the product yields (Table 1, entries 12–16), achieving a remarkable yield of 98% when the temperature was increased to 120 °C. Finally, both LiO^{t}Bu (Table 1, entry 17) and CO_2 (Table 1, entry 18) were confirmed to be essential components facilitating the reaction's progression.

With the optimal reaction conditions established, we began investigating the substrate scope (Scheme 2). First, we examined substrates with substituents on the aromatic ring at the *para* position of the amino group (**1b**–**1l**). As shown in Scheme 2, various functional groups, including electron-donating groups (Me, OMe and OCF_3), halogen groups (F, Cl and Br) and aryl groups (Ph, 4-MeC_6H_4, 4-MeOC_6H_4, and 4-$CF_3C_6H_4$), did not adversely affect the reaction. For substrates containing CN groups (**1l**), a significant decrease in product yield was observed, demonstrating the limited compatibility of this reaction system with base-sensitive functional groups. The yields of the target products were predominantly >80%. In general, the substrates with electron-rich groups (**1b**–**1d**, **1i**, **1j**) exhibited higher reactivity than the ones with electron-poor groups (**1f**, **1g**, **1k**), consistent with our previous findings [31]. Moreover, we investigated the reactivity of substrates with substituents on the aromatic ring at the *meta*-position of the amino group (**1m**–**1q**). The overall yields for these substrates slightly decreased, indicating that the position of substituent affected the reactivity. However, the electronic effects at this position were not prominently evident. Furthermore, we explored substrates with di-substituents on the phenyl ring (**1r**, **1s**), which also underwent this transformation, yielding the desired products in moderate to good yields. In addition to the cyclohexyl-substituted ketone, the cyclopentyl (**1t**) and isopropyl substituted ketones (**1u**) could also provide the target products in high yields.

To elucidate the reaction mechanism, a series of experiments were conducted. Initially, the carbonylation reaction was performed using $^{13}CO_2$ as the carbonyl source (Scheme 3A). The ^{13}C NMR spectrum confirmed that CO_2 is the primary carbonyl source in this reaction. Notably, when the reaction was conducted under an inert atmosphere, the target product was not obtained, further supporting this conclusion (Table 1, entry 18).



Scheme 3. Control experiments.



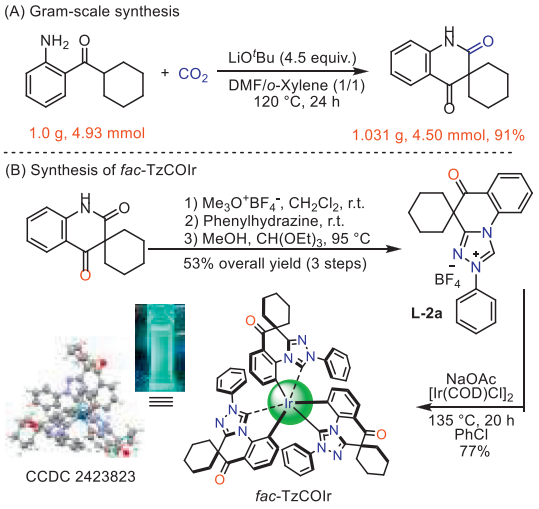
Scheme 4. Proposed mechanism of carbonylation of C(sp^3)–H bonds with CO_2.

Subsequently, the carbonylation reaction was carried out using triphosgene as the carbonyl source, yielding the target product in 84% yield (Scheme 3B). Since triphosgene can react with aniline to form an isocyanate intermediate, and based on our previous work [31], we propose that the isocyanate intermediate plays a key role in this reaction.

Furthermore, when a secondary amine derivative (**1a'**) was employed as the substrate, the yield of the corresponding product (**2a'**) significantly dropped to 7% (Scheme 3C). This observation suggests that the substituent on the nitrogen atom may hinder the formation of the isocyanate intermediate, thereby preventing the formation of the desired product.

Based on the experimental results and relevant literature [24,31], we propose the following reaction mechanism: Initially, in the presence of CO_2 and base, **1** is converted into the isocyanate intermediate **1–1** or **1–1′**. A 6π-electrocyclization of **1–1** then affords the cyclized intermediate **1–2**, which undergoes further rearrangement to yield the final product **2** (path a in Scheme 4). Given that **1–1** and **1–1′** can undergo keto-enol tautomerization, the enolate form **1–1′** may also participate in nucleophilic attack on the isocyanate group (–N=C=O), ultimately leading to the formation of the target product **2** (Path b in Scheme 4, Fig. S8 in Supporting information). At the current stage, the dominant reaction pathway cannot be unequivocally determined from experimental evidence. Alternatively, the available experimental data do not allow the exclusion of other routes to the final product involving an isocyanate intermediate.

Notably, when the *N*-substituted substrate **1a'** was subjected to the standard reaction conditions, a small amount of product **2a'** was still obtained. This observation suggests that the product may be formed, at least in part, through alternative minor pathways.



Scheme 5. Gram-scale reaction and derivatization reaction.

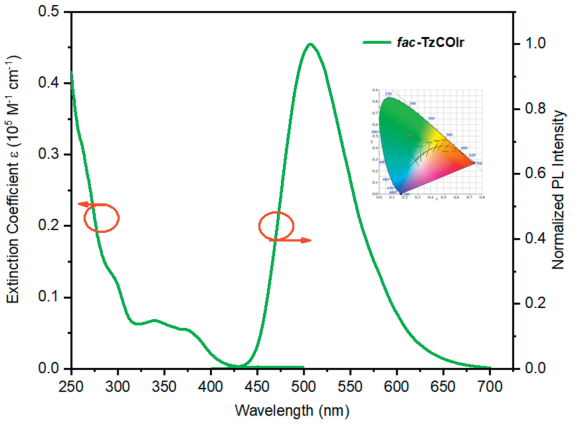
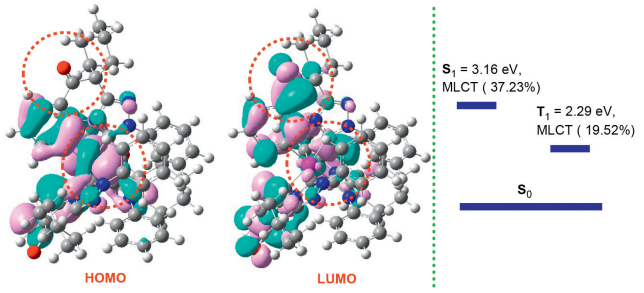


Fig. 1. Photophysical properties of ***fac*-TzCOIr**, measured in DCM at room temperature (10^{-5} mol/L).

Following the establishment of the methodology, we demonstrated its utility in organic synthesis. First, we conducted a gram-scale reaction of **1a** and obtained the target product **2a** in 91% yield (Scheme 5A). As discussed earlier in the article, *N*-heterocyclic carbene (NHC) compounds play a significant role in the catalysis reaction and the development of luminescent materials [41,42]. 2,4-Quinolinedione with the spiral-ring structure possesses the unique dual carbonyl configuration and strong rigidity. By converting this compound into an NHC ligand and coordinating it with iridium, it could unlock surprising possibilities for luminescent OLED materials [43,44]. Accordingly, we successfully synthesized a carbonyl-containing NHC ligand with the triazole-spiral-ring (**L-2a**) from **2a**, and obtained the associated Ir(III) complex ***fac*-TzCOIr**. The structure of Ir(III) complex was confirmed by single-crystal X-ray diffraction (Scheme 5B and Fig. S1 in supporting information).

Subsequently, we investigated the photophysical properties of ***fac*-TzCOIr** by measuring its UV–vis absorption and photoluminescence (PL) spectra in solution. The PL spectrum of Ir(III) complex in CH_2Cl_2 displays a green emission at 507 nm (Fig. 1) and a high photoluminescent quantum yield (PLQY) of 90% with the Commission International de l'Eclairage (CIE) coordinates of (0.240, 0.514). The radiative lifetime, calculated from the observed lifetime divided by PLQY, is 11.6 μs (see Table S1 in Supporting information for details).

We have also investigated the electrochemical properties of this Ir(III) complex using cyclic voltammetry and conducted theoreti-



Scheme 6. Electron cloud distribution of HOMO and LUMO orbital of ***fac*-TzCOIr**.

cal calculations to further elucidate its luminescence mechanism (Scheme 6, Table S2, and Fig. S2 in Supporting information).

The electrochemical curve of the Ir(III) complex clearly showed that the LUMO energy level had been notably stabilized compared with some other types of Ir(III) carbene complexes [41–45,48,49]. Furthermore, the analysis of HOMO–LUMO energy levels and their electron cloud distributions demonstrated that ***fac*-TzCOIr** would undergo a significant MLCT transition during its excitation process. In the LUMO, the electron density was observed to be primarily concentrated in the carbonyl fragment. As is well known, due to the electronegativity of oxygen and the resonance effect, the carbonyl group acts as a strong electron-withdrawing substituent, which effectively stabilizes the LUMO energy level. Hence, the HOMO–LUMO energy gap becomes narrowed, resulting in a significant redshift in the emission wavelength. Through theoretical calculations, we further analyzed the natural transition orbitals (NTOs) of ***fac*-TzCOIr** and the electron density distributions of HOMO/LUMO orbitals in the decarbonylated complex (***fac*-Ir1**). The results revealed that: (1) the LUMO energy level of ***fac*-Ir1** is significantly higher than that of ***fac*-TzCOIr**; (2) in ***fac*-TzCOIr**, electron transfer predominantly occurs between the metal center and the carbonyl group with its surrounding atoms (Tables S5 and S6, Fig. S7 in supporting information). These findings provide compelling evidence for the crucial role of the carbonyl ligand in modulating the luminescent properties of the iridium complex.

To gain deeper mechanistic insights into the photophysical behavior of ***fac*-TzCOIr**, we measured the temperature-dependent PL decay spectra from 77 K to 297 K and recorded the low-temperature and room-temperature PL profiles. Based on the result and analysis, the observed room-temperature emission of our Ir(III) complex appears to originate mainly from the ^{3}MLCT state, while the observed low-temperature emission of our Ir(III) complex is dominated by the mixed ^{3}LC and ^{3}MLCT states. We think that as ^{3}MLCT state often has a larger radiative decay rate (k_r) than ^{3}LC, at higher temperatures, thermal energy promotes population of the low-lying ^{3}MLCT state. When the temperature decreases, as ^{3}LC states typically exhibit stronger vibronic coupling and longer lifetimes at low temperatures, cooling causes population to "freeze" in the high-lying ^{3}LC state. Overall, the phosphorescence of our Ir(III) emitter is contributed by the hybridization between ^{3}MLCT and ^{3}LC states (please see Fig. S4 in supporting information for details) [50–52].

The OLED device using ***fac*-TzCOIr** as the green dopant emitter was fabricated and displayed the EL peak at 505 nm with CIEx,y coordinates of (0.24, 0.63). Impressively, it can afford a narrow full-width at half-maximum (FWHM) of 55 nm, which is smaller than devices based on the commercial emitter Ir(ppy)$_3$ [53–55]. The electroluminescence (EL) emission peak exhibits a narrower FWHM compared to its solution-phase counterpart, likely due to restricted molecular motion, homogenized microenvironment, confined exciton population and suppressed non-radiative decay in the solid state. The device revealed a relatively low turn-on voltage of

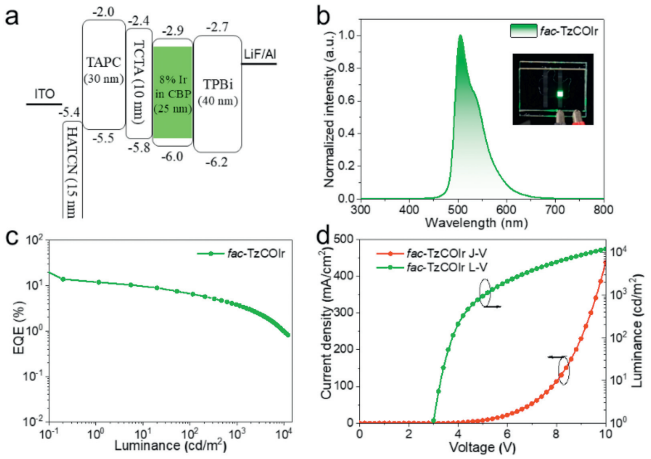


Fig. 2. The performance of OLED device based on ***fac*-TzCOIr**. (a) OLED device structure. (b) Electroluminescence spectrum (insert: the photograph of illuminated device). (c) External quantum efficiency–luminance (EQE–L) curves. (d) Current density–voltage–luminance (J–V–L) curves.

3.0 V at 1 cd/m^2, indicating a good charge carrier transport property of the Ir(III) complex incorporating carbonyl group ligands. A maximum luminance as high as 12,010 cd/m^2 was achieved and a moderate current intensity of *ca.* 8 mA/cm^2 at 1000 cd/m^2 was furnished. In addition, the OLED based on ***fac*-TzCOIr** attained a peak EQE of 13.95 % and retained a decent value of 6.71 % at 100 cd/m^2 (Fig. 2). In terms of current efficiency (CE) and power efficiency (PE), the remarkable maximum CE and PE up to 46.59 cd/A and 52.24 lm/W were obtained (Fig. 2, Table S3 and Fig. S5 in Supporting information for more details). We have also investigated devices with different doping concentrations (6 %, 10 % and 12 %), and the device results are shown in Fig. S6 (Supporting information). These findings suggest that such organometallic complex synthesized from CO_2 has a promising application potential in optoelectronic materials. Further studies on the other properties of the complex are currently underway in our group.

In summary, using CO_2 as an easily accessible carbonyl source, we successfully realized the carbonylation of tertiary C(sp^3)–H bonds in 2-aminophenyl-alkyl methanone derivatives to produce the key 2,4-quinolinediones in moderate to excellent yields. Additionally, by leveraging the unique structure of 2,4-quinolinedione, which features a quaternary carbon center, we developed an efficient Ir(III) emitter by incorporating the carbonyl group ligand. The OLED device based on the facial homoleptic Ir(III) complex delivered a competent device performance with CIEx,y coordinates of (0.24, 0.63), towards a green gamut. This work presents valuable insights into the development of efficient luminescent materials for OLED applications through the carbonylation of C–H bonds with CO_2.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Xiu-Mei Xie: Methodology, Investigation, Formal analysis, Data curation. **Hongyang Zhang:** Writing – review & editing, Software, Funding acquisition, Data curation. **Shao-Xuan Gong:** Validation, Methodology, Formal analysis. **Hong-Xia Sun:** Methodology. **Yu-Ting Liu:** Data curation. **Xue-Ling Chen:** Conceptualization. **Shuming Chen:** Software, Resources. **Tian-Yu Gao:** Data curation.

Wai-Yeung Wong: Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Zhen Zhang:** Writing – original draft, Supervision, Funding acquisition, Conceptualization. **Da-Gang Yu:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

Acknowledgments

We gratefully acknowledge the financial support from the National Natural Science Foundation of China (Nos. 21801025, 22225106), Natural Science Foundation of Sichuan Province (No. 2022NSFSC0200), Sichuan Science and Technology Program (No. MZGC20240116), the Hong Kong Research Grants Council (No. PolyU 15301922), CAS-Croucher Funding Scheme for Joint Laboratories (No. ZH4A), Research Institute for Smart Energy (CDAQ), Research Centre for Organic Electronics (No. CE33), Miss Clarea Au for the Endowed Professorship in Energy (No. 847S) Guangdong Basic and Applied Basic Research Foundation (No. 2022A1515111010), Shenzhen Science and Technology Program (No. RCBS20221008093229034). We also acknowledge Prof. Qi Zhao, Dr. Si-Shun Yan, and Dr. Jibiao Jin for their help and support in this work.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.cclet.2025.112003.

References

[1] L.N. He, Carbon Dioxide Chemistry, Science Press, Beijing, 2013.
[2] Y.Y. Gui, X.W. Chen, J.P. Yue, D.G. Yu, Chem. Synth. 4 (2024) 66.
[3] M. Lanzia, A.W. Kleij, Chin. J. Chem. 42 (2024) 430–443.
[4] Z. Wu, J. Wang, L. Liu, et al., Sci. China Chem. 67 (2024) 551–557.
[5] T.Y. Gao, X.Y. Mo, S.R. Zhang, et al., Chin. Chem. Lett. 35 (2024) 109364.
[6] Y. Chen, Y. Wang, J. Nong, et al., Chin. J. Chem. 42 (2024) 1571–1581.
[7] M. Miao, L. Zhu, H. Zhao, et al., Sci. China Chem. 66 (2023) 1457–1466.
[8] H. Luo, J. Ren, Y. Sun, et al., Chin. Chem. Lett. 34 (2023) 107782.
[9] C.K. Ran, Q. Qu, Y.Y. Tao, et al., Sci. China Chem. 67 (2024) 3366–3372.
[10] M. Du, Y. Sun, J. Zhao, H. Hu, et al., Chin. Chem. Lett. 34 (2023) 108269.
[11] L. Wang, C. Qi, W. Xiong, H. Jiang, Chin. J. Catal. 43 (2022) 1598–1617.
[12] S. Jia, X. Ma, X. Sun, B. Han, CCS Chem. 4 (2022) 3213–3229.
[13] G. Wang, J. Chen, Y. Ding, et al., Chem. Soc. Rev. 50 (2021) 4993–5061.
[14] Z. Zhang, J.H. Ye, T. Ju, et al., ACS Catal. 10 (2020) 10871–10885.
[15] L. Zhang, Z. Li, M. Takimoto, Z. Hou, Chem. Rec. 20 (2020) 494–512.
[16] J. Zhou, H. Liu, H. Wang, Chin. Chem. Lett. 34 (2023) 107420.
[17] S. Wang, C. Xi, Chem. Soc. Rev. 48 (2019) 382–404.
[18] A. Tortajada, F. Juliá-Hernández, M. Börjesson, T. Moragas, R. Martin, Angew. Chem. Int. Ed. 57 (2018) 15948–15982.
[19] Q. Liu, L. Wu, R. Jackstell, M. Beller, Nat. Commun. 6 (2015) 5933.
[20] Y. Tsuji, T. Fujihara, Chem. Commun. 48 (2012) 9956–9964.
[21] W. Zhang, X.B. Lü, Chin. J. Catal. 33 (2012) 745–756.
[22] Y. Yi, C. Xi, Green Synth. Catal. (2024), doi:10.1016/j.gresc.2024.09.003.
[23] J. Li, Z. Zhang, Y. Yi, C. Xi, Green Chem. 27 (2025) 3443–3450.
[24] L. Song, Y.X. Jiang, Z. Zhang, et al., Chem. Commun. 56 (2020) 8355–8367.
[25] Y.T. Liu, Z. Zhang, Chem. Heterocycl. Comp. 61 (2025) 54–56.
[26] K. Wang, J. Ouyang, H. Liu, et al., J. Org. Chem. 89 (2024) 18746–18751.
[27] L. Wang, H.X. Wu, Y.C. Zhao, B. Li, B.Q. Wang, Org. Lett. 26 (2024) 3940–3944.
[28] Y.T. Xu, Z.M. Ye, D.X. Liu, et al., Chin. Chem. Lett. 34 (2023) 107814.
[29] R. Zhang, M. Liu, Z. Zhao, Y. Qiu, Green Chem. 27 (2025) 1658–1666.
[30] L. Fu, S. Li, Z. Cai, et al., Nat. Catal. 1 (2018) 469–478.
[31] Z. Zhang, L.L. Liao, S.S. Yan, et al., Angew. Chem. Int. Ed. 55 (2016) 7068–7072.
[32] S. Wang, P. Shao, G. Du, C. Xi, J. Org. Chem. 81 (2016) 6672–6676.
[33] W.Z. Zhang, M.W. Yang, X.B. Lu, Green Chem. 18 (2016) 4181–4184.
[34] S. Sun, W.M. Hu, N. Gu, J. Cheng, Chem. Eur. J. 22 (2016) 18729–18732.
[35] S. Heeb, M.P. Fletcher, S.R. Chhabra, et al., FEMS Microbiol. Rev. 35 (2011) 247–274.
[36] J.P. Michael, Nat. Prod. Rep. 25 (2008) 166–187.
[37] E. Van Cutsem, H. Van De Velde, P. Karasek, H. Oettle, et al., J. Clin. Oncol. 22 (2004) 1430–1438.
[38] K. Didehban, E. Vessally, M. Salary, L. Edjlali, M. Babazadeh, J. CO_2 Util. 23 (2018) 42–50.
[39] B. Wang, S. Sun, J.T. Yu, Y. Jiang, J. Cheng, Org. Lett. 19 (2017) 4319–4322.
[40] W.Z. Zhang, S. Liu, X.B. Lu, Beilstein J. Org. Chem. 11 (2015) 906–912.
[41] G. Ni, J. Yan, Y. Wu, et al., Inorg. Chem. Front. 10 (2023) 1395–1401.
[42] D.M. Flanigan, F. Romanov-Michailidis, N.A. White, T. Rovis, Chem. Rev. 115 (2015) 9307–9387.
[43] B.S. Yun, S.Y. Kim, J.H. Kim, et al., ACS Appl. Electron. Mater. 4 (2022) 2699–2710.
[44] C. You, X.Q. Wang, X. Zhou, et al., ACS Appl. Mater. Interfaces 13 (2021) 59023–59034.
[45] G. Guisado-Barrios, M. Soleilhavoup, G. Bertrand, Acc. Chem. Res. 51 (2018) 3236–3244.
[46] L. Yuan, Y.P. Zhang, Y.X. Zheng, Sci. China Chem. 67 (2024) 1097–1116.
[47] Z. Zhang, X.L. Chen, X.M. Xie, et al., Chin. Chem. Lett. 36 (2025) 110056.
[48] Z. Chen, L. Wang, S. Su, et al., ACS Appl. Mater. Interfaces 9 (2017) 40497–40502.
[49] Z. Zhang, H. Zhang, P. Tao, et al., Inorg. Chem. 64 (2025) 15381–15391.
[50] C. Wu, M. Wang, K.N. Tong, et al., Adv. Opt. Mater. 11 (2023) 2201998.
[51] C. Wu, K.N. Tong, K. Shi, et al., Adv. Sci. 10 (2023) 2301112.
[52] Z.P. Yan, M.X. Mao, Q.M. Liu, et al., Adv. Funct. Mater. 34 (2024) 2402906.
[53] X. Yang, G.E. Jabbour, J. Mater. Chem. C 1 (2013) 4663–4666.
[54] Y. Kim, S. Park, Y.H. Lee, et al., Inorg. Chem. 55 (2016) 909–917.
[55] J. Jayabharathi, V. Thanikachalam, S. Thilagavathy, Coord. Chem. Rev. 483 (2023) 215100.