

Pd-Chitosan-based Microspheres as Tunable Soft-Materials for Sonogashira Cross-Coupling in Water-Ethanol Mixture

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S1. Experimental section.

General Remarks

Commercially available reagents and solvents were purchased from Across and Aldrich and used without further purification. Chitosan of medium molecular weight and deacetylation degree of 80% was purchased from Sigma Aldrich and was used as support material.

Characterization techniques

Scanning electron microscopy (SEM) images were acquired by using a JEOL JSM 6300 apparatus. Transmission electron microscopy (TEM) images were taken in a Philips CM 300 FEG system with an operating voltage of 100 kV. DRIFT spectra were monitored using NICOLET iS10 spectrometer. XPS spectra were recorded on a SPECS spectrometer equipped with a Phoibos 150 9MCD detector using a nonmonochromatic X-ray source (Al and Mg) operating at 200 W. The samples were evacuated in the prechamber of the spectrometer at 1×10^{-9} mbar. Some of the samples have been activated in situ in N₂ flow at 450 °C for 3 h followed by evacuation at 10⁻⁸ mbar. The measured intensity ratios of components were obtained from the area of the corresponding peaks after nonlinear Shirley-type background subtraction and corrected by the transmission function of the spectrometer. ICP optical emission spectrometer were acquired by using a 715-ES Varian apparatus. BET analysis were monitored using micrometric ASP2420 instrument. Solid-state ¹³C MAS NMR experiments were performed on a Varian VNMRS 400 MHz solid spectrometer fitted with a 9.4 T magnetic field using a twochannelprobe with 7.5 mm ZrO₂ rotors with 3 and 5 kHz spinning rates.

S1a. Preparation of chitosan microspheres CS

Chitosan gel microspheres were prepared as follow: aqueous solution of chitosan are obtained by dissolving 500 mg of chitosan in 100 mL of 1% (v/v) acetic acid solution (excess of acetic acid to completely dissolve the polymer). Total dissolution was obtained by stirring for 3 h at

room temperature. This solution was added dropwise through a 0.8 mm syringe needle into a NaOH solution (0.1 M). The resulting chitosan microspheres were stored in the alkaline solution for 2 h, filtered and washed until a neutral pH solution. The beads matured under these conditions are called “hydrogel”. Alcogel microspheres were obtained by their immersing in increased solution ration of ethanol: water (respectively: 10/90; 30/70; 50/50; 70/30; 90/10) until 100% ethanol solution.

S1b. Preparation of cross-linked chitosan microspheres CS-Glu

Chemical cross-linking of chitosan microspheres using glutaraldehyde (GLA) as a cross-linking agent was carried out according to the procedure described in reference 15. Chitosan microspheres reacted with glutaraldehyde solution (4% v/v) which corresponds to 1:1 ratio of amine groups of chitosan and aldehyde functions of the cross-linking agent. The reaction was left for 72 h at room temperature. The cross-linked chitosan microspheres were intensively washed with distilled water to eliminate any adsorbed chemicals, filtered and exchanged with ethanol: water solutions until 100% ethanol and then stored in ethanol.

S1c. Preparation of thiolated chitosan microspheres CS-SH

The introduction of thiolated arms to the chitosan microspheres has been carried out following the procedure described in reference 16. Under nitrogen, a solution containing 7.25 mmol of alcogel microspheres chitosan, a large excess of γ -thiobutyrolactone (36.25 mmol) and toluene ($V = 3.5$ mL) was heated at 80°C during 96 h. The microspheres were copiously washed with the used solvent in order to remove all physisorbed chemicals.

S1d. Immobilization of palladium onto chitosan and modified chitosan microspheres

To 0.203 g of Pd (OAc)₂ in 20 mL ethanol was added 625 mg of chitosan microspheres (3.625 mmol). The resulting mixture was stirred for 2 h at room temperature under inert atmosphere. The color of the chitosan microspheres immediately turned from white into orange or black

depending on the microspheres used (**CS**, **CS-Glu** or **CS-SH**). The resulting supported microspheres were then filtered and washed several times with absolute ethanol. The alcogel materials were then used directly in catalysis (alcogel catalysts) or firstly dried under supercritical conditions (see below) to yield catalytic aerogel microspheres.

S1f. CO₂-alcogel drying

Aerogel microspheres were obtained by CO₂ supercritical drying of the corresponding modified alcogels. This method consists in the extraction of the solvent above the critical point. Ethanol was replaced by liquid CO₂ and the microspheres were dried under supercritical CO₂ conditions (73.8 bar and 31.5 °C) in a Polaron 3100 apparatus.

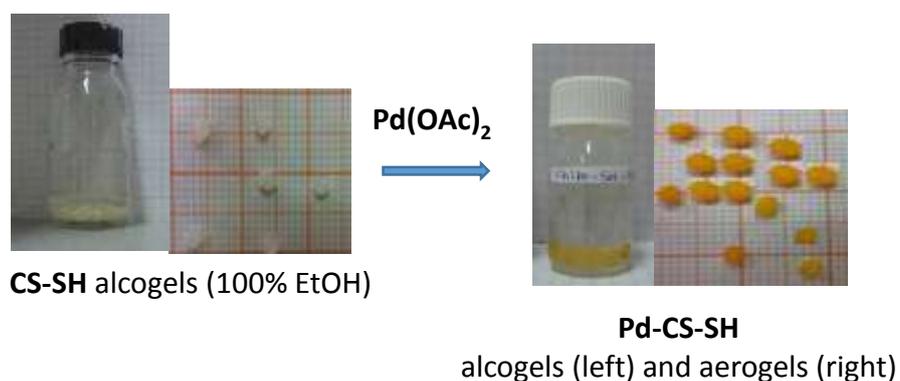
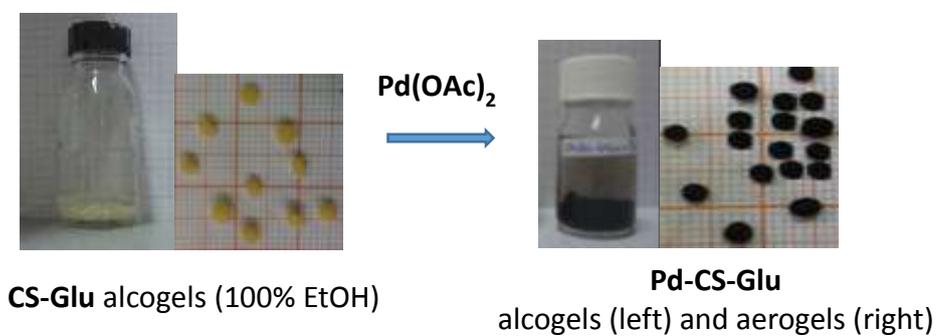
S2. Digital photos of the microspheres

S2a. Native microspheres.

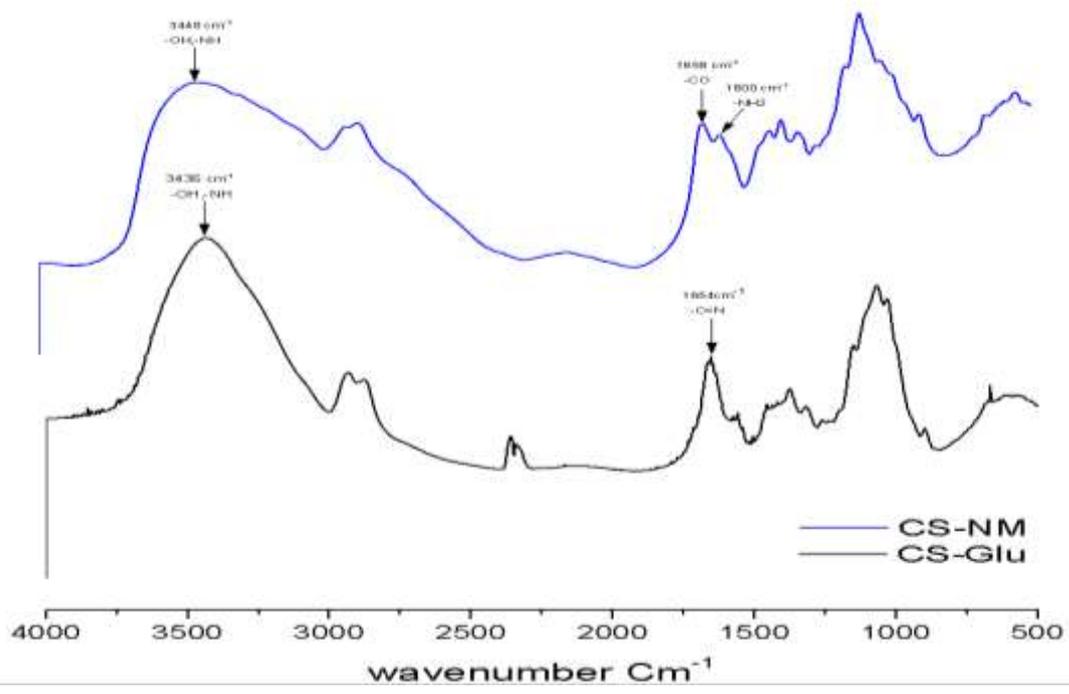
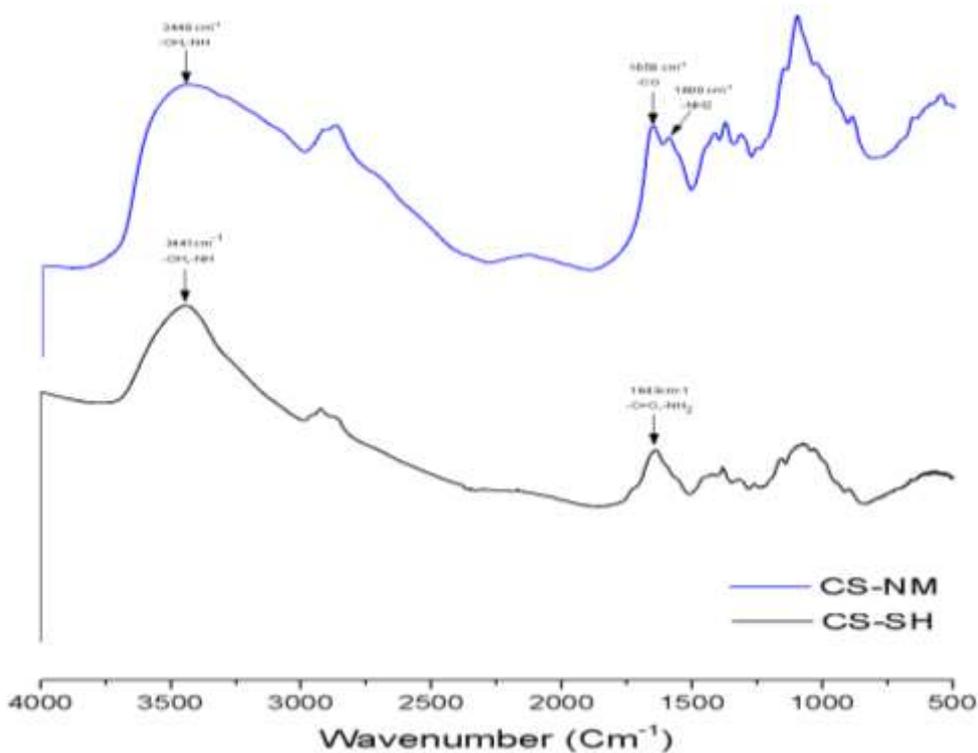


CS, **CS-Glu** and **CS-SH** alcogel microspheres. While **CS** and **CS-SH** appear with White color, reticulated chitosan beads (**CS-Glu**) turned yellow upon reacting with glutaraldehyde as a result of C=N formation.

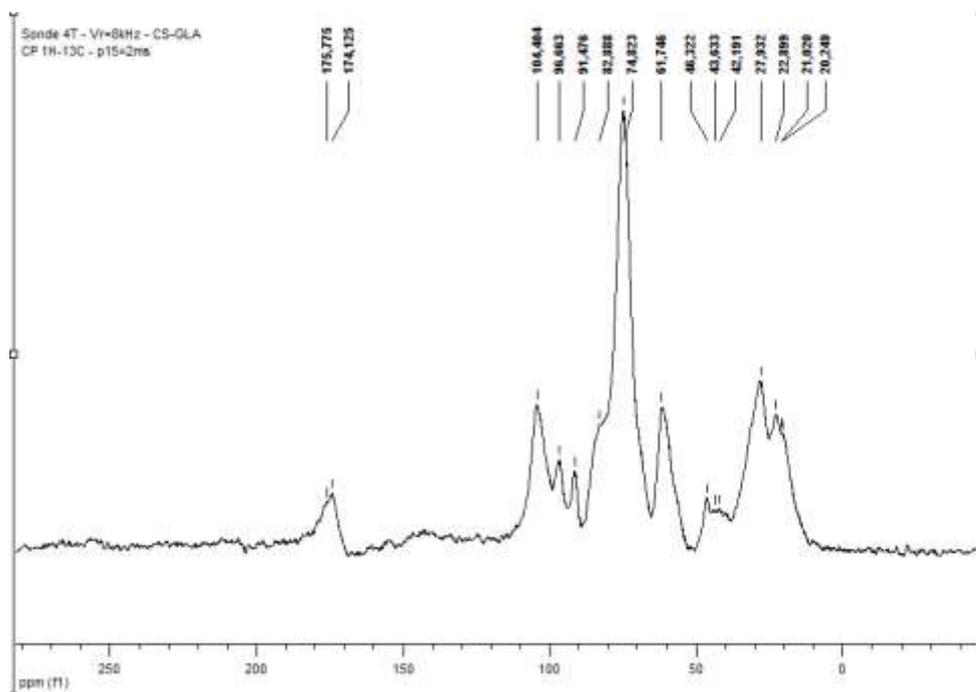
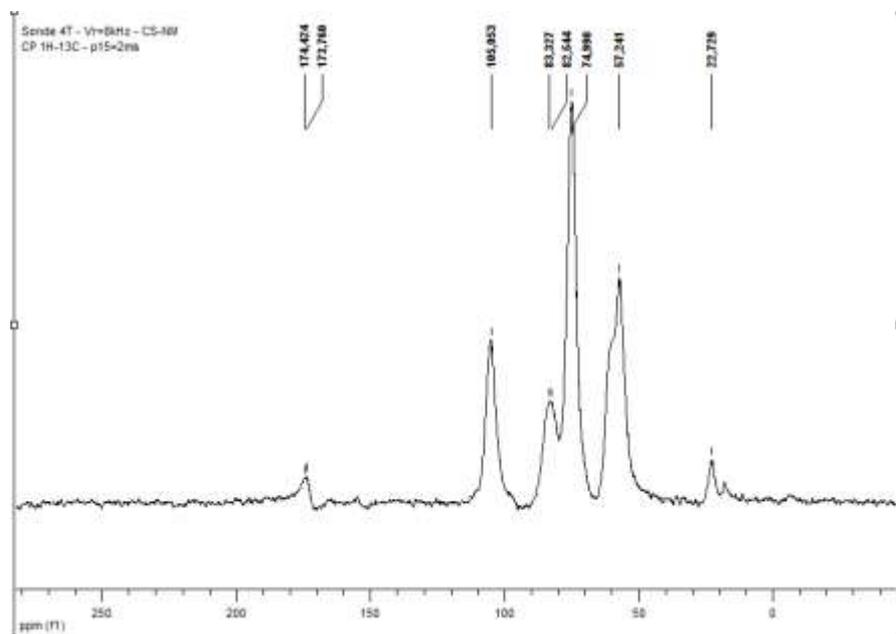
S2b. digital photos of Pd supported microspheres.

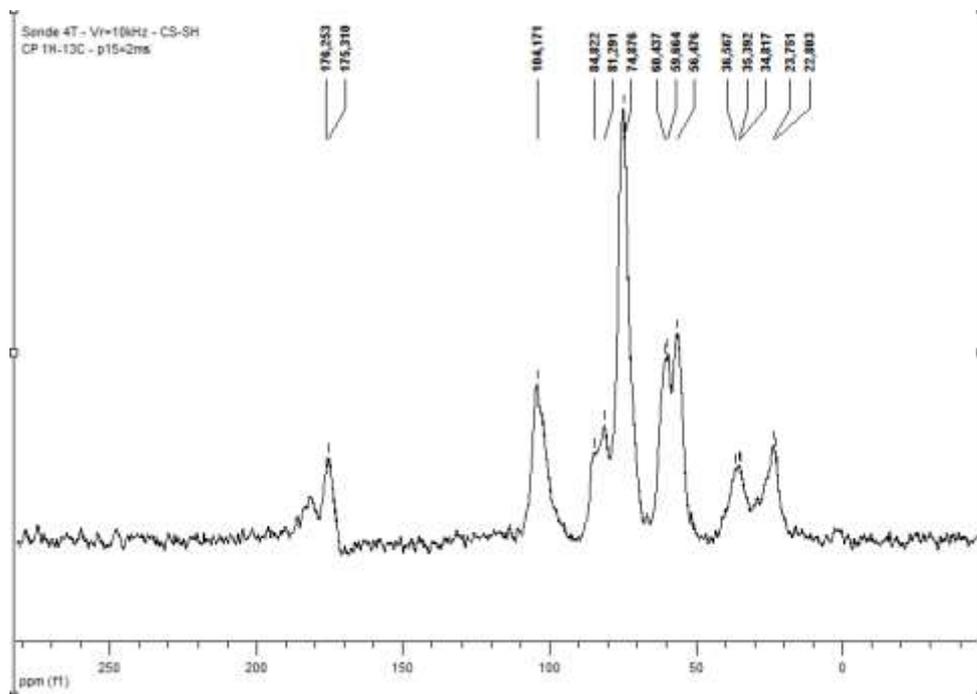


S3. DRIFT analysis.

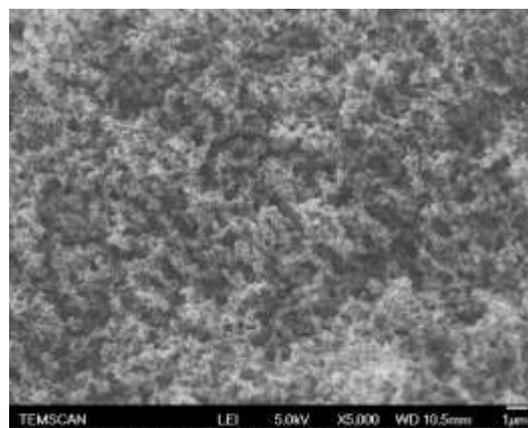
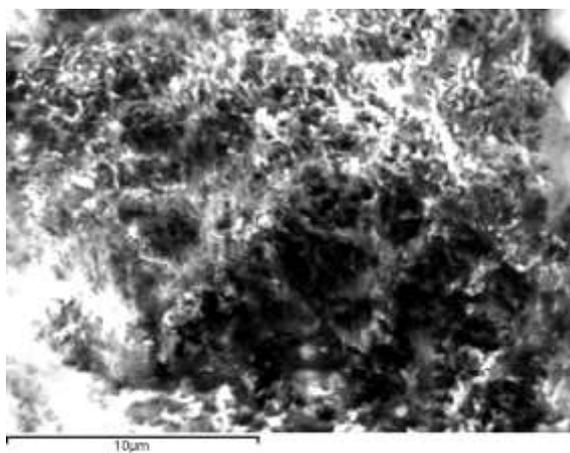


S4. CP MAS NMR analysis



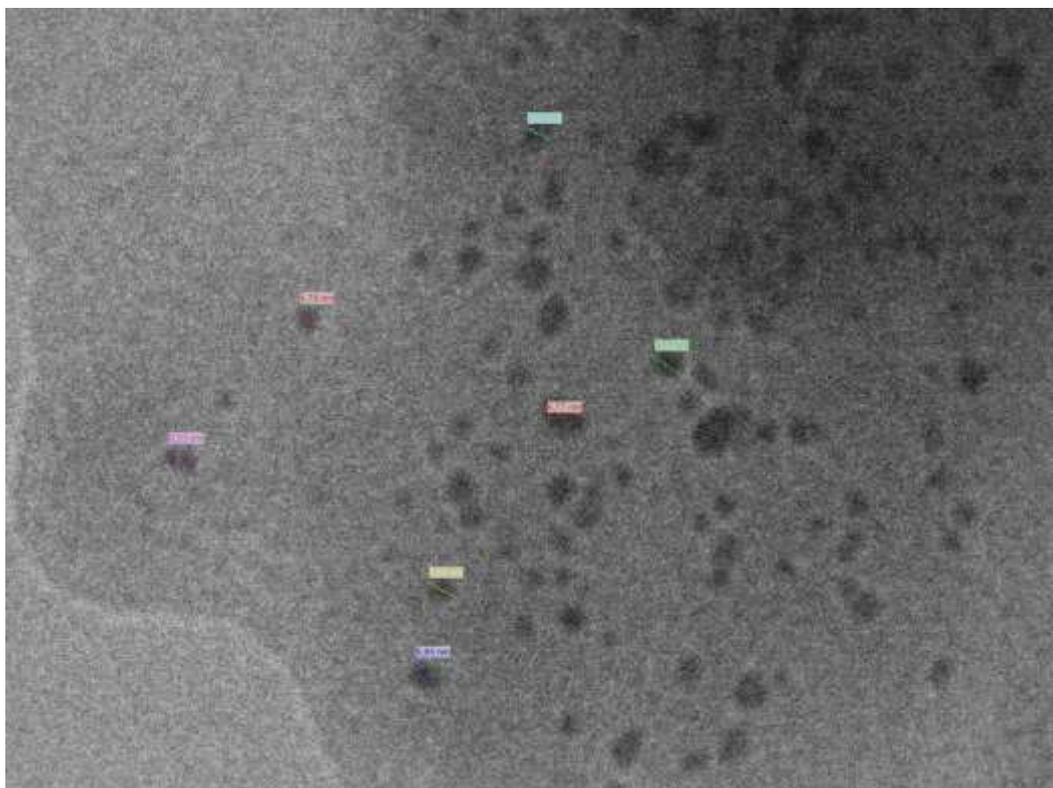
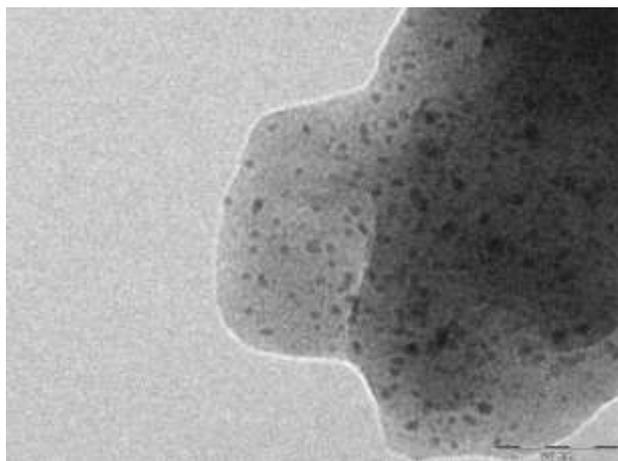


S5. SEM analysis



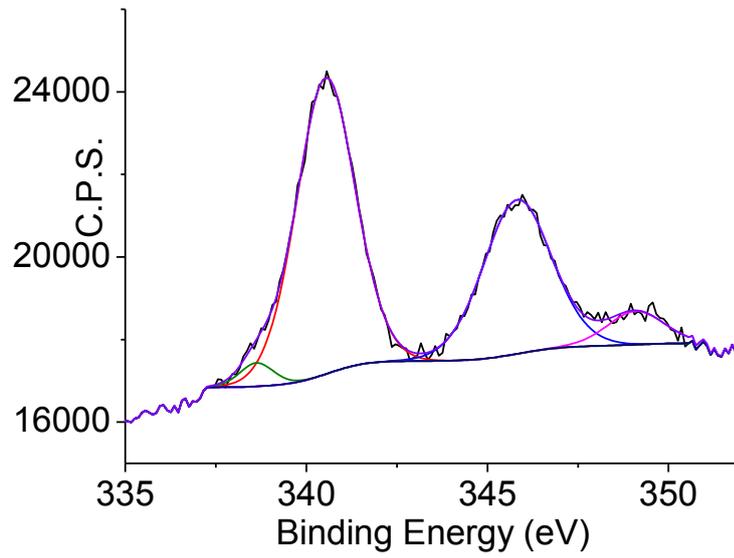
SEM of **Pd-CS** (left) and **Pd-CS-Glu** (right).

S6. TEM analysis

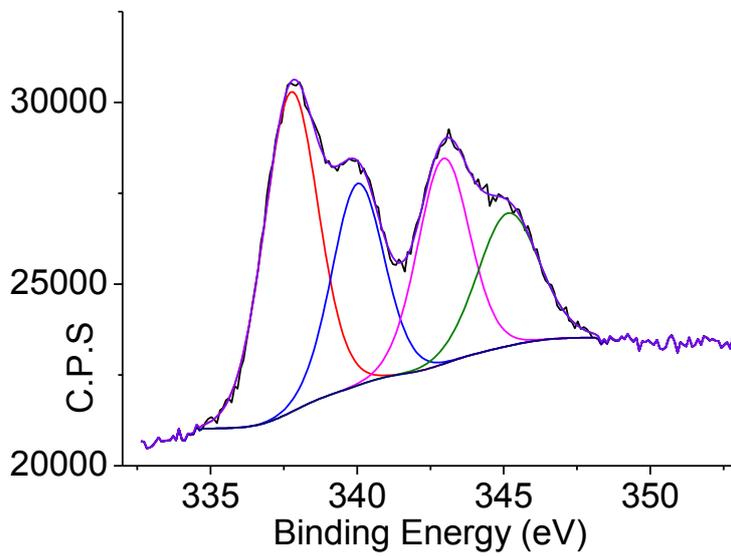


S7. XPS analysis

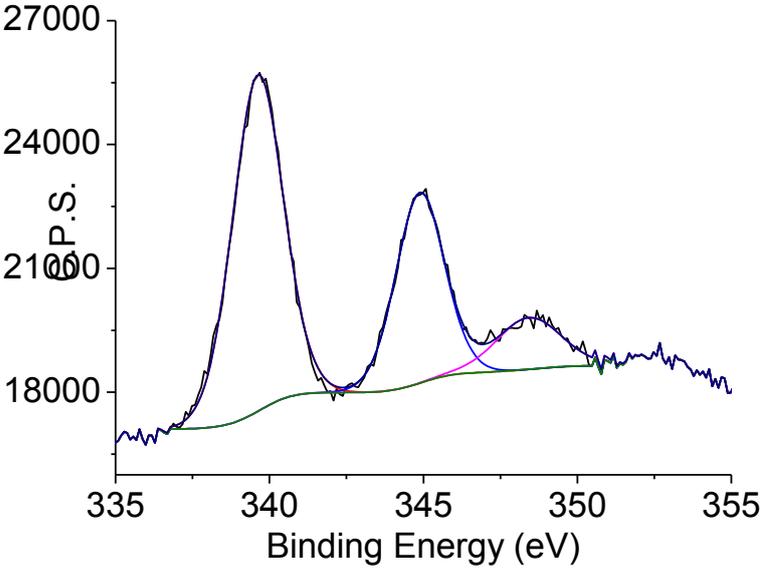
Pd3d (Pd-CS)



Pd3d (Pd-CS-Glu)



Pd3d (Pd-CS-SH)



S8. Catalysis.

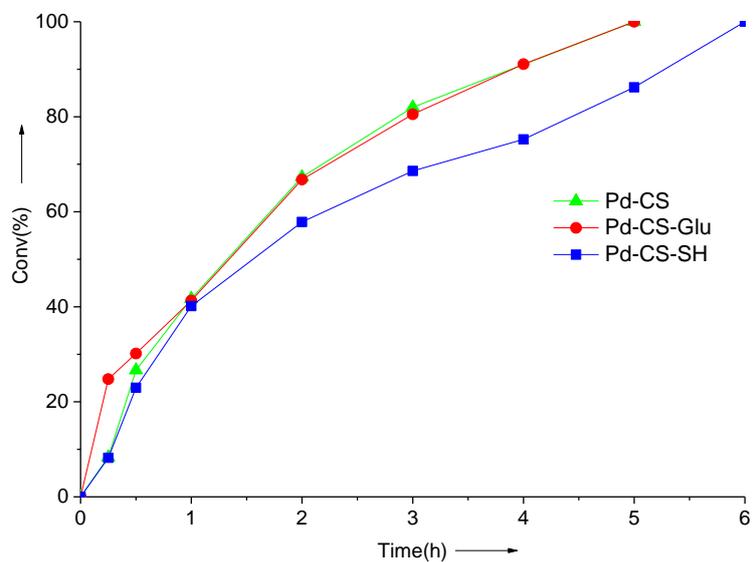
S8a. Typical procedure in catalysis:

The typical procedure of the Sonogashira reaction employed: (0.054 g, 0.07 mmol) of the supported Pd catalyst, (1 mmol , 0.204 g) of aryl halides, phenylacetylene (1.2 mmol , 0.122g) and (3 mmol , 0.414 g) K_2CO_3 in 6 mL water: ethanol mixture [1:5 v /v] were mixed in a round flask under nitrogen. The reaction mixture was stirred at 65°C for a fixed time. After a stipulated period, the reaction mixture was filtered. The solvent was evaporated under vacuum and then the product was extracted three times with 15 mL of ethyl ether.

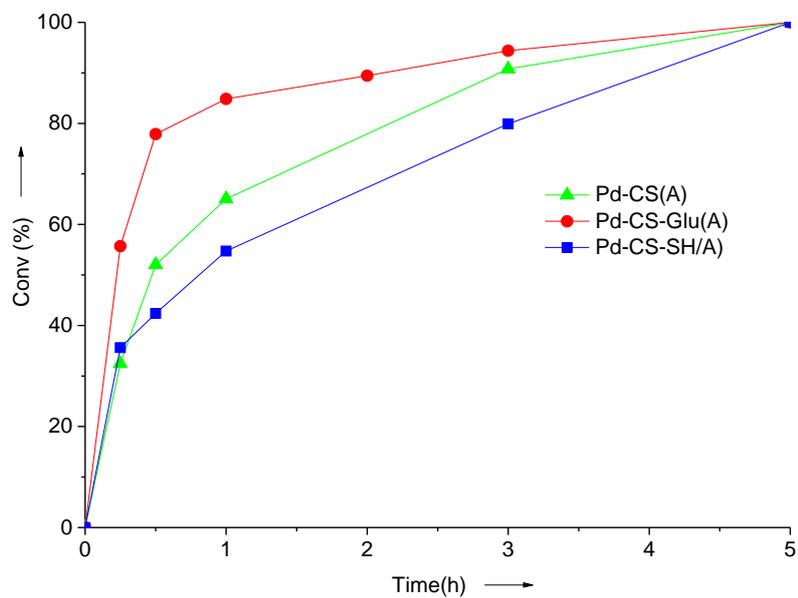
S8b. Reusability study of heterogeneous palladium catalysts:

After completion of the first cycle as described above, the supported Pd on chitosan or modified microspheres were separated from the reaction mixture by simple filtration. The microspheres were rinsed with ethanol and water (necessary to remove salts in the form of excess base) for 3 times and then with ethanol twice. The recycled palladium catalyst was used again in the next run of the cross-coupling reaction under the same reaction conditions (e.g. concentration of reactants) as the first run.

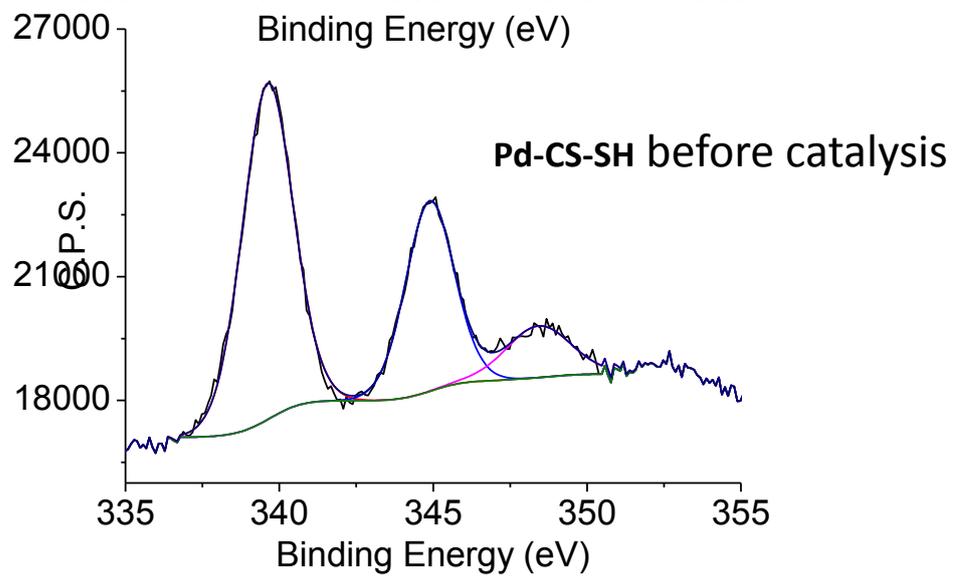
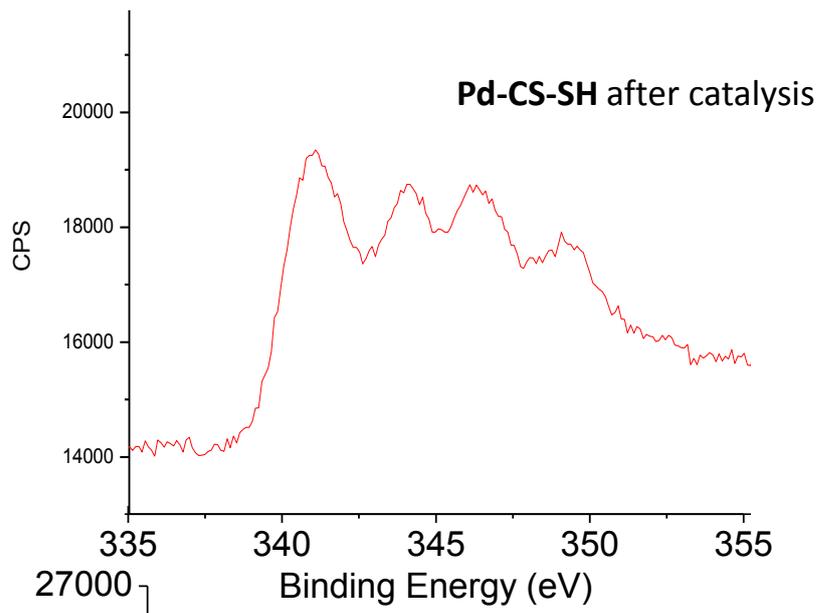
S8c. Kinetics of the three functional alcogel microspheres.



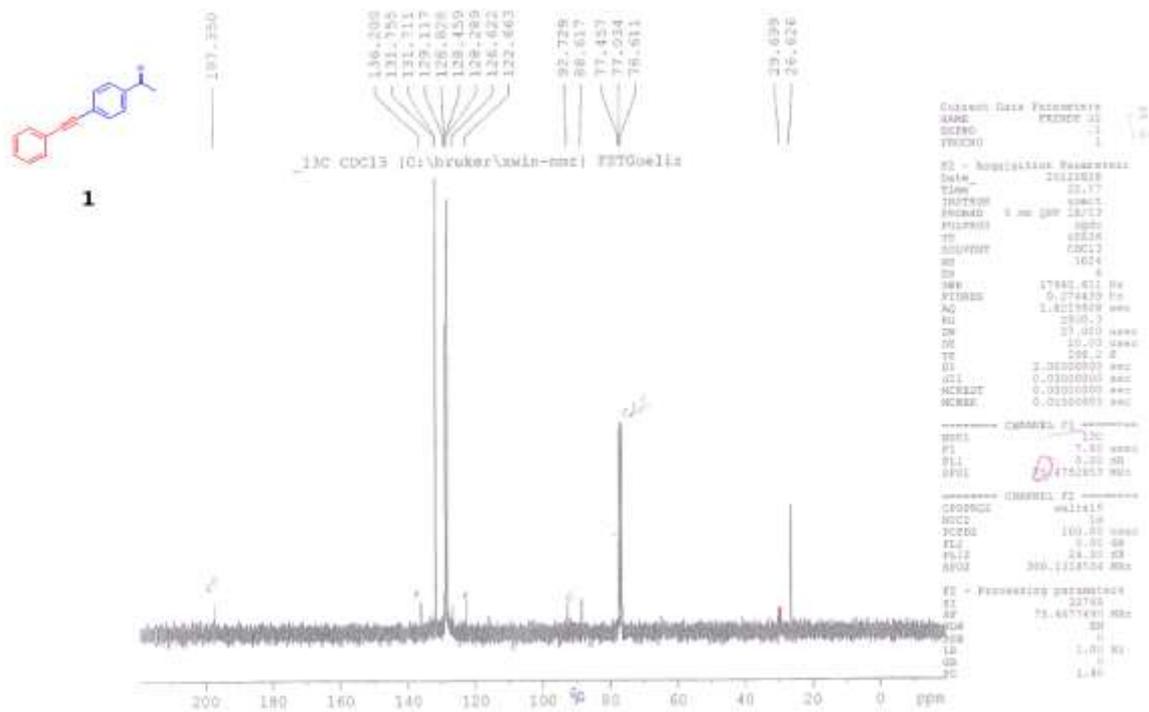
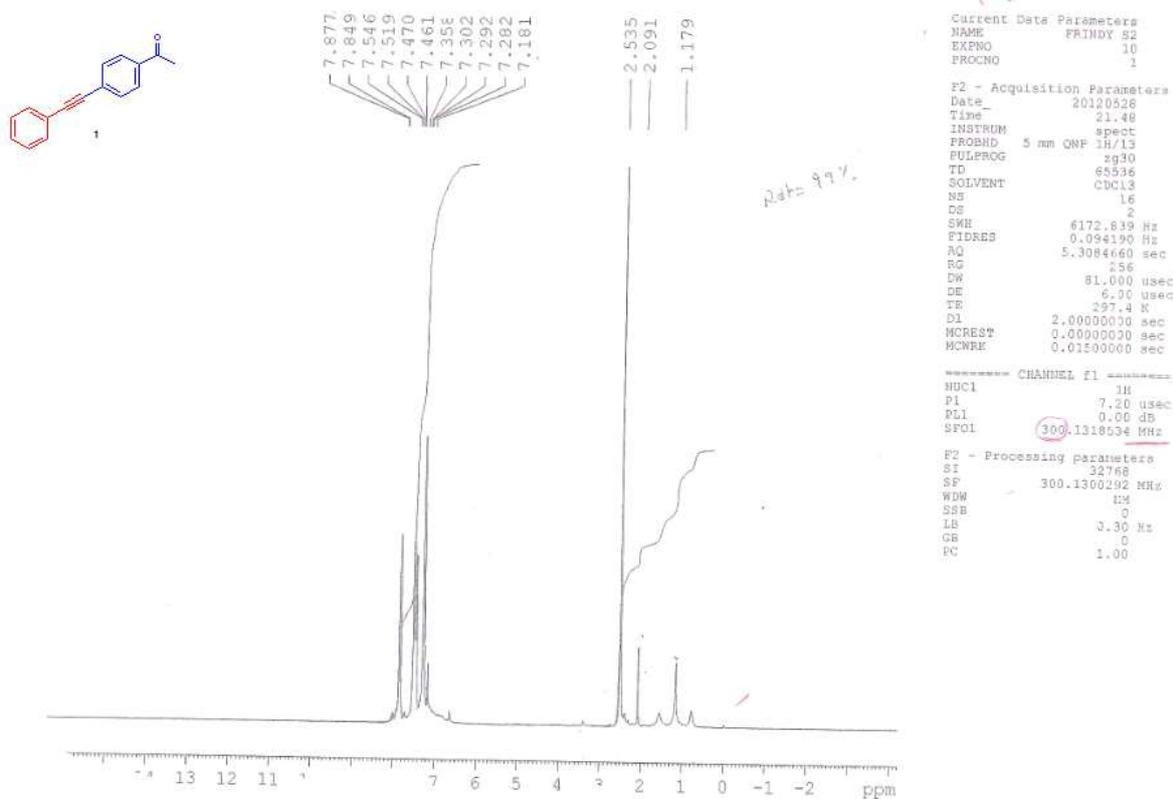
S8d. Kinetics of the three functional aerogel microspheres.

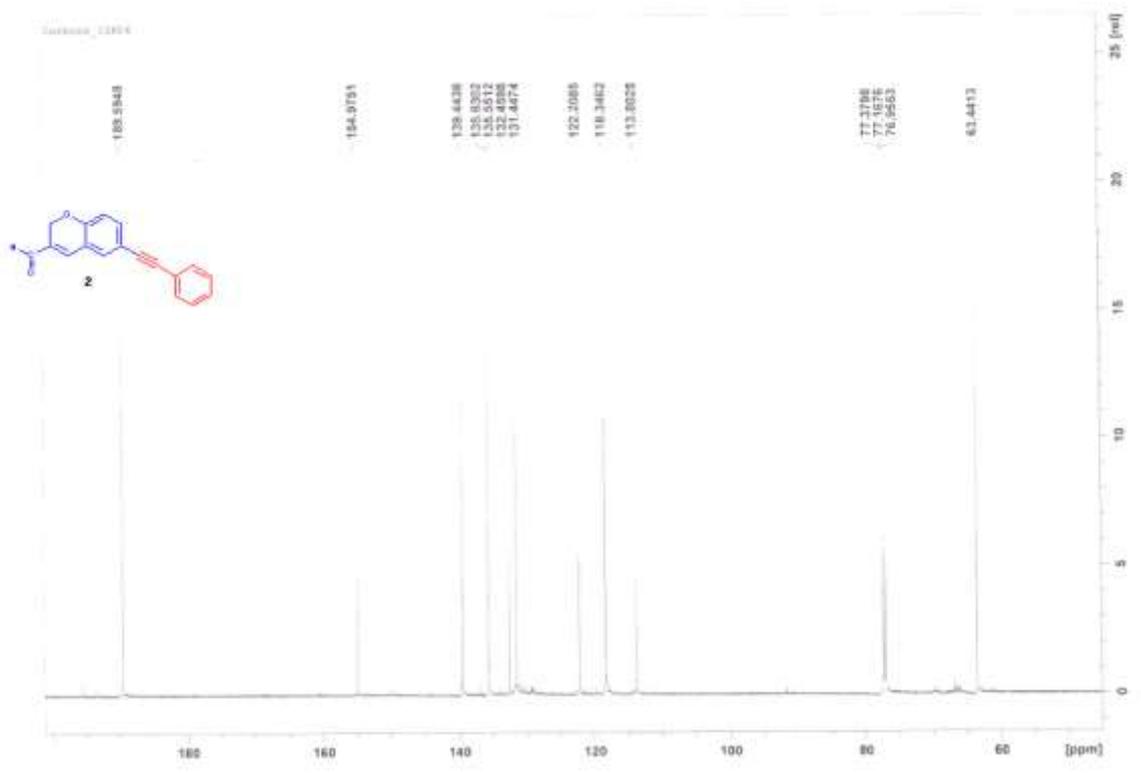
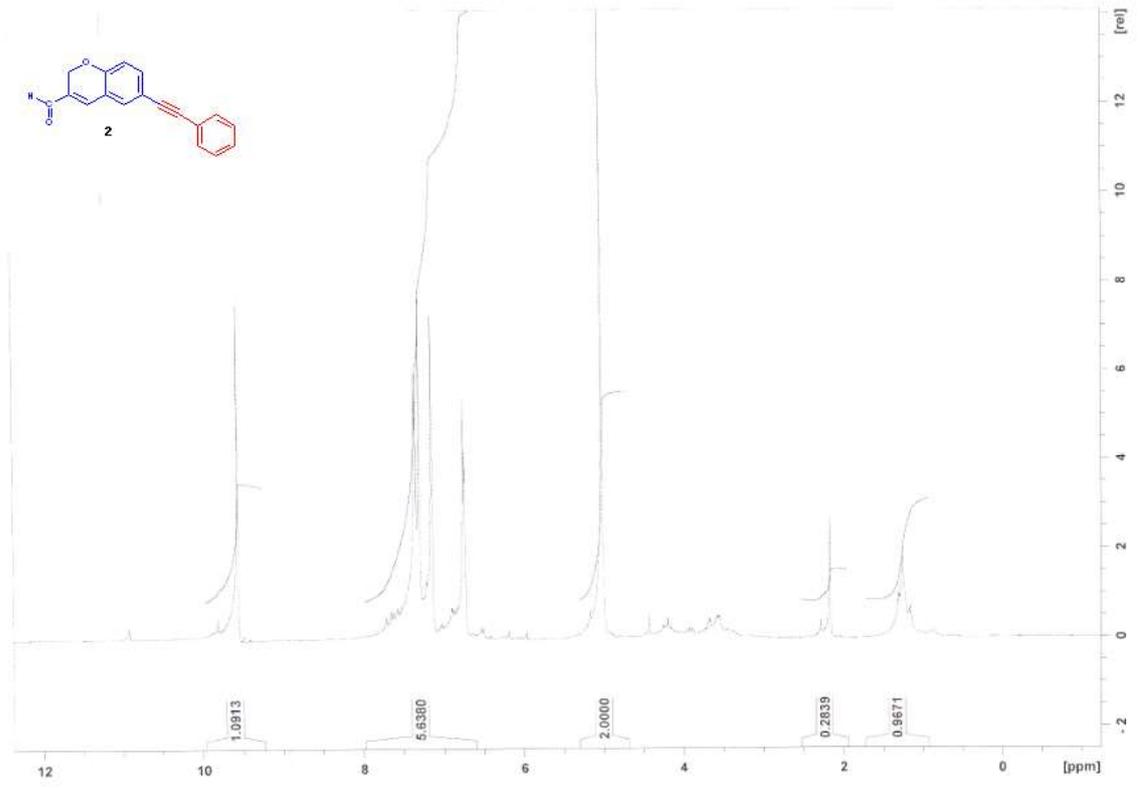


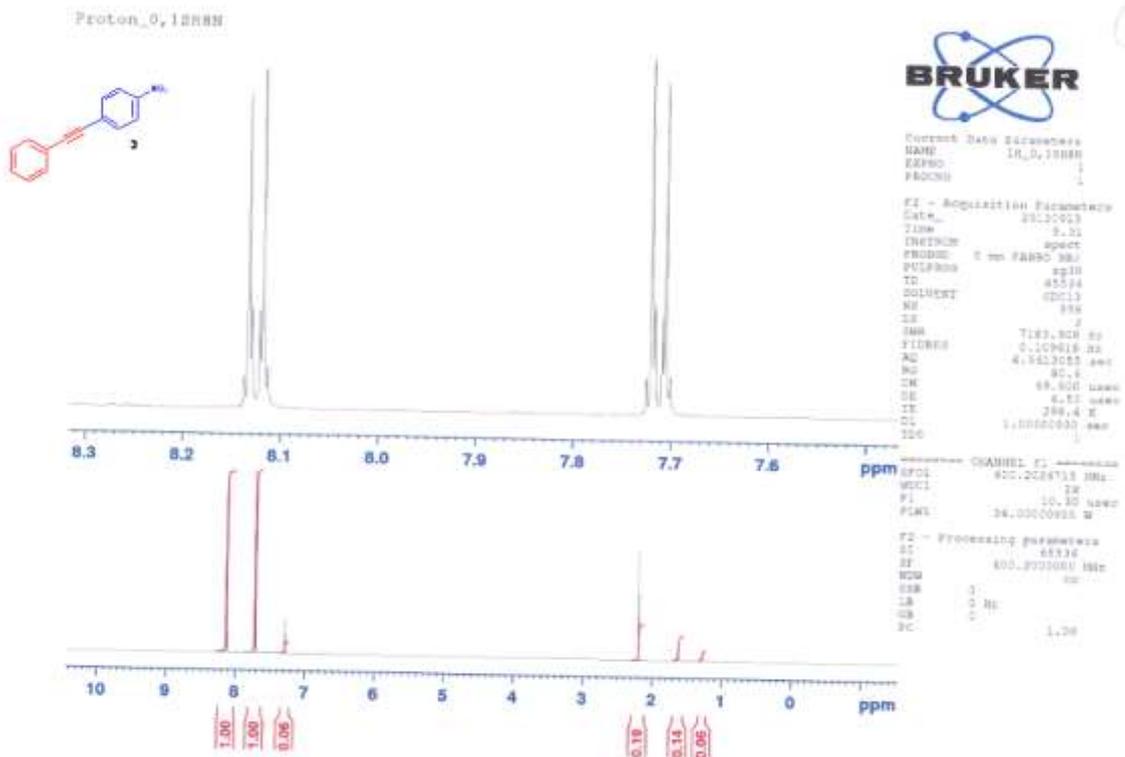
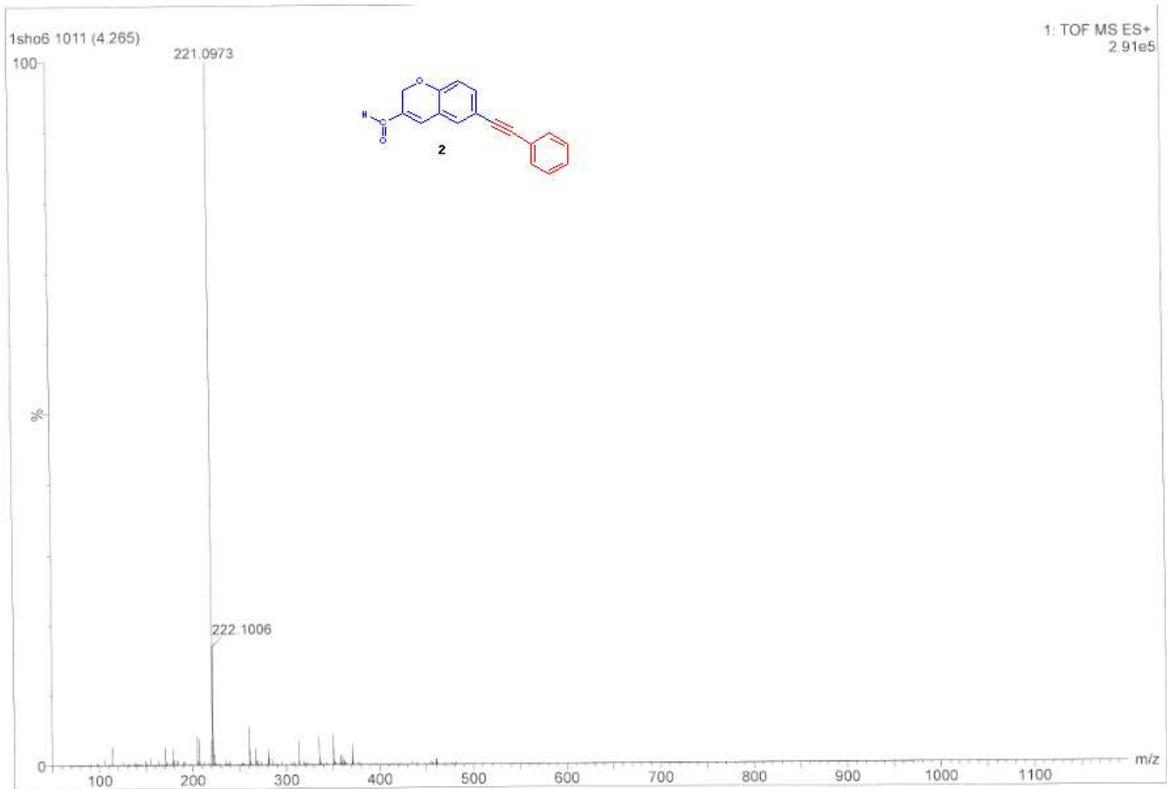
S9. XPS before and after catalysis



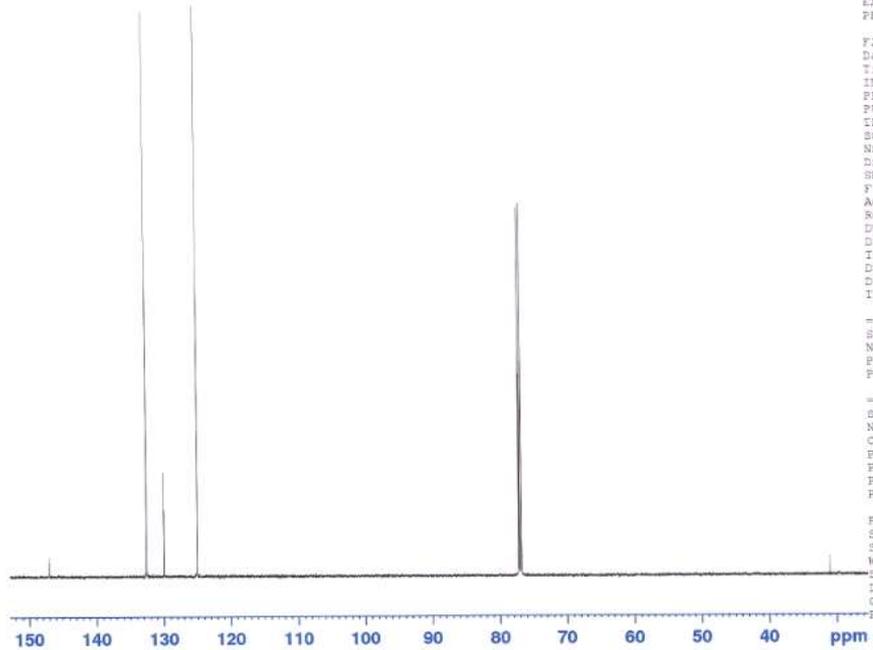
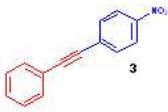
S10. NMR spectra of some substrates.







Carbone_0,1SH8N



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 PROCNO 1

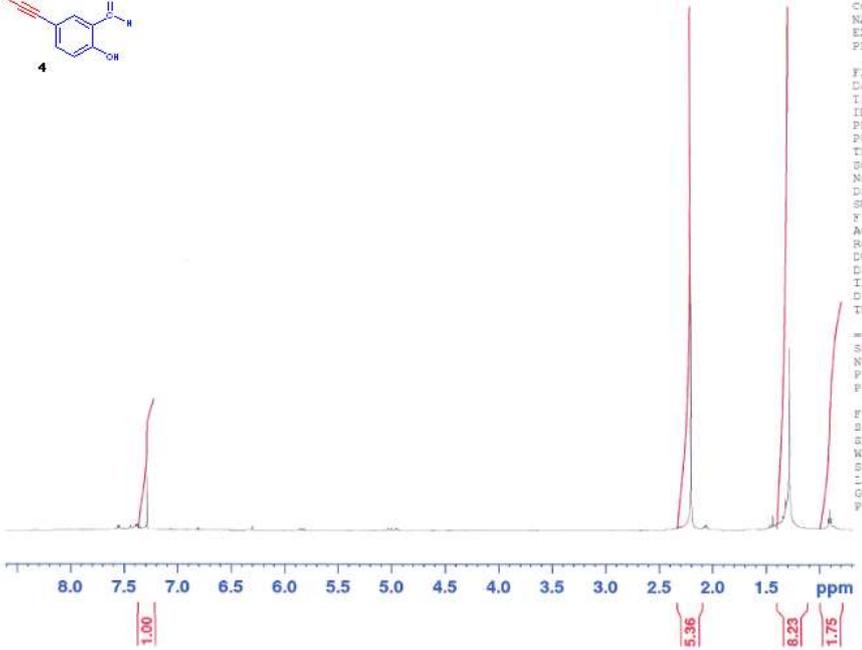
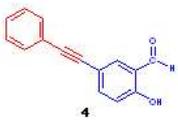
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 FIDRES 0.550197 Hz
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 D11 0.0300000 sec
 ID0 1

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 NUC1 13C
 P1 11.80 usec
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----- CHANNEL f2 -----
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 PCPD2 70.00 usec
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 PLW13 0.38192001 W

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Proton_1SHS20



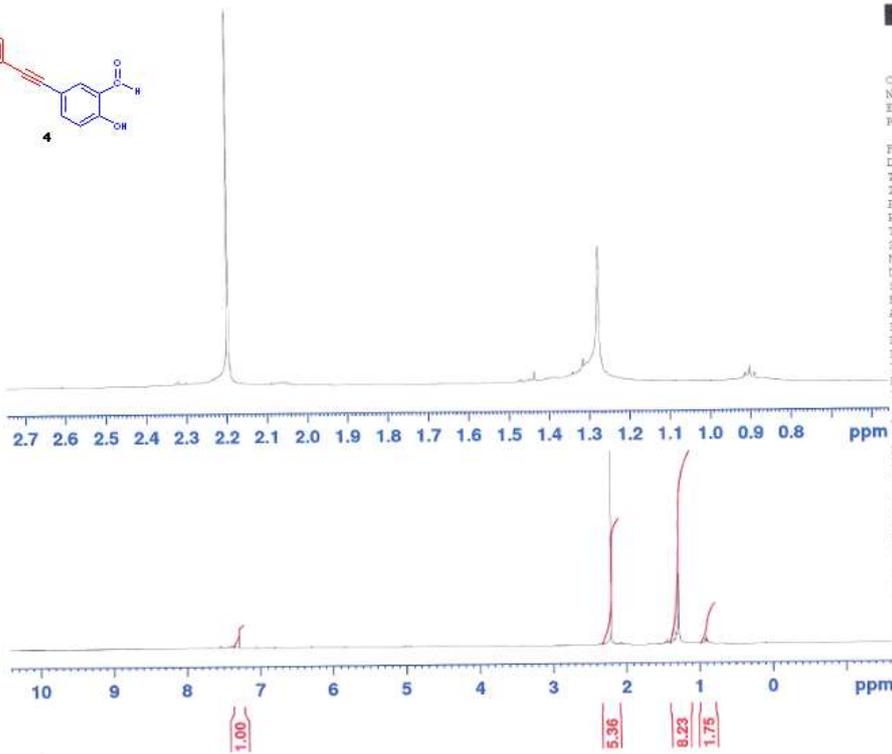
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 EXPNO 1
 PROCNO 1

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 FIDRES 0.110571 Hz
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 RG 80.6
 DW 69.000 usec
 DE 6.50 usec
 TE 298.4 K
 D1 1.0000000 sec
 ID0 1

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 NUC1 1H
 P1 10.30 usec
 PLW1 36.0000000 W

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Proton_1SHS20



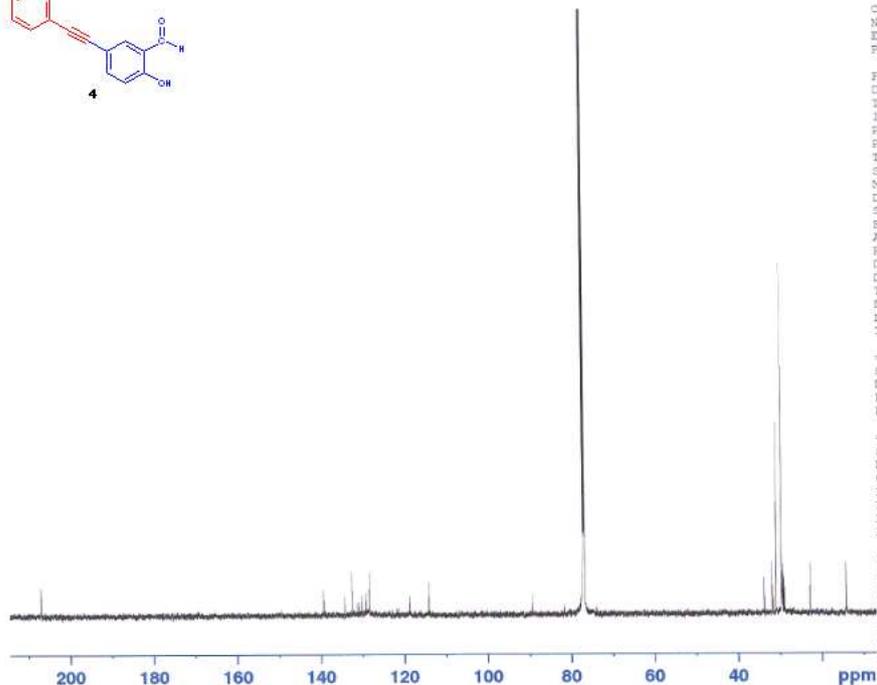
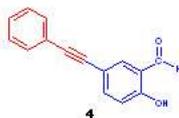
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 SOLVENT CDCl3
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 P1 10.30 usec
 PLW1 36.00000000 W

F2 - Processing parameters
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 SSB no
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Carbone_1SHS20



Current Data Parameters
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 EXPNO 1
 PROCNO 1

F2 - Acquisition Parameters
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 PLW1 90.00000000 W

CHANNEL f2
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 PLW13 0.38192601 W

F2 - Processing parameters
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 LB 2.00 Hz
 GB 0
 PC 1.40

