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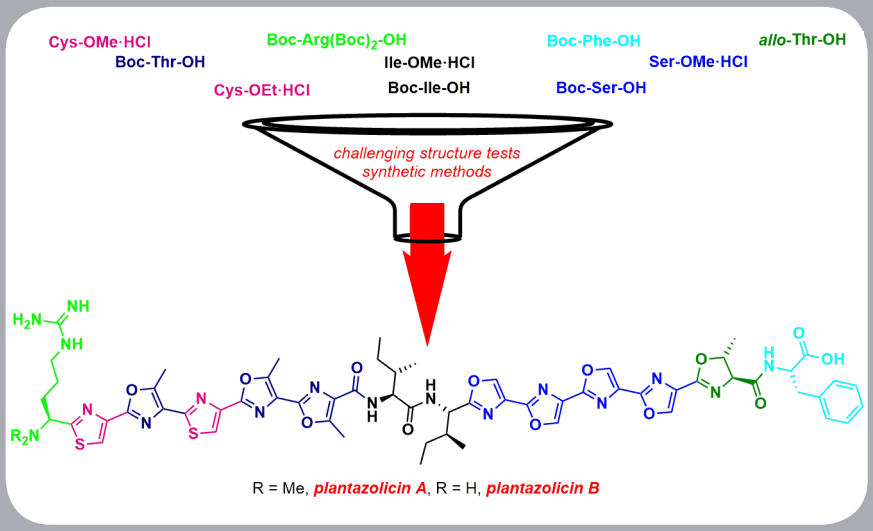
People, Trends and Views in Chemical Synthesis

2015/07

Total Synthesis of Linear Polythiazole/ Oxazole Plantazolicin A and Its Biosynthetic Precursor Plantazolicin B

Highlighted article by Z. E. Wilson, S. Fenner, S. V. Ley



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Dear Readers,

This issue of SYNFORM is opened by a Young Career Focus featuring an up-and-coming researcher from the P. R. of China, Professor Shuanhu Gao, who shares his thoughts and research interests in organic synthesis and medicinal/biological chemistry with the readership. The second article is truly special, and not just because the protagonist is one of the world-leading organic chemists and among the founders of SYNLETT – Professor Steven Ley from the University of Cambridge (UK) – but also because this article celebrates another remarkable achievement in Professor Ley's outstanding career: his publication no. 800!! And what a publication!! It's the amazing total synthesis of a complex natural compound, plantazolicin A, and its biosynthetic precursor plantazolicin B, by means of a spectacular and challenging synthetic marathon! Hats off to Professor Ley and congratulations for this milestone towards the publication no.1000. Third article of the issue is a story covering the new regio- and stereoselective approach to branched aldols developed by Professor Rai-Shung Liu (Taiwan) who figured out how to exploit a Zn(II)-catalyzed reaction between 3-en-1-ynamides and aldehydes. Finally, we have the privilege to watch organocatalysis meeting visible light meeting carbon monoxide, as it occurs in the research developed by the group of Professor Axel Jacobi von Wangelin (Germany) who found a truly smart method for exploiting photocatalysis for achieving a novel carbonylation process.

Enjoy your reading!

In this issue

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Young Career Focus: Professor Shuanhu Gao (East China Normal University (P. R. of China)

Background and Purpose. From time to time SYNFORM meets young up-and-coming researchers who are performing exceptionally well in the arena of organic chemistry and related fields of research, in order to introduce them to the readership. This Young Career Focus presents Professor Shuanhu Gao (East China Normal University, P. R. of China).

Biographical Sketch

Prof. S. Gao

Shuanhu Gao was born in Ningxia province, China. He obtained his BS degree from Lanzhou University (P. R. of China) in 2001. He then joined the group of Professor Yongqiang Tu at Lanzhou University to begin his doctoral study on natural product synthesis involving indole alkaloids and polyketides. After achieving his PhD in 2006, he began to work with Professor Chuo Chen at the UT Southwestern Medical Center at Dallas (USA) as a postdoctoral fellow. During this period, he worked on the total synthesis of nakiterpiosin and related chemical biology. He started his independent career in the Department of Chemistry at East China Normal University (P. R. of China) in October 2010. His current research interests are primarily focused on the total synthesis of natural products and medicinal chemistry.

INTERVIEW

SYNFORM *What is the focus of your current research activity?*

Prof. S. Guo My research interests are devoted to the total synthesis of natural products and related medicinal chemistry. The selected target molecules may have novel molecular structures, potent biological activities, and the potential for mechanistic studies. All the programs will begin with the synthesis of the corresponding natural products, and once the target molecules have been completed, we plan to carry out function-oriented synthesis of their analogues and derivatives to further study their potential medicinal functions and chemical biology through collaborations. We also try to develop some useful methodologies, especially photoreactions, to address issues of efficiency and diversity during the total synthesis.

SYNFORM *When did you get interested in synthesis?*

Prof. S. Guo I became interested in synthesis when I conducted undergraduate research in the laboratory of Professor Yongqiang Tu. During this period, I worked with Dr. Yanxing Jia on the total synthesis of madindolines. Professor Tu, an inspirational supervisor, taught me the science and research of synthesis, which had a significant influence on my academic career. I realized that creativity and innovation play key roles in the synthesis of molecules after five years of doctoral studies under the guidance of Professor Tu. My interest in synthesis grew after the experience of working with Professor Chuo Chen in UT Southwestern. Professor Chen broadened my horizon regarding the role of synthesis in both organic chemistry and related medical chemistry and chemical biology.

SYNFORM *What do you think about the modern role and prospects of organic synthesis?*

Prof. S. Guo I believe that organic synthesis of natural products and designed molecules serves, and will continue to serve, as the most effective tool for preparing target molecules, while dramatically facilitating the development of chemical biology, materials science as well as drug discovery. Clearly, organic synthesis is the indispensable driving force for developing new synthetic methods. The emergence of novel methodologies and strategies is also changing classical synthetic design. Therefore, organic synthesis is an important science in both academia and pharmaceutical areas. I also believe that the merging of chemical synthesis and biosynthesis will be an important research field and an unstoppable trend in the future.

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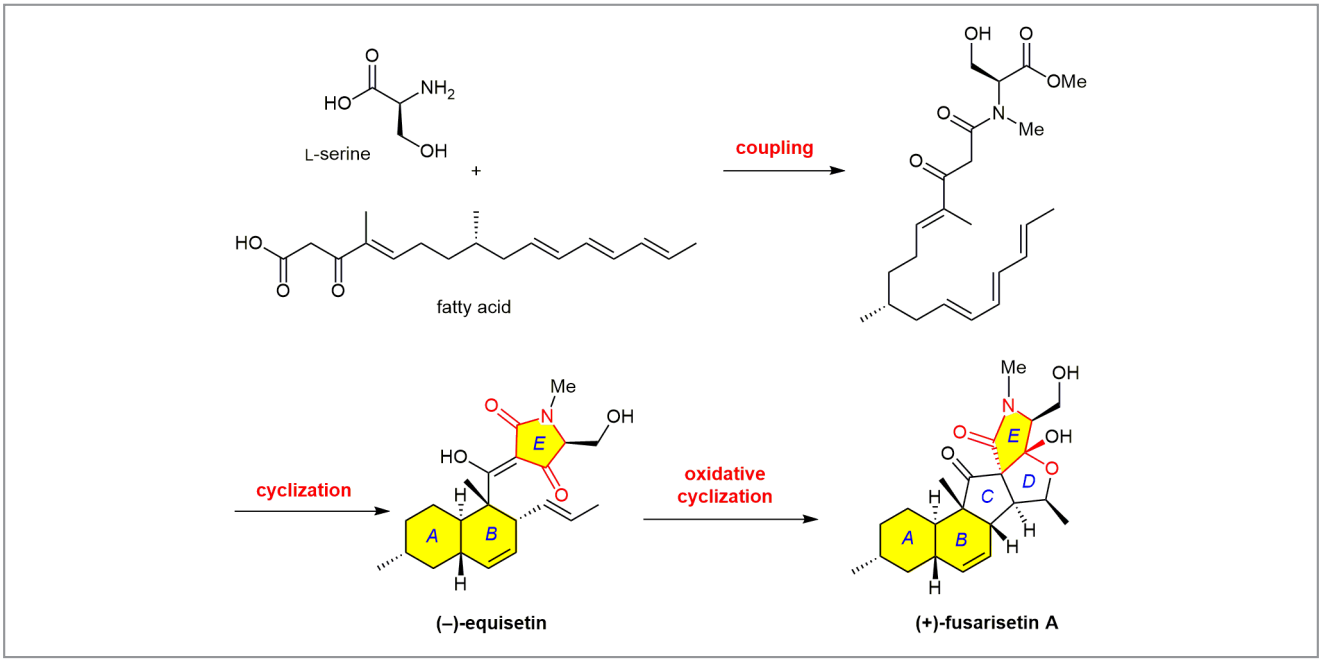
SYNFORM *Your research group is active in the areas of total synthesis and medicinal/biological chemistry. Could you tell us more about your research and its aims?*

Prof. S. Guo Currently, our research is focused on the synthesis of natural products, which include alkaloids, xanthones and terpenoids, among others. The target molecule always represents a family of natural products that are derived from the same biosynthetic pathway. We want to develop novel and efficient strategies to prepare the representative natural products, that will serve as common approaches for the synthesis of other biogenetically related natural molecules as well as their analogues and derivatives. In this way, we can provide the target molecules efficiently in adequate amounts. We believe this will be the foundation of further studies of the related medicinal chemistry and chemical biology. For instance, we developed an efficient strategy for the total synthesis of (+)-fusarisetin A, one of the most challenging naturally occurring tetramic acids with potential to be an anticancer agent, based on a biomimetic approach (Scheme 1).[1,2] We have already prepared a variety of related natural tetramic acids and derivatives of fusarisetin A by using a similar strategy. This facilitates the study of structure–activity relationships and further studies on medicinal chemistry.[3]

We also try to develop some useful synthetic methods to solve the problems encountered in classical chemical transformations. We found that photochemistry, promoted by either UV or visible light, provides unprecedented opportunities for the development of new reactions. In pursuing this idea, we have developed photoreactions, or strategies based on photochemistry, that have been used successfully in natural products synthesis.

SYNFORM *What is your most important scientific achievement to date and why?*

Prof. S. Guo My independent academic career started at the end of 2010, so our group is still very young. I hope the most important scientific achievements lie ahead of us. In the past four years, we have completed the total synthesis of four families of natural products, including tetramic acids, cyanthiwigins, hamigerans and hexahydrofluorenone-containing natural products. If I have to choose one contribution to organic chemistry, it should be the photo-Nazarov reaction and its application (Scheme 2).[4,5] After systematic studies of the photo-Nazarov cyclization of vinyl aryl ketones, we found this reaction proceeds under very mild conditions in neutral or basic solution and leads efficiently to the formation of hexahydrofluorenone. In contrast, the traditional Brønsted or Lewis acid promoted Nazarov cyclizations require much harsher conditions. We have also successfully applied this reaction in the total syntheses of taiwaniaquinol B and



Scheme 1 Biomimetic Synthesis of Tetramic Acids: Equisetin and Fusarisetin A

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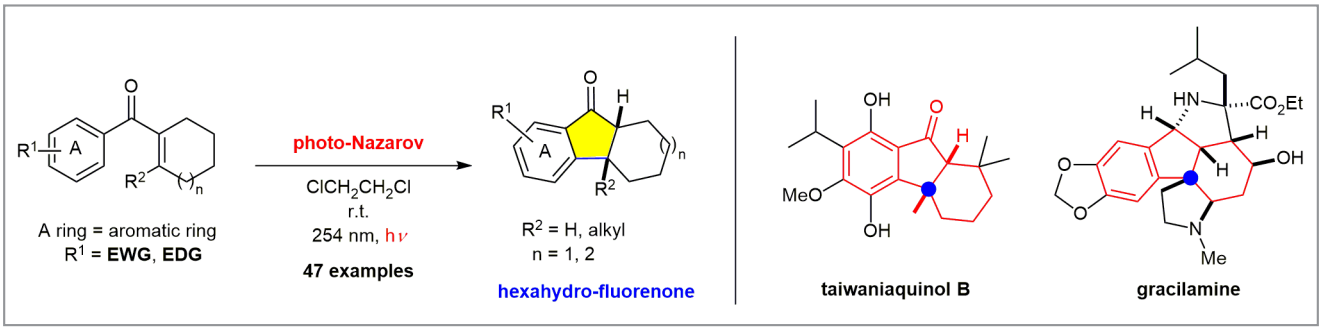


Scheme 2 Photo-Nazarov Reaction and Its Application in the Total Synthesis of Taiwaniaquinol B and Gracilamine

gracilamine. We firmly believe these photo-electrocyclized products may prove useful for synthesizing a variety of natural products and their derivatives.

REFERENCES

(1) J. Yin, C. Wang, L. Kong, S. Cai, S.-H. Gao *Angew. Chem. Int. Ed.* **2012**, *51*, 7786.
(2) J. Yin, L. Kong, C. Wang, Y. Shi, S. Cai, S.-H. Gao *Chem. Eur. J.* **2013**, *19*, 13040.
(3) L. Kong, M. Rao, J. Ou, J. Yin, W. Lu, M. Liu, X. Pang, S.-H. Gao *Org. Biomol. Chem.* **2014**, *12*, 7591.
(4) S. Cai, Z. Xiao, Y. Shi, S.-H. Gao *Chem. Eur. J.* **2014**, *20*, 8677.
(5) Y. Shi, B. Yang, S. Cai, S.-H. Gao *Angew. Chem. Int. Ed.* **2014**, *53*, 9539.

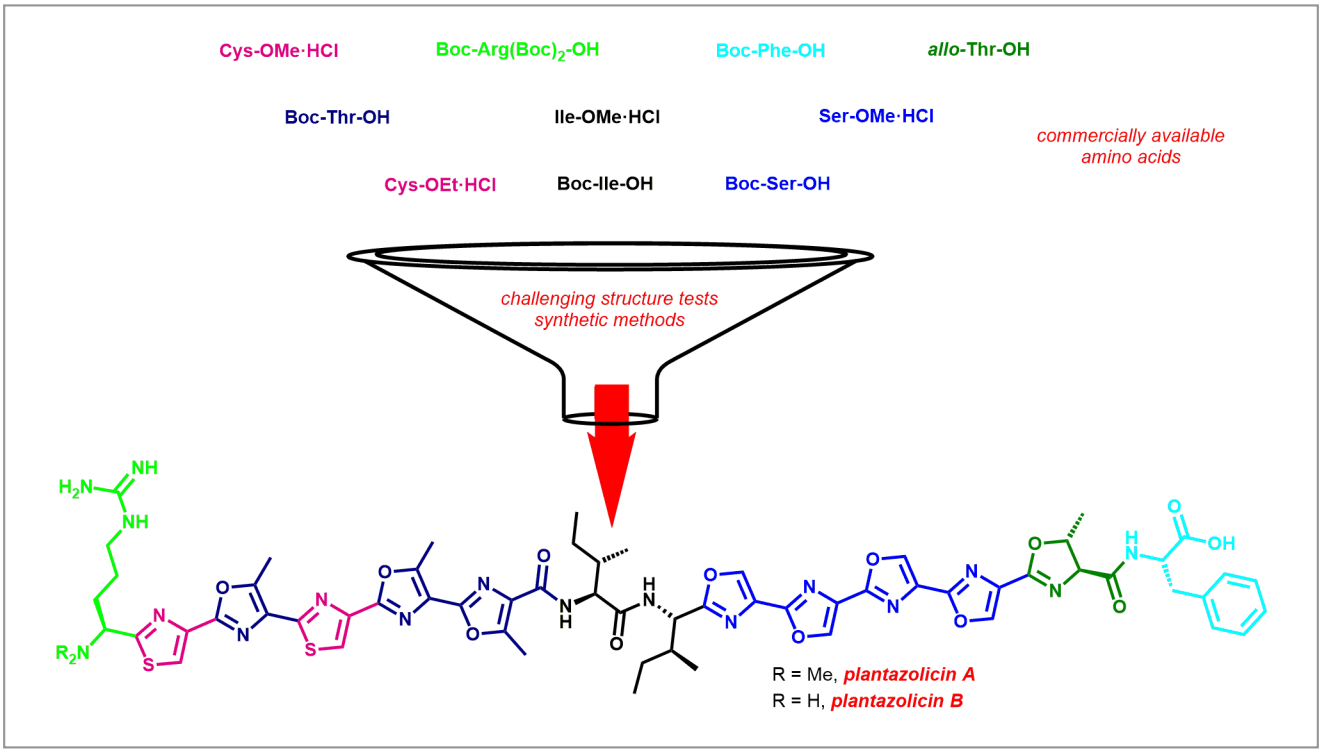
Total Synthesis of Linear Polythiazole/Oxazole Plantazolicin A and Its Biosynthetic Precursor Plantazolicin B

Angew. Chem. Int. Ed. **2015**, *54*, 1284–1288

Plantazolicin A has garnered much interest since its structure was first reported in 2011 due to its highly selective activity against the causative agent of anthrax toxicity, *Bacillus anthracis*. With ten heterocyclic rings, including one which is saturated, plantazolicin A and its biosynthetic precursor plantazolicin B offer a significant challenge to the synthetic chemist, and the successful synthesis of these molecules by the group of Professor Steven Ley at the University of Cambridge (UK) is a reminder of the power of modern synthetic methods. Professor Ley said: "This was by no means a straightforward synthesis – the final coupling step to join the two large pieces was first attempted in May 2013; it took over 1.5 years to optimize this step and the deprotection and purification of the resulting natural products."

Professor Ley continued: "One of our key considerations was that we wanted to have very strong support for our synthesis in the form of robust characterization of all intermediates and independent full characterization of the final natural products, as there was some variability and omissions in the reported data for plantazolicin A across the literature, and full characterization of plantazolicin B had not previously been reported. This led to a supporting information section larger than some theses at 130 pages! The advice of Professor Douglas Mitchell at the University of Illinois at Urbana-Champaign (USA) on the purification of the natural products, as well as the provision of an authentic sample of plantazolicin A to enable comparison, was greatly appreciated."

This project was originally proposed by Dr. Sabine Fenner in her application for a German Academic Exchange service (DAAD) fellowship and she was joined on the project by Dr. Zoe Wilson. Professor Ley told SYNFORM that Sabine largely focused on the synthesis of the common right-hand-side molecule while Zoe focused on the synthesis of appropriate left-hand fragments to allow the synthesis of both plantazolicin A and B. They then collaborated closely on the final coupling and deprotection steps to give the natural products.



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Professor Ley revealed that some of the group's key aims were to gain access to both plantazolicin A and plantazolicin B via a common convergent route, and additionally to make the approach as applicable to the future synthesis of analogues as possible: "The application of dicyclizations of two amino acid residues simultaneously at two stages of the synthesis allowed us to form concatenated rings in a single step, which contributed to an overall longest linear step count of only 14 (plantazolicin B) or 15 (plantazolicin A) steps," he commented. In order to make the synthesis as cost-effective as possible, commercially available protected amino acids were used as starting materials, with all but one being of the natural L configuration (the mechanism of cyclization using Deoxo-Fluor requiring the use of *allo*-threonine in synthesizing the oxazoline ring). Rather than using the more conventional Hantzsch-type thiazole synthesis from thioamides, which often necessitates the use of unpleasant sulfurating agents, the condensation of cysteine esters with amino aldehydes followed by the oxidation of the resulting thiazolidine to the thiazole using manganese dioxide readily gave access to the desired thiazoles. This method was especially beneficial for the synthesis of the key arginine-derived thiazole residue which proved to be very challenging.

"With the synthesis for these natural products successfully established, we now have access to analogues and simplified fragments which are unavailable through biological methods such as codon reprogramming," said Professor Ley, continuing: "It is hoped that these can be used to help further establish the structure–activity relationship for plantazolicin A."

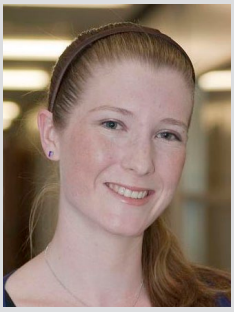
Additionally, this paper has the distinction of being Professor Ley's 800th publication. Dr. Zoe Wilson commented: "The entire Ley group was looking forward to the champagne party on the 20th of March."

Professor Dieter Enders, a synthetic organic chemistry expert from Aachen University (Germany) and Editor for Reviews of SYNTHESIS, commented: "With the total synthesis of plantazolicin A and B, the Ley group has added yet another masterpiece to their impressive list of numerous elegant and very efficient syntheses of biologically active natural products. The convergent route starting from commercially available amino acids carried out by Dr. Zoe Wilson and Dr. Sabine Fenner is most convincing and will certainly allow access to analogues of these important compounds. Being almost of the same age as Steve, I know what it means to have published 800 papers in the field of synthetic chemistry. This is a paramount accomplishment and indeed deserves a lot of champagne!"

About the authors

Prof. S. V. Ley

Steven Ley is currently Professor of Chemistry and Director of Research at the University of Cambridge (UK), where he is a Fellow of Trinity College. He was BP 1702 Professor of Chemistry for 21 years. Steve obtained his PhD from Loughborough University (UK) with Professor Harry Heaney and afterwards carried out postdoctoral research with Professor Leo Paquette (Ohio State University, USA), then Professor Derek Barton (Imperial College, UK). He was appointed as a Lecturer at Imperial College in 1975, promoted to Professor in 1983, and then to Head of Department in 1989. In 1990 he was elected to the Royal Society (London) and was President of The Royal Society of Chemistry from 2000–2002. Steve's research interests are varied and span many disciplines including new synthetic methodologies, the total synthesis of natural products and the development of enabling technologies for chemical synthesis especially in the area of flow chemistry technologies. He has published nearly 800 papers and has gained 50 major awards including the Tetrahedron Prize for Creativity in Organic Chemistry (Elsevier); Heinrich Wieland Prize (Boehringer Ingelheim, Germany); The Paracelsus Prize (Swiss Chemical Society); The Royal Medal (The Royal Society, London) and, most recently, The Longstaff Prize (The Royal Society of Chemistry).



Dr. Z. Wilson

Zoe Wilson grew up in the small town of Warkworth, New Zealand. She attended the University of Auckland (New Zealand) where she completed a Bachelor of Science in Medicinal Chemistry, then a BSc (Hons) in Medicinal Chemistry (researching the synthesis of anti-*Helicobacter pylori* compounds) and a PhD in synthetic chemistry (working on the synthesis of the natural product berkelic acid) with Professor Margaret Brimble. Upon completion of her PhD in 2010 she was awarded a Newton International Fellowship from the Royal Society to join the research group of Professor Steven V. Ley. Upon completion of the fellowship, she was then employed as a Postdoctoral Research Associate to continue working in the Ley group. Her interests lie in the areas of

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natural product synthesis and how this leads to the development of novel chemistry. Additionally, Zoe has been a College Lecturer and Fellow at Murray Edwards College at the University of Cambridge since October 2013.

Dr. Z. Wilson

Sabine Fenner was born in Homberg/Efze (Germany). She studied chemistry at the Georg-August-University of Göttingen (Germany) with an internship at Sanofi-Aventis, Frankfurt am Main (Germany) in 2007. Under the guidance of Professor Lutz Ackermann she received her Diploma in 2008 and her PhD in 2012 (with distinction summa cum laude) for investigations into transition-metal-catalyzed C–H bond functionalization. She then joined the group of Professor Steven V. Ley at Cambridge University as a Postdoctoral Fellow of the German Academic Exchange Service (DAAD), focusing on the total syntheses of the natural products plantazolicin A and B. In 2014 she assumed her current position in the Process Development department of GlaxoSmithKline, Stevenage (UK).

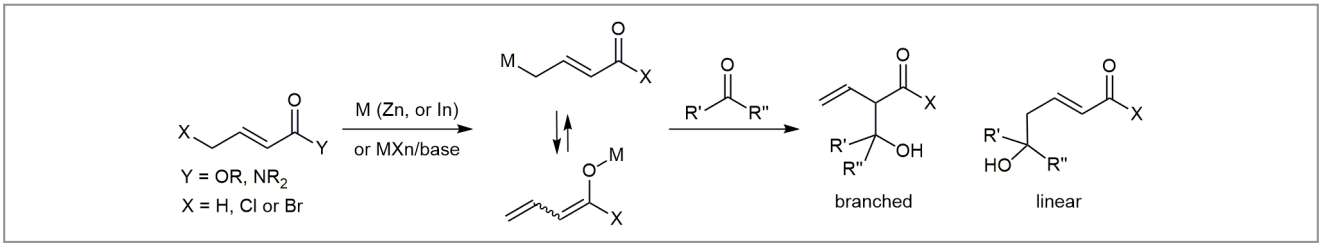
Zn(II)-Catalyzed Intermolecular Hydrative Aldol Reactions of 3-En-1-ynamides with Aldehydes and Water to Form Branched Aldol Products Regio- and Stereoselectively

Angew. Chem. Int. Ed. **2015**, *54*, 3812–3816

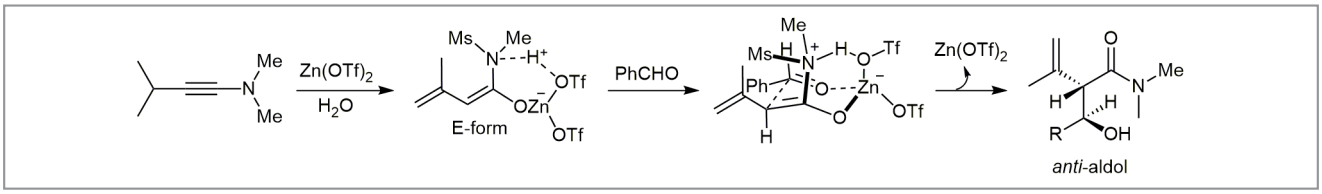
The aldol reaction occupies a prominent position in organic synthesis and remains one of the most used methodologies for producing chiral compounds in non-racemic form. Metal dienolates are versatile carbanions that can react with carbonyl electrophiles to afford linear or branched products. The stereo- and regioselectivities of the aldol reaction have been extensively examined for various metal salts including Zn(II), Si(IV), Sn(IV), Li(I), B(III) or In(III) because their linear and branched aldol products are useful building blocks for accessing natural products. One major drawback in current methods is the use of metal reagents in stoichiometric proportions (>1.0 equiv, Scheme 1). The development of their catalytic surrogates is highly desirable, but only an Ir-catalyzed enantioselective synthesis of linear aldol products, by Krische et al. (*Angew. Chem. Int. Ed.* **2011**, *50*, 3493), has been achieved.

Recently, the laboratory of Professor Rai-Shung Liu at the National Tsing-Hua University (Taiwan) developed a Zn(II)-catalyzed hydrative aldol reaction to generate stable O-bound Zn(II)-dienolates that can react with aldehydes to afford branched aldol products stereoselectively. "Although metal-catalyzed hydrations of alkynes are well known for many transition metals," said Professor Liu, "their resulting enolates have not been elaborated for any C–C bond formation due to rapid proto-demetalation reactions. In this work, 3-en-1-ynamides replace unsaturated esters as reagents together with water and $Zn(OTf)_2$ (5 mol%) as other partners." With $Zn(OTf)_2$ as catalyst and a 3-en-1-ynamide, Professor Liu's group observed the formation of a kinetically stable *E*-configured Zn(II)-dienolate that complexes with a HOTf molecule to impede an undesired proto-demetalation reaction. Professor Liu postulated: "This trapped 'HOTf' can enhance the Zn(II) acidity of this dienolate to enable an aldol reaction in water via a chair-like transition state (Scheme 2), yielding anti-configured aldol products stereoselectively. This hydrative aldol reaction represents a successful model of 'Lewis acid activated by Brønsted acid'."

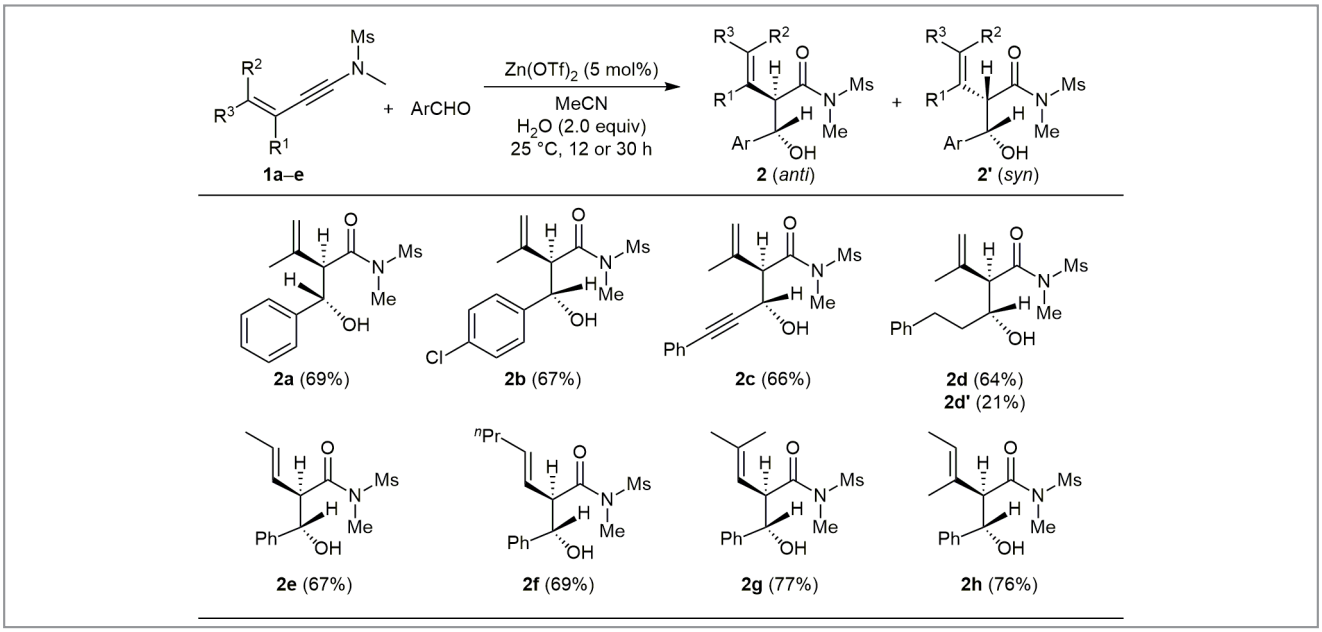
Scheme 3 outlines the reaction scope of this hydrative aldol reaction with various substituted 3-en-1-ynamide**s** and aldehydes. These reactions provide *anti*-configured branched aldol products as sole diastereomers in most instances (dr > 20:1), whereas a mixture of *anti*/*syn* diastereomers were obtained for aliphatic aldehydes (**2d**/**2d'**). "Applicable alde-



Scheme 1 Aldol reactions involving metal dienolates



Scheme 2 O-bound Zn(II)-dienolates from alkyne hydration

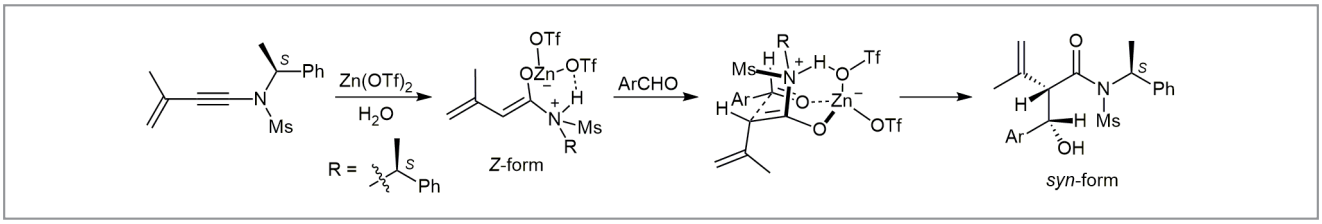


Scheme 3 Branched aldol products with anti-selectivity

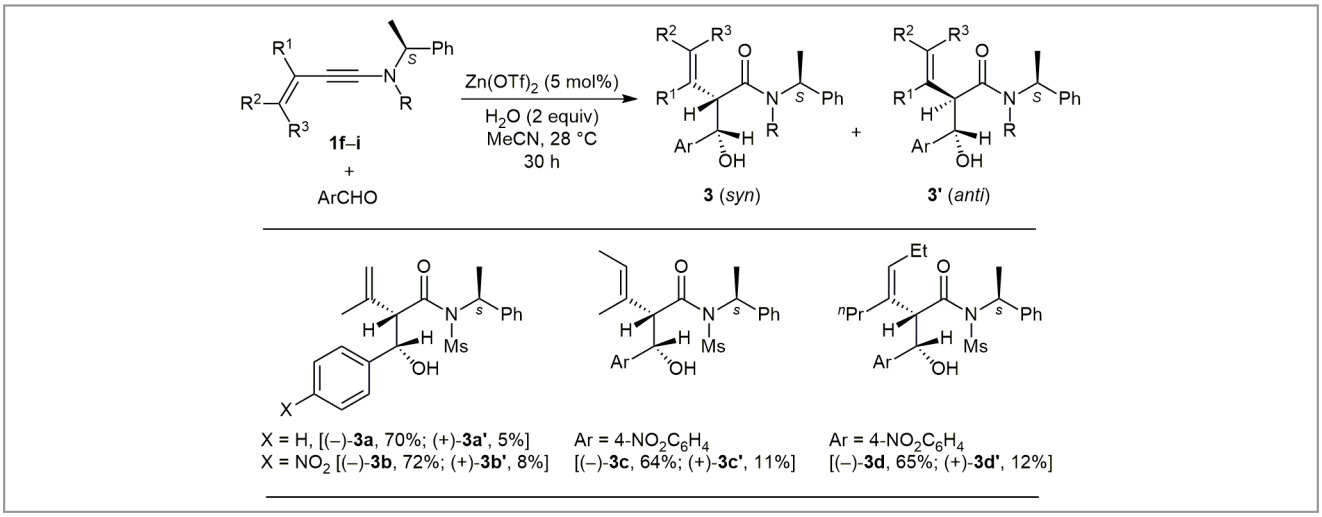
hydes include benzaldehyde, alkynyl-, alkenyl- and 3-phenylpropyl aldehyde, whereas operable 3-en-1-ynamides can comprise 1,1- and 1,2-disubstituted as well as 1,1,2- and 1,2,2-trisubstituted alkenyl moieties," explained Professor Liu. "X-ray diffraction studies have been performed to confirm the *syn* configuration of several representative aldol products."

The laboratory of Professor Liu has made successful attempts to modulate the *syn* selectivity using 3-en-1-ynamides bearing a large sulfonamide. "The alteration of stereoselectivity is attributed to preferable formation of *Z*-configured O-bound dienolates in which a large sulfonamide is preferably in a *cis* position relative to a small hydrogen," explained Professor Liu. Scheme 5 shows several examples for obtaining enantiopure branched aldol products using 3-en-1-ynamides bearing a cheap chiral sulfonamide (R = (*S*)-α-methylbenzyl, EWG = Ms). Professor Liu said: "The reactions preferably afforded *syn*-aldol products as major products. Their *syn* geometries and absolute configurations were confirmed by X-ray diffraction of one representative product. Unfortunately, this large sulfonamide decreases the reactivity of aldol reactions so that only benzaldehyde and their reactive analogues are applicable substrates."

Professor Liu also commented: "The success of such hydrative aldol reactions is attributed to the use of a sulfonamide to trap a released HOTf, thus impeding competitive protodemetalations of Zn(II) dienolates. Importantly, *E*- and *Z*-configured dienolates can be generated selectively by the sizes of sulfonamides." He concluded: "This work might inspire research interest on catalytic alkyne hydrations, including the following aspects: (1) new electrophilic reactions of O-bound Zn dienolates, (2) asymmetric hydrative aldol reactions using chiral Zn(II) catalysts and (3) the use of Zn(II)-enolates as reaction partners for Negishi coupling reactions."



Scheme 4 The use of a bulky sulfonamide to alter stereoselectivity



Scheme 5 Enantiopure aldol products with *syn*-selectivity

About the authors

Prof. R.-S. Liu

Rai-Shung Liu received his BS degree in chemistry (1976) from National Tsing-Hua University (Taiwan), and his PhD in chemistry in 1981 from Columbia University (USA). He then carried out postdoctoral work at Texas A&M University (USA) from 1981 to 1982. In 1982, he started his academic career as an Associate Professor at National Tsing-Hua University. In 1987, he was promoted to Full Professor and he is currently the Dean of the College of Science.

Dr. D. B. Huple

Deepak B. Huple was born in Kuntegaon (India) in 1981. He received his BSc (2003) and MSc from Swami Ramanand Teerth Marathwada University Nanded (India) in 2005. He worked as a senior research chemist from 2006–2008 in reputed pharmaceutical companies in India. In 2008, he joined the research group of Professor Liu and received his PhD in 2013. Currently, he is working as a postdoctoral fellow in Professor Liu's group.

Dr. A. M. Jadhav

Appaso M. Jadhav was born in Sangli, MS (India) in 1982. He obtained his BSc from Willingdon College, Sangli (India) and MSc in 2006 from University of Pune (India). From 2006–2008, he worked as research associate in Jubilant Chemistry Ltd. and Ranbaxy Laboratories Ltd. (India). In 2009, he joined the group of Professor Liu to pursue his PhD degree, and completed it in 2013. His doctoral research focused on the development of new organic reactions using gold catalysts. Subsequently, he worked as a postdoctoral researcher in same group for nearly two years. Currently, he is pursuing his second postdoctoral experience at Ohio State University, Columbus (USA).

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Dr. V. V. Pagar

Vinayak Vishnu Pagar was born in Nasik, Maharashtra (India) in 1983. He obtained his BSc and MSc degrees in chemistry from the University of Pune (India) in 2004 and 2006, respectively. From 2006–2010, he worked as research associate in pharmaceutical companies like Jubilant Chemsys Ltd. and Ranbaxy Laboratories Ltd. (India). In 2010, he joined the group of Professor Liu and completed his PhD in 2014. His doctoral research focused on the development of new organic reactions by using transition-metal catalysts. He is now a postdoctoral researcher in the same group.

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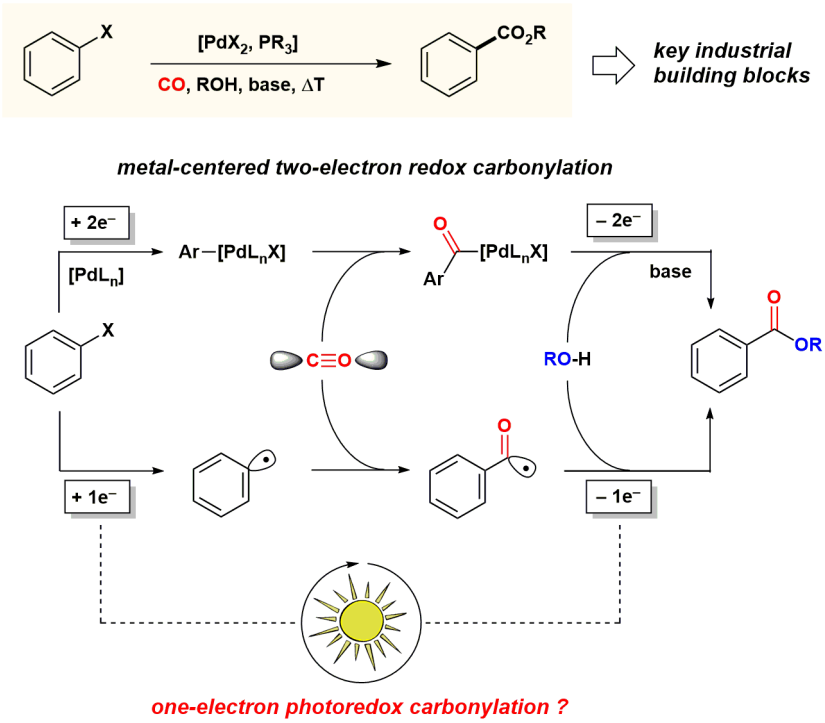
Organocatalysis Meets Visible Light Meets Carbon Monoxide

Angew. Chem. Int. Ed. **2015**, *54*, 2270–2274

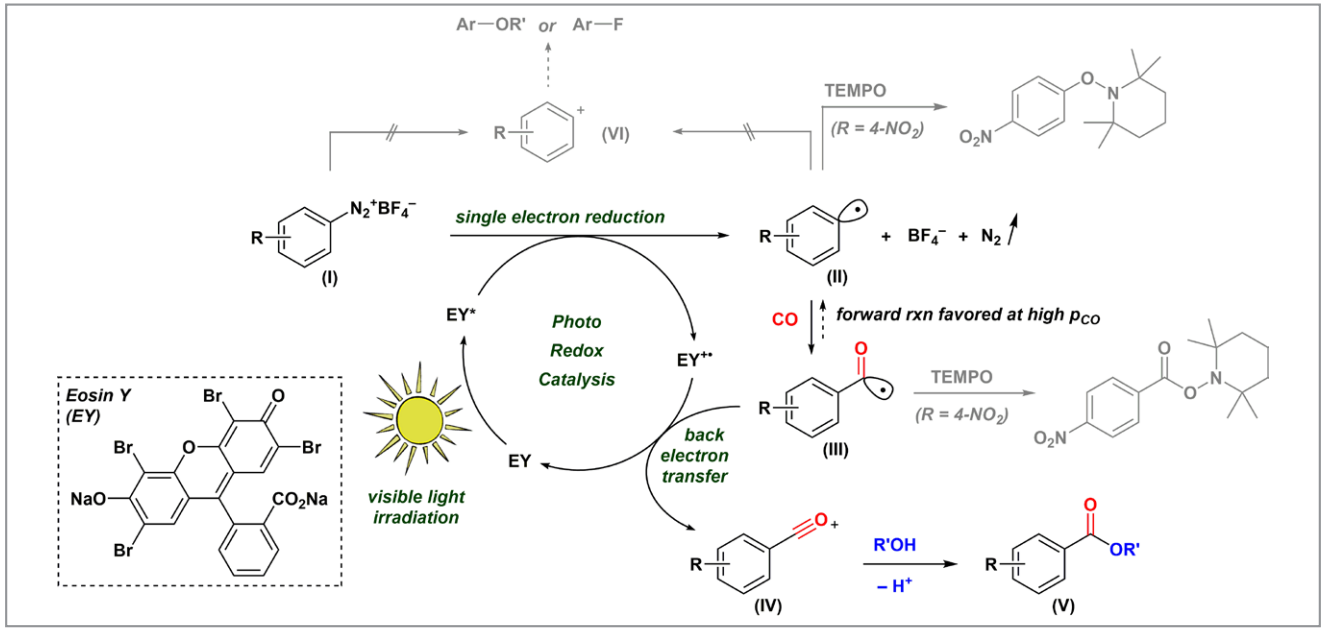
"The formation of C–C bonds is at the very heart of organic synthesis," said Professor Axel Jacobi von Wangelin from the Institute of Organic Chemistry, University of Regensburg (Germany). "For example, the advent of transition-metal-catalyzed cross-coupling has probably changed the way we think about C–C bond formation like no other method in the last century. For good reason, this was acknowledged by the bestowal of the Nobel Prize in Chemistry 2010 to Heck, Suzuki, and Negishi," he continued. "An extension of such chemistry can be used to form various carbonyl compounds by application of a carbon monoxide atmosphere to similar reaction conditions." The CO molecule formally inserts between the two cross-coupling reagents, thus allowing for a modular assembly of ketones.[1] Professor Jacobi von Wangelin explained that only very recently, photocatalysis in the presence of visible light was introduced as a new reaction concept to C–C bond formations which commonly would have been forged by Pd-catalyzed Suzuki or Stille reactions. "Such visible-light-driven reactions with metal-free organic dye catalysts (such as eosin Y) use arenediazonium salts as good electrophiles and electron-rich arenes as nucleophilic coupling partners although the mechanism involves single-electron redox steps,"[2] he said. Professor Jacobi von Wangelin's group is embedded within the Graduate School on Photocatalysis at the University of Regensburg and is running a highly successful research program on cross-coupling reactions. Professor Jacobi van Wangelin said: "Our situation surely helped to breed the idea of adopting a photoredox mechanism for carbonylative coupling reactions. However, our initial efforts toward a carbonylative aryl–aryl coupling were not met with success. When we resorted to methanol as a solvent, we were delighted to observe the formation of the methyl ester instead. Et voilà!"

According to Professor Jacobi von Wangelin, there are isolated literature reports of Pd-catalyzed carbonylations of arenediazonium salts to esters[3] but the group rapidly realized that their mechanism was very distinct and novel. In fact,



Scheme 1

neither metal nor ligand nor base was required. Cheap eosin Y served as organic sensitizer, and green LEDs were used for irradiation of the reactions. "The design of a pressure reactor that would accommodate gas/liquid mixtures up to 50 bar and at the same time allow effective irradiation of the liquid phase was the major challenge," said Professor Jacobi von Wangelin. "After extensive mechanistic studies and strong support by DFT calculations, we firmly believed that a one-electron redox cycle is operating that does not require any sacrificial redox partners." He acknowledged that the initial photocatalytic reduction of arenediazonium ion to the aryl radical was already postulated in related transformations. "Subsequent reaction with CO appeared to be the key step, probably being also rate-limiting. However, the ester can only be formed if the



Scheme 2

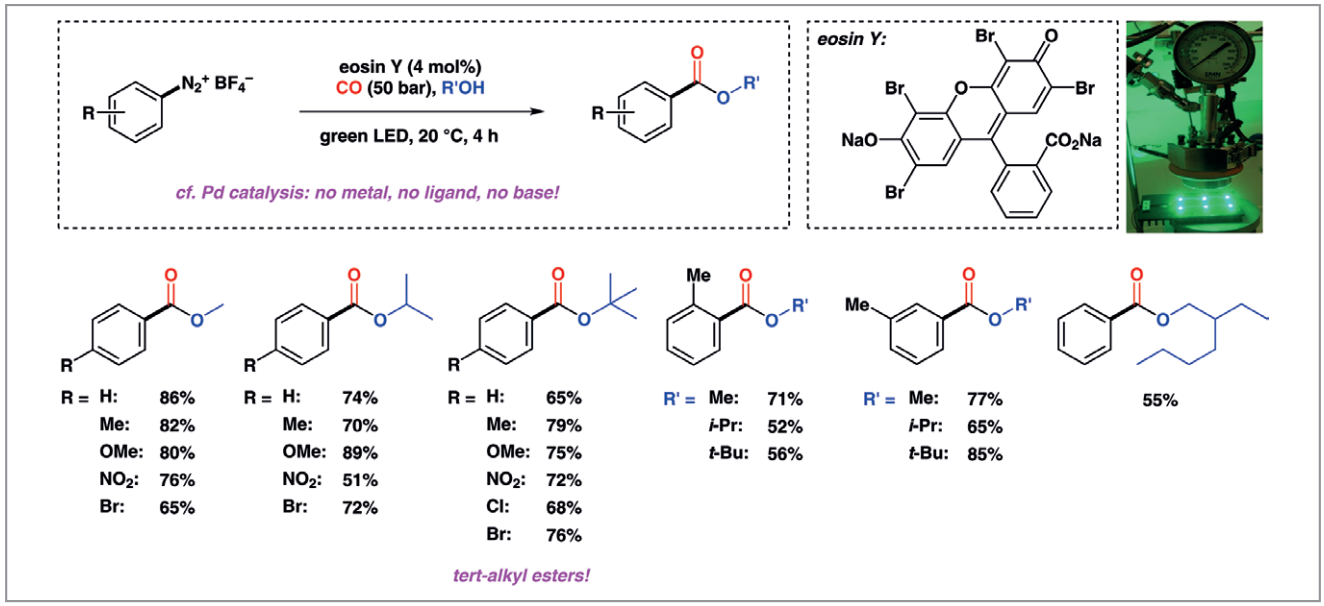


Figure 1

resultant acyl radical can be oxidized to the acylium ion by the eosin radical cation since methanol is not a competent radical trap. Once this oxidation occurs, ionic reaction with the bulk solvent gives the desired methyl benzoate," said Professor Jacobi von Wangelin. "The mechanistic beauty of this process resides within the operation of the two usually incompatible reduction and oxidation processes in the same system. The selectivity of the reaction is dictated by the matching redox potentials of the photocatalyst, the substrate, and the acyl radical intermediate. As our colleagues Armido Studer and Dennis P. Curran put it: the electron is the catalyst!"[4]

According to Professor Jacobi von Wangelin, this new carbonylation mechanism distinguishes itself from the conventional Pd catalysis in that it formally cycles around one electron driven by visible light rather than two electrons driven by the Pd/Pd^{2+} redox couple and stoichiometric base. "Furthermore, the intermediacy of the highly electrophilic and rather unhindered (planar) acylium ion engages in nucleophilic trappings with *n*-, *i*- and *t*-alkanols," he said. "With *tert*-butanol, efficient synthesis of *tert*-butyl benzoates was achieved which is not possible under Pd or Ni catalysis."

"We are aware – even more so after the more than half-year period from initial submission to publication – that the competition is keen in this research area but we hope to be able to make further contributions to the development of metal-free formal cross-coupling methodologies. Clearly, the conversion of less activated electrophiles is desirable, as is the application of optimized reactor types. The International Year of Light 2015 will certainly produce more exciting photochemistry and hopefully some transitions into manufacture," concluded Professor Jacobi von Wangelin.

REFERENCES

(1) X.-F. Wu, H. Neumann, M. Beller *Chem. Soc. Rev.* **2011**, *40*, 4986.
(2) D. P. Hari, P. Schroll, B. König *J. Am. Chem. Soc.* **2012**, *134*, 2958.
(3) S. Sengupta, S. K. Sadhukhan, S. Bhattacharyya, J. Guha *J. Chem. Soc., Perkin Trans. 1* **1998**, 407.
(4) A. Studer, D. P. Curran *Nat. Chem.* **2014**, *6*, 765.

About the authors

Axel Jacobi von Wangelin (left) was born into the 1974 World Cup euphoria in Berlin (Germany) and spent a joyful boyhood in the backyards of Berlin-Friedrichshain. Axel abandoned capital city pace when he took up chemistry studies at the University of Erlangen (Germany). His Masters thesis and a subsequent research stay with John A. Gladysz allowed him to work at the University of Utah (USA) where he also advanced his mountaineering skills. Back in Germany, Axel joined Matthias Beller's group at the Leibniz-Institute of Catalysis in Rostock from where he obtained a Ph.D. in 2002. After a short industrial stay at Degussa AG in Frankfurt (Germany), he was a postdoctoral fellow with Kingsley J. Cavell at Cardiff University (UK) and Barry M. Trost at Stanford University (USA). In 2006, he started his independent career at the University of Cologne (Germany). Since 2011, Axel is Professor of Organic Chemistry at the University of Regensburg. His recent research achievements were recognized with the ORCHEM Award of the Liebig Association (2012), the Heisenberg fellowship (2011), and the Science Award of the Industrieclub (2009).

Michal Majek (right) is a native of the Slovak Republic where he attended a high school with maths and natural science focus in Bratislava. From 2006–2012, he studied at the Institute of Chemical Technology in Prague (Czech Republic) and enjoyed inspiring research stays at the Universities of Glasgow and St. Andrews (UK). In 2012, he joined the group of AJvW at the University of Regensburg where he was admitted to the Graduate College "Photocatalysis". In his research, he combines theoretical, physical and chemical approaches to light-driven chemical transformations. He single-handedly initiated a research program with special emphasis on organocatalytic, visible-light-mediated aromatic substitutions. In his spare time, he travels and – when at home – coaches the Slovak Chemistry Olympic teams.

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- Homepage: www.thieme-chemistry.com

Publication Information
Synform will be published 12 times in 2015 by Georg Thieme Verlag KG, Rüdigerstraße 14, 70469 Stuttgart, Germany, and is an additional online service for Synthesis, Synlett and Synfacts.

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