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Polystyrene-supported recyclable palladacycle catalyst for Heck, Suzuki and Sonogashira reactions

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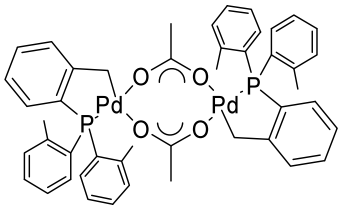
Abstract—A new type of soluble polystyrene-supported palladium complex as an excellent and recyclable palladacycle catalyst was discovered for carbon–carbon bond formation in Heck, Suzuki and Sonogashira reactions. Precipitation and filtration process for recycling the catalyst was also achieved.

Palladacycles have been known for over 20 years; yet they have been used as catalysts recently.[1] Nitrogen-, phosphorus-, and sulfur-containing palladacycles are emerging as a new family of palladium catalyst precursors, and they have recently become the most simple and efficient catalyst in applying to Heck–Mizoroki, Suzuki–Miyaura and Sonogashira reactions.[1g] Herrmann and his co-workers have demonstrated that palladacycle **1** is thermally stable and efficient catalyst for Heck–Mizoroki, Suzuki–Miyaura, and Sonogashira reactions.[2] It also had been shown to have high reactivity toward arylation of olefins with aryl chlorides.[2e] Although the palladacycle catalyst, as Herrmann reported, have high reactivity to promote a lot of reactions, only a few reports on the recovery of palladacycle catalysts were reported in the literature.[3] Bergbretier and his co-workers have synthesized the palladacycle **2** with (SCS)-type tridentate ligand bounded by thermomorphic polymer. They have discovered that the recyclability of **2** has been enhanced significantly; yet its reactivity is not effective with aryl bromides.[3a–d] Nowotny has suggested a new cyclopalladated imine catalyst **3** bounded by polystyrene (PS) to improve its recyclabilities. But, it was deactivated after the second run.[3e] On the other hand, phosphorous-containing PS was generally used as the ligand to trap and reuse Pd catalysts after the reaction.[4] Herein, we report the synthesis of a new PS-supported palladacycle catalyst **4** which can be used as an efficient recyclable palladium catalyst for running Heck–Mizoroki, Suzuki–Miyaura and Sonogashira reactions.

The synthesis of the PS-supported palladacycle catalyst is shown in Scheme 1. Thus, *trans*-di(μ-acetato)-bis[2-(diphenylphosphino)-4-vinylbenzyl]dipalladium(II) **6** was synthesized from 3-(diphenylphosphino)-4-methylstyrene **5** by heating with Pd(II) acetate in toluene at 50°C.[2a] Compound **5** was prepared in moderate yield by bromination ($Br_2/AlCl_3$)[5a] of 4-methylacetophenone followed by the reduction (LAH/ether), dehydration ($KHSO_4/\Delta$)[5b] and coupling with chlorodiphenylphosphine (Mg/THF; $ClPPh_2$).[5c] Considering the proper space around the palladium in the catalyst, the palladacycle precursor **6** was copolymerized with 6 equiv. of styrene at 70°C. The phosphorous-containing compounds were analyzed by solution phase ^{31}P NMR in



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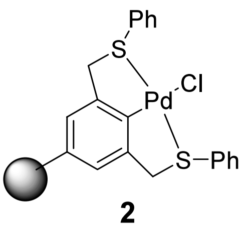

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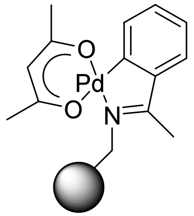

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Keywords: polystyrene-supported palladacycle catalyst; recyclable catalyst; Suzuki coupling reaction; Heck reaction; Sonogashira reaction.

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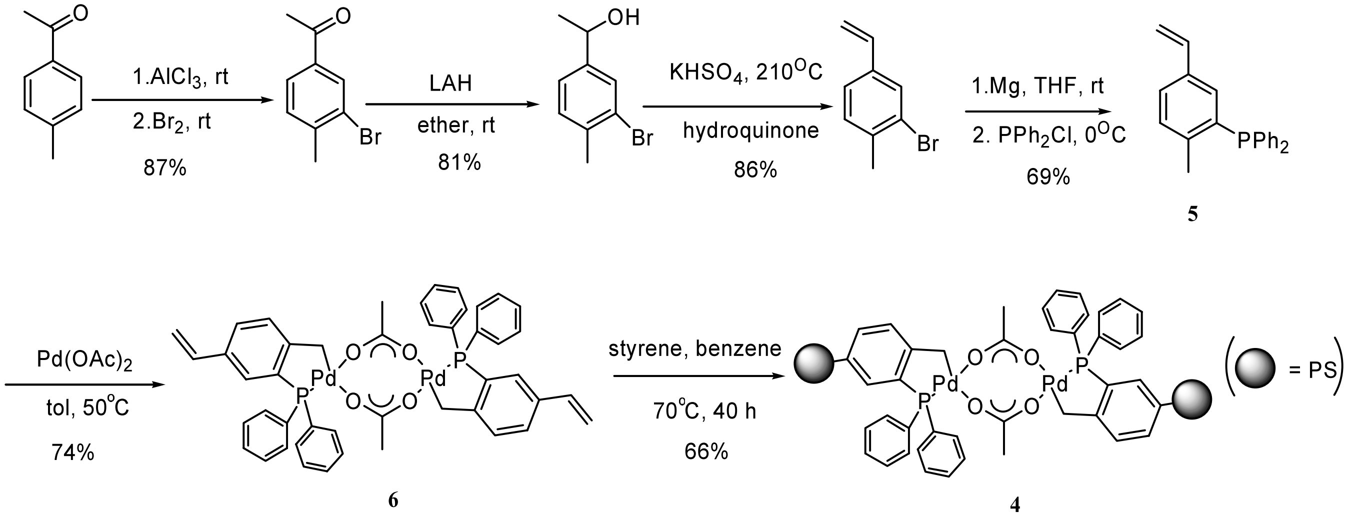
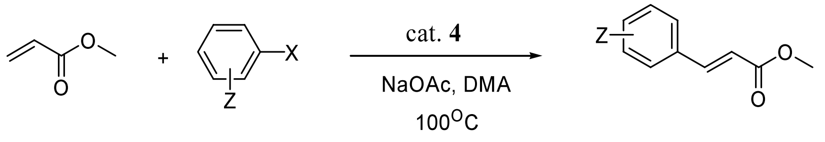


Scheme 1. Synthesis of PS-supported pallacycle catalyst **4**.

$CDCl_3$. The chemical shift of phosphorus in **5** was appeared at −12 ppm as a singlet, while it was shifted to 17 ppm as a singlet in **6**. On the other hand, the methyl protons (3H) in **5** appeared at 2.3 ppm as a singlet, while the methylene protons (4H) in **6** appeared at 3.25 ppm as a broad singlet. The ^{31}P signal of catalyst **4** was observed at 53 ppm before and after Heck reaction, while the ^{31}P signal of catalyst **6** observed at 17 ppm before Heck reaction but appeared at 17 ppm along with a new peak at 53 ppm after Heck reaction (the peaks ratio at 17 and 53 ppm is about 7:3). The peak at 53 ppm in ^{31}P NMR spectrum was become the sole peak after six times recycling of the catalyst **6**. Thus, the catalyst **6** was polymerized completely under the reaction conditions.

To test the applicability of PS-supported palladacycle catalyst **4**, we examined the Heck reaction of methyl acrylate and various aryl halide in the presence of NaOAc in DMA (*N*,*N*-dimethylacetamide) as shown in Table 1. Under various reaction conditions, all the desired products were isolated in more than 90% yields. Thus, the PS-supported catalyst **4** can easily promote the Heck reaction of aryl bromides- and iodides-containing either electron-rich or electron-withdrawing groups (Eq. (1)), which produced only one major product as determined from GC and crude ^1H NMR spectral analysis. The PS-supported catalyst **4** prepared with different ratio of styrene (mole ratio of styrene/**6** = 3 or 9) were also synthesized and were run as the catalyst in the above Heck reactions. No obvious difference was observed among these PS-supported catalyst prepared from different ratio of styrene/**6**. In addition, we also tested the applicability of catalyst **4** in Suzuki cross-coupling and Sonogashira reactions. The Suzuki cross-coupling of 4-bromoacetophenone and phenylboronic acid (1.5 equiv.) in the presence of 0.2 mol% of catalyst **4** and K_2CO_3 (1.5 mol) was proceeded well in *o*-xylene at 130°C (Eq. (2)). We could isolate only the desired product in high yields (>99%) after 5 h. The Sonogashira reaction of 4-bromoacetophenone and phenylacetylene (1.5 equiv.) was carried out with 0.2 mol% of catalyst **4** in Et_3N at 90°C (Eq. (3)). After 72 h, we could get only one major product in more than 98% yield. Thus, the reactivity of catalyst **4** in our different model reaction conditions proved to be similar to Herrmann's palladacycle catalyst **1**.

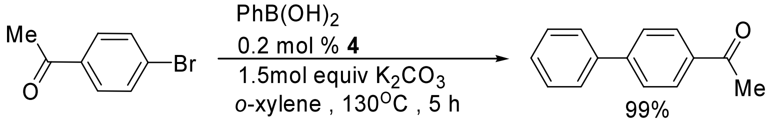
Table 1. Heck reaction using PS-supported catalyst **4**



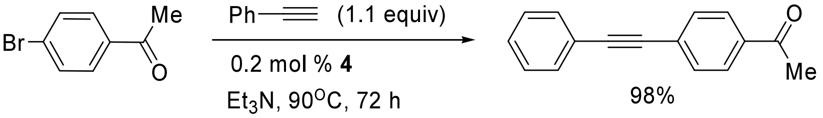
(1)

X = Br, I
Z = H, Me, OMe, CHO, CN.

Entry	Haloarene	Cat. **4** (equiv.)	Temp. (°C)	Time (h)	Iso. yield (%)
1	4-Bromobenzonitrile	0.02	100	10	>99
2	Bromobenzene	0.05	130	48	97
3	4-Bromotoluene	0.05	130	48	95
4	4-Bromoanisole	0.05	130	48	92
5	Iodobenzene	0.02	100	8	>99
6	2-Bromobenzaldehyde	0.002	100	10	>99



(2)



(3)

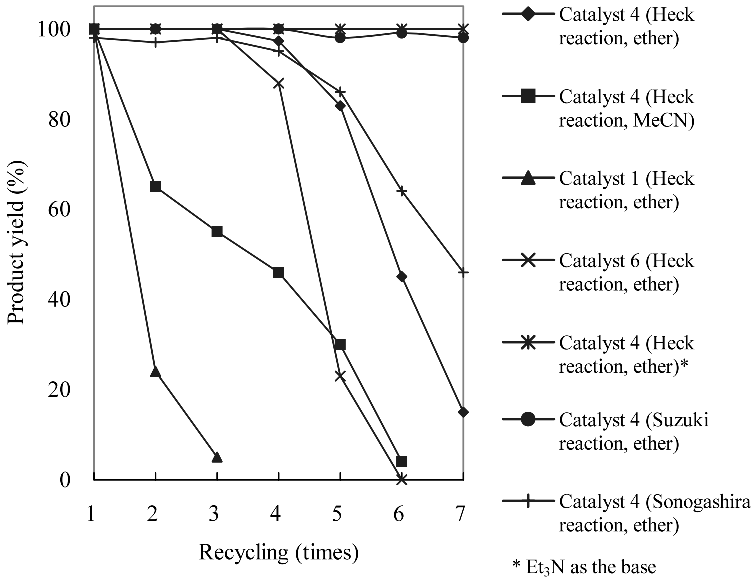


Figure 1. Recycling of catalysts in different reactions from selected solvent.

The PS-supported catalyst **4** was soluble in THF, DMA, DMF, $CHCl_3$, CH_2Cl_2 and not very soluble in MeOH, MeCN, hexane, and ether. Ether and MeCN were used here to precipitate our new catalyst. Salt removal was skipped due to the palladacycle catalyst, which can be deactivated easily by water. Probably, the phosphine ligand may form phosphine oxide in the presence of water. The Heck reaction of 4-bromobenzonitrile and methyl acrylate (1.5 equiv.) with 2 mol% of catalyst **4** and NaOAc (1.5 equiv.) in DMA at 100°C was proceeded as the model reaction. Figure 1 shows that the yield of the product can be isolated more than 80% after being recycled four times with ether as the solvent to precipitate our PS-supported catalyst **4**. Using MeCN as the solvent may drop the yield of the product below 60% after the second run. Figure 1 also shows that the reactivity of Herrmann's catalyst **1** diminished thoroughly after being recycled two times in the model reaction. The use of catalyst **6** in the model reaction also diminished the yields to near 20% after recycled four times in the model Heck reaction. We also found that the yield can be kept more than 99% after recycling six times, using Et_3N in stead of NaOAc as the base in the model Heck reaction. The yield can be kept more than 95% after repeating 7 times Suzuki cross-coupling reaction (Eq. (2)), using the initial 5 mol% catalyst **4**. The conversion of 4-bromoacetophenone can be maintained more than 90% with 5 mol% catalyst **4** after repeating Sonogashira reactions (Eq. (3)) four times.

In conclusion, we have synthesized a new PS-supported palladacycle catalyst **4** which was successfully employed in the carbon–carbon bond formation to give good yields in the Heck–Mizoroki, Suzuki–Miyaura and Sonogashira model study. Our catalyst exhibited a high reactivity as Herrmann's palladacycle catalyst **1** and, in addition to its high reactivity, it gave us a promising solution to lower the reaction cost by its good recyclabilities of using pertinent organic solvents.

Acknowledgements

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