

# Electronic Supplementary Information for

## **Chemoselective reaction system using a two inlet micro-flow reactor: Application to carbonyl allylation**

Fumihiro Amemiya, Keishi Fuse, Toshio Fuchigami, and Mahito Atobe\*

*Department of Electronic Chemistry, Tokyo Institute of Technology, Yokohama 226-8502,*

*Japan*

\*To whom the correspondence should be addressed.

E-mail: [atobe@echem.titech.ac.jp](mailto:atobe@echem.titech.ac.jp)

### **This PDF file includes:**

Instrumentation

Materials

Experimental procedure

Spectroscopic data

References

## 1. Instrumentation

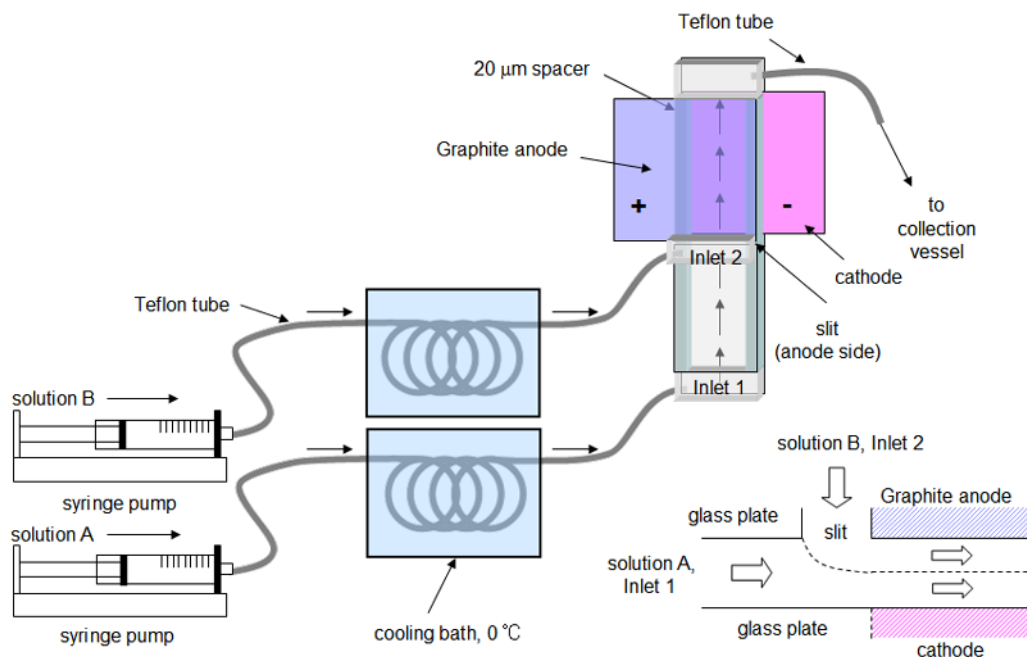
Nuclear magnetic resonance ( $^1\text{H}$  NMR,  $^{13}\text{C}$  NMR) spectra were measured on JEOL JNM EX-270 spectrometer operating at 270 MHz ( $^1\text{H}$  NMR), 67.8 MHz ( $^{13}\text{C}$  NMR) in  $\text{CDCl}_3$ . All  $^1\text{H}$  NMR chemical shifts were reported in ppm relative to internal references of TMS at  $\delta$  0.00.  $^{13}\text{C}$  NMR chemical shifts were reported in ppm relative to carbon resonance in chloroform- $d_1$  at  $\delta$  77.00. EI mass spectra were measured with a Shimadzu GCMS-QP5050A mass spectrometer. IR spectra were recorded on a Shimadzu FTIR-8100A spectrometer. Cyclic voltammetry was performed by using a computer-controlled electrochemical analyzer (ALS/CH Instruments 630C). Preparative electrolyses were carried out with a HOKUTO DENKO HA-501 Potentiostat/Galvanostat. GC analyses were performed with a Shimadzu GC-2014 gas chromatograph with Tween 80 (2 m column).

## 2. Materials

1-Chloro-3-methyl-2-butene (**1a**) was purchased from Aldrich and purified by distillation before use. Hexamethylphosphoric triamide (HMPA), tetrabutylammonium perchlorate ( $n\text{-Bu}_4\text{NClO}_4$ ), benzaldehyde (**2a**), 4-(trifluoromethyl)benzaldehyde (**2b**), 2-naphthaldehyde (**2c**) *p*-tolualdehyde (**2d**) and 3-furaldehyde (**2e**) were purchased from Tokyo Chemical Industry and used as received.

## 3. Two inlet micro-flow reactor

Figure S1 shows schematic illustration of the two inlet micro-flow reactor. The two inlet micro-flow reactor consisted of two plates. Each plate was glued the electrode plate (cathode plate (Pt or Ag) or anode plate (graphite), 3 cm width, 3 cm length) and glass plate (2.6 cm width, 3 cm length) together. A slit was provided on anode side for introducing solution B of Figure S1 into the reactor. A spacer (both sides adhesive tape, 20  $\mu\text{m}$  thickness, Nitto Denko) was used to leave a rectangular channel exposed, and the two plates were simply sandwiched together. After connecting Teflon tubing to inlets and outlet, the reactor was sealed with epoxy resin. The dimensions of the channel were 1 cm width, 20  $\mu\text{m}$  depth, and 6 cm total length and area of the two electrodes was 3  $\text{cm}^2$ .



**Figure S1.** Schematic illustration of the two inlet micro-flow reactor.

#### 4. Estimation of diffusion coefficient for **2a** in HMPA solvent

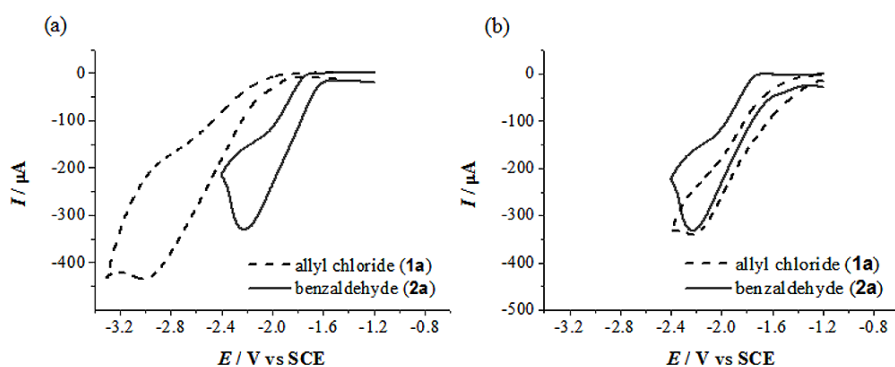
According to the Stokes-Einstein theory, diffusion coefficient  $D$  relates to solvent viscosity  $\eta$  and effective radius  $r$  of the diffusing species modeled as a sphere:

$$D = kT / 6\pi r \eta$$

where  $k$  is the Boltzmann constant and  $T$  is the temperature. The diffusion coefficient for **2a** was determined as  $2.4 \times 10^{-6} \text{ cm}^2 \text{ s}^{-1}$  by using above equation with  $\eta = 3.245 \times 10^{-3} \text{ Pa s}$  and  $r = 0.28 \text{ nm}$ .

#### 5. Cyclic voltammetry for the reduction of **1a** and **2a**

The cyclic voltammograms of **1a** and **2a** were recorded using an undivided cell equipped with a working disk electrode ((a) Pt or (b) Ag, 3 mm diameter), an auxiliary electrode (Pt plate,  $2 \times 3 \text{ cm}^2$ ), and a saturated calomel reference electrode.

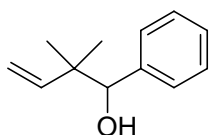


**Figure S2.** Cyclic voltammograms of 50 mM 1-chloro-3-methyl-2-butene (**1a**) / HMPA and 50 mM benzaldehyde (**2a**) / HMPA recorded at (a)Pt and (b)Ag disk electrodes (3 mm diameter). Scan rate was 100 mV s<sup>-1</sup>.

## 6. General Procedure for Preparative Electrolysis

KdScientific model 100 syringe pumps were used to pump the reaction solutions. Two solutions were flowed through a cooling bath (0 °C) before introducing into the cell. All reactions were conducted galvanostatically. Conditions of the cathodic cross-coupling reaction between **1** and **2** in the two inlet micro-flow reactor are described in footnotes *a* of Table 1 in the main text. The reaction mixture was analyzed by GC. For isolation of the products, the reaction mixture (5 mL) was added to a 50 mL of water and the aqueous layer was extracted three times with a 30 mL of diethyl ether. The combined organic fractions were washed with brine, dried over Na<sub>2</sub>SO<sub>4</sub> and concentrated in *vacuo*. The residue was purified by column chromatography on silica gel with hexane/AcOEt. <sup>1</sup>H NMR yields of the crude mixture was determined with an internal standard (MeNO<sub>2</sub>). All products except for **4b** were identified by authentic samples and literatures (**3a**,<sup>2</sup> **4a**,<sup>2</sup> **3e**,<sup>2</sup> **4e**,<sup>2</sup> **3b**,<sup>3</sup> **4c**,<sup>4</sup> **3c**,<sup>5</sup> **3d**<sup>5</sup> and **4d**<sup>6</sup>) using <sup>1</sup>H NMR and mass spectroscopy. Compound **4b** was identified by using <sup>1</sup>H and <sup>13</sup>C NMR, IR, mass, and high-resolution mass spectroscopy.

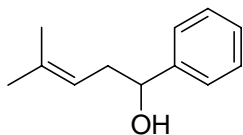
## 7. Spectroscopic Data



### 2,2-Dimethyl-1-phenylbut-3-en-1-ol (**3a**)

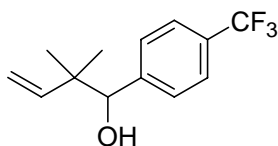
colorless oil; <sup>1</sup>H NMR (270 MHz, CDCl<sub>3</sub>) δ 7.29(s, 5H), 5.92(dd, *J* = 17.3, 10.5 Hz, 1H),

5.16-5.04(m, 2H), 4.43(s, 1H), 1.02(s, 3H), 0.96(s, 3H); MS (EI)  $m/z$  (relative intensity) 176( $[M^+]$ , 0.26), 107(100), 79(93), 70(98).



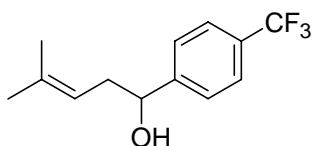
**4-Methyl-1-phenyl-pent-3-en-1-ol (4a)**

colorless oil;  $^1\text{H}$  NMR (270 MHz,  $\text{CDCl}_3$ )  $\delta$  7.40-7.23(m, 5H), 5.20-5.14(m, 1H), 4.68(dd,  $J = 8.1, 5.7$  Hz, 1H), 2.55-2.38(m, 2H), 1.83(bs, 1H), 1.72(s, 3H), 1.61(s, 3H); MS (EI)  $m/z$  (relative intensity) 176( $[M^+]$ , 4.3), 107(99), 79(95), 70(100).



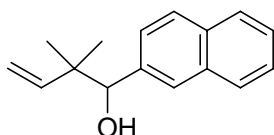
**2,2-Dimethyl-1-(4-trifluoromethyl-phenyl)-but-3-en-1-ol (3b)**

colorless oil;  $^1\text{H}$  NMR (270 MHz,  $\text{CDCl}_3$ )  $\delta$  7.56(d,  $J = 8.1$  Hz, 2H), 7.41(d,  $J = 8.1$  Hz, 2H), 5.88(dd,  $J = 17.6, 10.8$  Hz, 1H), 5.20-5.05(m, 2H), 4.48(s, 1H), 2.11(bs, 1H), 1.02(s, 3H), 0.96(s, 3H); MS (EI)  $m/z$  (relative intensity) 244( $[M^+]$ , 0.01), 225(9), 175(98), 147(33), 127(88), 70(100).



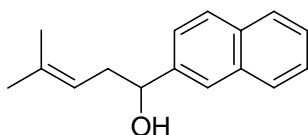
**4-Methyl-1-(4-trifluoromethyl-phenyl)-pent-3-en-1-ol (4b)**

colorless oil; IR (neat NaCl,  $\text{v}/\text{cm}^{-1}$ ) 3370, 2920, 1620, 1420, 1330, 1170, 1130, 1070, 1020, 890;  $^1\text{H}$  NMR (270 MHz,  $\text{CDCl}_3$ )  $\delta$  7.60(d,  $J = 8.10$  Hz, 2H), 7.48(d,  $J = 8.10$  Hz, 2H), 5.18-5.12(m, 1H), 4.75(t,  $J = 5.67$ , 1H), 2.48-2.42(m, 2H), 2.08(bs, 1H), 1.74(s, 3H), 1.61(s, 3H);  $^{13}\text{C}$  NMR (67.8 MHz,  $\text{CDCl}_3$ )  $\delta$  148.00, 136.45, 125.95, 125.11(q,  $J = 3.9$  Hz), 118.85, 73.31, 38.37, 25.94, 18.01; MS (EI)  $m/z$  (relative intensity) 244( $[M^+]$ , 0.09), 225(3), 175(62), 147(10), 127(49), 70(100); HRMS (EI)  $m/z$  Calcd. for  $\text{C}_{13}\text{H}_{13}\text{F}_3\text{O}$  [ $M^+ - 2\text{H}$ ]: 242.0913 Found: 242.0912.



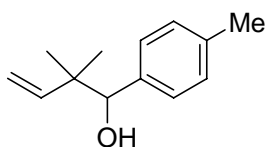
**2,2-Dimethyl-1-naphthalen-2-yl-but-3-en-1-ol (3c)**

pale yellow oil;  $^1\text{H NMR}$  (270 MHz,  $\text{CDCl}_3$ )  $\delta$  7.84-7.74(m, 4H), 7.48-7.42(m, 3H), 5.97(dd,  $J = 17.6, 10.8$  Hz, 1H), 5.18-5.06(m, 2H), 4.60(s, 1H), 2.14(bs, 1H), 1.06(s, 3H), 1.01(s, 3H); MS (EI)  $m/z$  (relative intensity) 226( $[\text{M}^+]$ , 4.6), 157(100), 129(92), 102(3), 77(6).



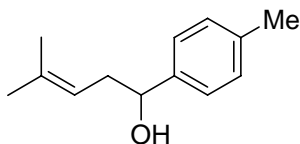
**4-Methyl-1-naphthalen-2-yl-pent-3-en-1-ol (4c)**

pale yellow oil;  $^1\text{H NMR}$  (270 MHz,  $\text{CDCl}_3$ )  $\delta$  7.84-7.81(m, 4H), 7.51-7.42(m, 3H), 5.23-5.16(m, 1H), 4.85(dd,  $J = 7.6, 5.4$  Hz, 1H), 2.58-2.51(m, 2H), 2.11(bs, 1H), 1.73(s, 3H), 1.63(s, 3H); MS (EI)  $m/z$  (relative intensity) 226( $[\text{M}^+]$ , 5.1), 208(12), 193(21), 178(16), 157(100), 129(96), 115(4), 89(5), 77(6).



**2,2-Dimethyl-1-p-tolyl-but-3-en-1-ol (3d)**

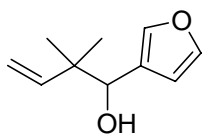
colorless oil;  $^1\text{H NMR}$  (270 MHz,  $\text{CDCl}_3$ )  $\delta$  7.20-7.10(m, 4H), 5.92(dd,  $J = 17.5, 10.9$  Hz, 1H), 5.15-5.04(m, 2H), 4.40(s, 1H), 2.34(s, 3H), 1.01(s, 3H), 0.95(s, 3H); MS (EI)  $m/z$  (relative intensity) 190( $[\text{M}^+]$ , 0.29), 121(100), 93(81), 77(64), 70(69).



**4-Methyl-1-p-tolyl-pent-3-en-1-ol (4d)**

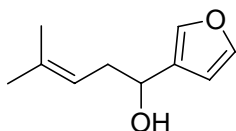
colorless oil;  $^1\text{H NMR}$  (270 MHz,  $\text{CDCl}_3$ )  $\delta$  7.25(d,  $J = 8.07$  Hz, 2H), 7.15(d,  $J = 8.07$  Hz, 2H), 5.20-5.14(m, 1H), 4.64(dd,  $J = 7.91$  Hz, 5.27, 1H), 2.58-2.29(m, 2H), 2.34(s, 3H), 1.94(bs, 1H), 1.73(s, 3H), 1.62(s, 3H); MS (EI)  $m/z$  (relative intensity) 190( $[\text{M}^+]$ , 1.3), 172(10),

157(16), 142(11), 121(100), 93(80), 77(57), 70(58).



**1-Furan-3-yl-2,2-dimethyl-but-3-en-1-ol (3e)**

yellow oil;  $^1\text{H NMR}$  (270 MHz,  $\text{CDCl}_3$ )  $\delta$  7.36-7.734(m, 2H), 6.37-6.36(m, 1H), 5.91(dd,  $J = 17.3, 10.8$  Hz, 1H), 5.17-5.07(m, 2H), 4.40(s, 1H), 1.03(s, 3H), 1.00(s, 3H); MS (EI)  $m/z$  (relative intensity) 166( $[\text{M}^+$ , 8]), 133(1), 97(100), 70(90).



**1-Furan-3-yl-4-methyl-pent-3-en-1-ol (4e)**

yellow oil;  $^1\text{H NMR}$  (270 MHz,  $\text{CDCl}_3$ )  $\delta$  7.39-7.37(m, 2H), 6.42-6.41(m, 1H), 5.20-5.12(m, 1H), 4.66(dd,  $J = 7.26, 5.79$  Hz, 1H), 2.55-2.37(m, 2H), 1.85(bs, 1H), 1.73(s, 3H), 1.65(s, 3H); MS (EI)  $m/z$  (relative intensity) 166( $[\text{M}^+$ , 10.9), 148(4.4), 133(3.5), 119(4.1), 97(100), 70(95).

**8. References**

- (1) W. R. Fawcett and J. S. Jaworski, *J. Phys. Chem.*, 1983, **87**, 2972; M. Hoon and W. R. Fawcett, *J. Phys. Chem. A*, 1997, **101**, 3726.
- (2) M. Tokuda, S. Satoh and H. Sugimoto, *J. Org. Chem.*, 1989, **54**, 5608.
- (3) H. S. Schrekker, M. W. G. de Bolster, R. V. A. Orru and L. A. Wessjohann, *J. Org. Chem.*, 2002, **67**, 1975.
- (4) H.-S. Cheng and T.-P. Loh, *J. Am. Chem. Soc.*, 2003, **125**, 4990.
- (5) H.-M. Chang and C.-H. Cheng, *Org. Lett.*, 2000, **22**, 3439.
- (6) Y. Kusuyama, *Bull. Chem. Soc. Jpn.*, 1998, **71**, 685.