Supporting Information

A Highly Sensitive Fluorogenic Chemodosimeter for Rapid Visual Detection of Phosgene

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Experimental Procedures

Triphosgene was purchased from Acros Organics. Phenanthridine was purhased from J&K Chemicals. All other reagents were obtained from Alfa Aesar and used without further purification. RB-EDA,[1] dRB-EDA,[2] Rhodamine-hydroxamate[3] and rhodamine-hydrazide[4] were syntheszied following published procedures. Gaseous phosgene was generated in situ from triphosgene and phenanthridine as described in a literature.[5] Column chromatography was performed on silica gel (300-400 mesh). NMR spectra (^{1}H at 400 MHz and ^{13}C at 100 MHz) were recorded on a Bruker instrument using tetramethyl silane as the internal reference. The mass analysis was performed in Bruker En Apex ultra 7.0T FT-MS. The fluorescence spectra and UV-vis absorption spectra were performed on a spectrofluorimeter (Spectamax M5, Molecular Device) using the excitation wavelength (λex) of 560 nm.

Isolation of Compound 2

dRB-EDA (100 mg) was dissolved in chloroform (15 ml). To the solution was added triethyamine (215 mg) and triphosgene (63 mg). The mixture was stirred at room for 6 hours. The solution was concentrated by rotary evaporation to remove the solvent. The residue was purified by silica gel column chromatography using dichloromethane followed by methanol as the eluent to give 70 mg of solid as the desired product (71% yield). ^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.57 (m, 1H), 7.50 (m, 2H), 7.20 (m, 1H), 7.11 (d, 2H, J = 9.48 Hz), 6.93 (dd, 2H, J_1 = 9.56 Hz, J_2 = 2.42Hz), 6.77 (d, 2H, J = 2.40 Hz), 4.60 (s, 1H), 4.02 (s, 2H), 3.62 (q, 8H, J = 7.10 Hz), 3.12 (m, 4H), 1.30 (t, 12H, J = 7.10 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): 161.44, 157.78, 156.04, 155.54, 135.86, 131.31, 131.08, 130.28, 129.44, 129.17, 127.97, 114.32, 113.72, 96.22, 46.08, 45.53, 44.30, 37.61, 12.58 ppm; HRMS ($C_{31}H_{37}N_4O_2^+$) calculated (M^+): 497.2911, found: 497.2910.

Effects of reaction media on the assay efficiency

dRB-EDA was added to DMF, acetonitrile or aqueous DMF (H_2O:DMF=1:50, v/v) containing triphosgene (1 μM) and triethylamine (3%, v/v) to a final concentration of 1 mg ml^{-1}. dRB-EA (1 mg ml^{-1}) in DMF containing TEA (3%, v/v) was used as the control. The formation rates of color development in the reaction solutions were immediately recorded by fluorescence emission at 590 nm using an excitation wavelength of 560 nm on Spectamax-M5.

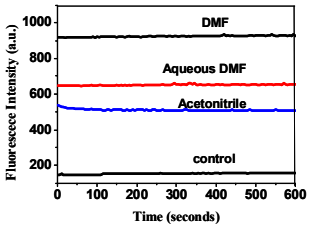


Fig. S1 Reaction rates of dRB-EDA (1 mg ml^{-1}) and triphosgene (1 μM) in a variey of media containing TEA (3%, v/v).

Reaction kinetics of dRB-EDA towards triphosgene

Aliquots of the stock solution of triphosgene in chloroform were respectively added to DMF solution containing triethylamine (3%, v/v) and dRB-EDA (1 mg ml^{-1}) to prepared a serial of assay solutions with various amount of the analyte. The rates of color development in the reaction solutions were immediately recorded by fluorescence emission at 590 nm using an excitation wavelength of 560 nm on Spectamax-M5.

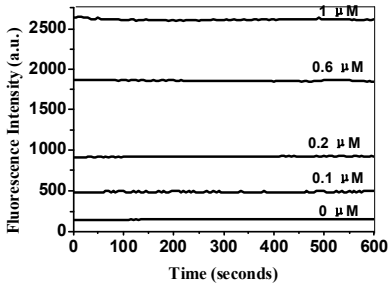


Fig. S2 Kinetic profiles of the reaction between dRB-EDA (1 mg ml^{-1}) and various amount of triphosgene (1, 0.6, 0.2, 0.1, 0 μM, from top to bottom) in DMF. The fluorescence emission intensity at 590 nm (*λex*@560 nm) was recorded as a function of time.

Reaction kinetics of rhodamine-hydroxamamte or rhodamine-hydrazide towards triphosgene

Aliquots of the stock solution of triphosgene in chloroform were respectively added to DMF solution containing triethylamine (3%, v/v), and rhodamine-hydrazide or rhodamine-hydroxamate (1 mg ml^{-1}) to prepare a serial of assay solutions with various amount of the analyte. The rates of color formation in the reaction solutions were immediately recorded upon addition of triphosgene by fluorescence emission at 590 nm using an excitation wavelength of 560 nm.

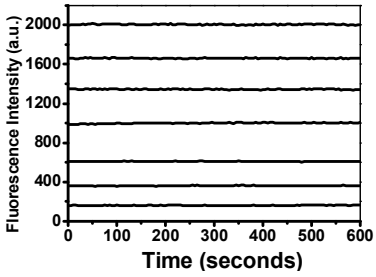


Fig. S3 Kinetic profiles of fluorogenic detection of triphosgene (20, 16, 12, 8, 4, 2, 0 μM, from top to bottom) with rhodamine-hydroxamate (1 mg ml^{-1}) in DMF containing TEA (3%, v/v).

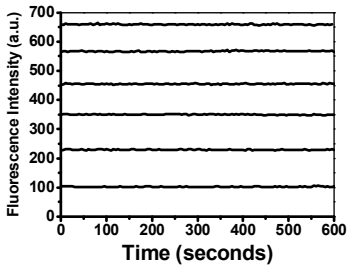


Fig. S4 Kinetic profiles of fluorogenic detectionof triphosgene (200, 160, 120, 80, 40, 0 μM, from top to bottom) with rhodamine-hydrazide (1 mg ml^{-1}) in DMF containing TEA (3%, v/v).

Comparison of the fluorescent spectral properties of the colored species in the assay solution of dRB-EDA with rhodamine B

dRB-EDA was added into 20 ml of DMF solutions containing triphosgene (1 μM) and TEA (3%, v/v) to a concentration of 1 mg ml^{-1}. The solution was mixed and then characterized for fluorescence excitation spectrum (Em@590 nm) and fluorescence emission spectrum as compared to rhodamine B in DMF solution.

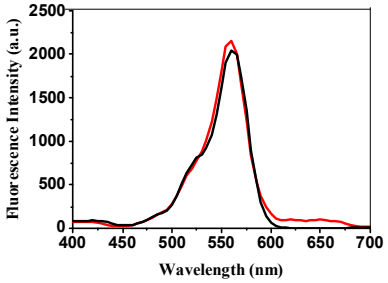


Fig. S5 Fluorescence excitation spectrum of the assay solution containing dRB-EDA (1 mg ml^{-1}) (in black) and triphosgene (1 μM) as compared to rhodamine B (in red) in DMF.

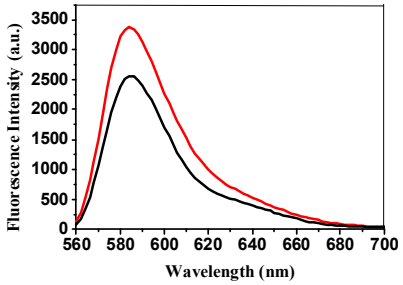


Fig. S6 Fluorescence emission spectra of of the assay solution containing dRB-EDA (1 mg ml^{-1}) (in black) and triphosgene (1 μM) as compared to rhodamine B (in red) in DMF.

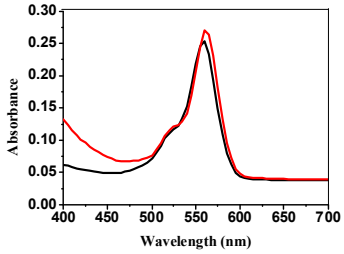


Fig. S7 Absorption spectra of the assay solution containing dRB-EDA (1 mg ml^{-1}) (in black) and triphosgene (1 μM) as compared to rhodamine B (in red) in DMF.

Sensitivity of dRB-EDA based Assay fro triphosgenen

Triphosgene was added into a serial of DMF solutions containing dRB-EDA (1 mg ml^{-1}) and triethylamine (3%, v/v) to a final concentration of 1, 0.8, 0.6, 0.4, 0.2, 0.1, 0.05, 0 μM. The assay solutions were directly analyzed for UV-vis absorption spectra or fluorescence emission spectra after addition.

Sensitivity of rhodmaine-hydroxamate or rhodamine-hydrazide based assays fro triphosgenene

Triphosgene was added into a serial of DMF solutions containing dRB-EDA (1 mg ml^{-1}) and triethylamine (3%, v/v) to various concentrations between 200 and 0 μM. The assay solutions were directly analyzed for UV-vis absorption spectra or fluorescence emission spectra after addition.

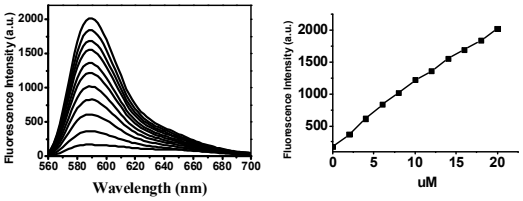


Fig. S8 Fluorescence emission spectra of rhodamine-hydroxamate in the presence of triphosgene (20, 18, 16, 14, 12, 10, 8, 6, 4, 2 and 0 μM, from top to bottom). The titration curve of fluorescence emission intensity at 590 nm (λex @560 nm) was plotted vs analyte concentrations.

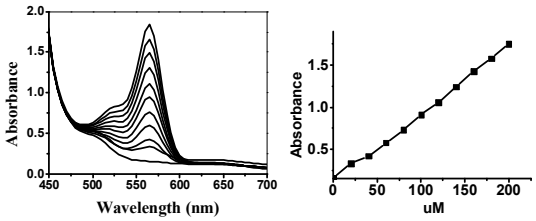


Fig. S9 UV-vis absorbance spectra of rhodamine-hydroxamate in the presence of triphosgene (200, 180, 160, 140, 120, 100, 80, 60, 40, 20 and 0 μM, from top to bottom) (*λex*@560 nm). The titration curve of absorbance at 560 nm was plotted vs analyte concentrations (right).

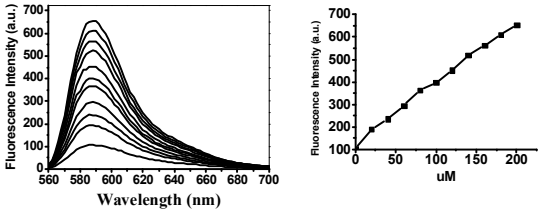


Fig. S10 Fluorescence emission spectra of rhodamine-hydrazide in the presence of triphosgene (200, 180, 160, 140, 120, 100, 80, 60, 40, 20 and 0 μM, from top to bottom) (*λex*@560 nm). The titration curve was plotted using fluorescence emission intensity at 590 nm as a funtion of analyte concentrations (right).

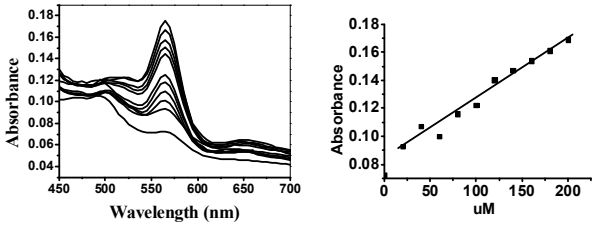
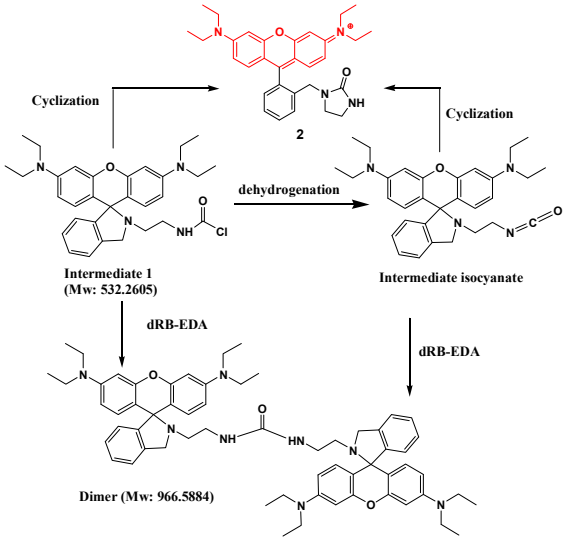


Fig. S11 UV-vis absorbance spectra of rhodamine-hydrozide in the presence of triphosgene (200, 180, 160, 140, 120, 100, 80, 60, 40, 20 and 0 μM, from top to bottom) (*λex*@560 nm). The titration curve was plotted using absorbance at 560 nm as a function of analyte concentrations.

Characterization of dRB-EDA based assay solution with High Resolution Mass Spectrometry

Phosgene was added into DMF solutions containing dRB-EDA (1 mg ml^{-1}) and triethylamine (3%, v/v) to a final concentration of 1 μM. The solution was incubated at room temperature for 2 hours and then analyzed by high resolution mass spectrometry for the presence of remaining dRB-EDA, compound **2** and dimeric dRB-EDA (dimer).



Scheme S1. Competition between formation of compound **2** *via* intramolecular cyclization and dimeric dRB-EDA *via* intermolecular coupling from intermediate **1** or possibly its dehydrohalogenated drivative of rhodamine-isocyanate.

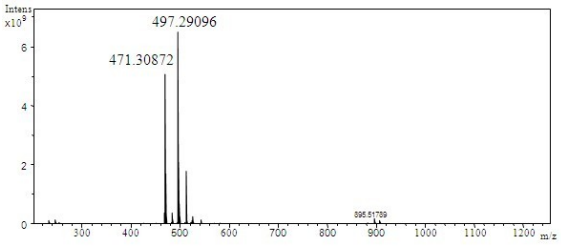


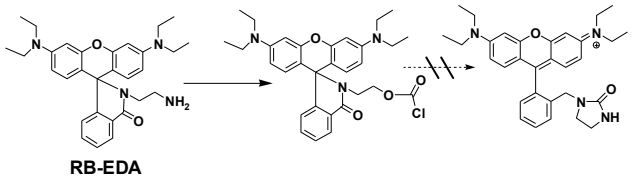
Fig. S12 Probing the pssible presence of dimeric dRB-EDA in the assay solution by HRMS. The peak at 471.3087 is ascribed to dRB-EDA in excess in the assay solution, and the peak located at 497.29096 is ascribed to the compound **2** whereas the dimeric dRB-EDA (Mw: 966.5884) can not be identified in the HRMS analysis**.**

Comparison of the assay efficiency of dRB-EDA towards triphosgene and formaldehyde

To the solution of dRB-EDA (1 mg ml^{-1}) in DMF containing TEA (3%, v/v) was respectively added triphosgene (to a final concentration of 1 μM) or formaldehdye (to a final concentration of 10 mM). The solutions were incubated at room temperature for 2 hours and then the fluorescence emission spectra of the solutions were recorded using an excitation wavelength of 560 nm. The solution of dRB-EDA (1 mg ml^{-1}) in DMF containing TEA (3%, v/v) was used as the control.

Comparison of the assay efficiency of dRB-EDA and RB-EDA towards triphosgene.

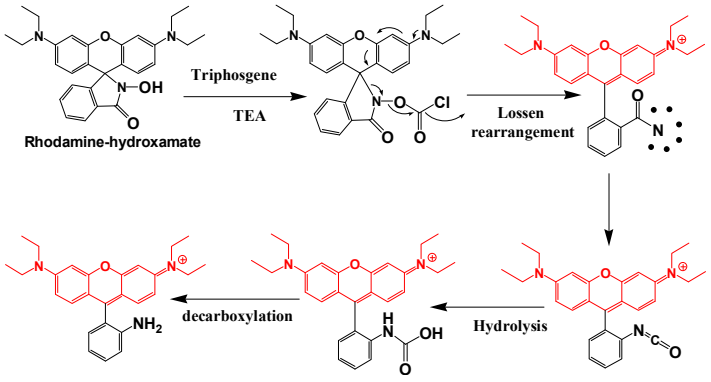
To the solution of RB-EDA or dRB-EDA (1 mg ml^{-1}) in DMF containing TEA (3%, v/v) was respectively added triphosgene to a final concentration of 1 μM. The fluorescence emission spectra of both solutions were recorded immediately after addition of triphosgene using an excitation wavelength of 560 nm.



Scheme S2. The decreased nucleophilicity of the amide of RB-EDA prevent the opening of the intramolecular lactam in the presence of triphosgene.

Characterization of rhodamine-hydrazide or rhodamine-hydroxamate based assay solutions with High Resolution Mass Spectrometry

Triphosgene (500 mg) was respectively added into chloroform (20 mL) containing rhodamine-hydrazide (800 mg) or rhodamine-hydroxamate (1000 mg) and triethylamine (2 mL). The solutions were incubated at room temperature for 2 hours and then trituated between dichloromethane (200 mL) and water (300 mL). The organic layers were concnetrated by rotary evaporation, and the residues were purified by column chromatography on silica get to isolate the colored species. The isolated products (100 mg for rhodamine-hydrazide, 200 mg for rhodamine-hydroxamate) were analyzed by high resolution mass spectrometry.



Scheme S3. Proposed sensing mechanisms of rhodamine-hydroxamate for triphosgene.

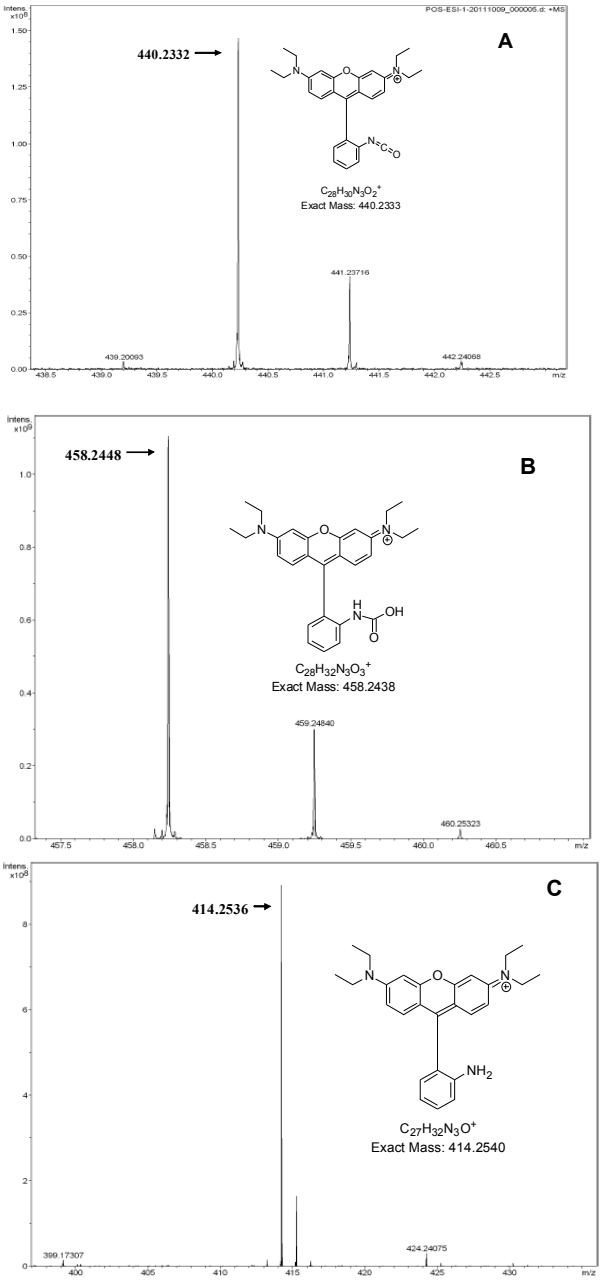
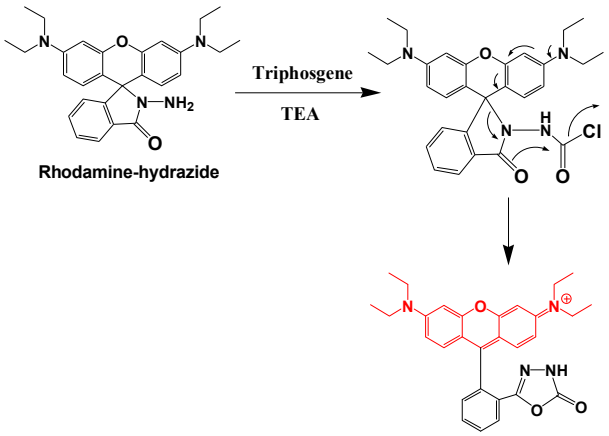


Fig. S13 HRMS confirmation of the proposed colored species generated in the reaction between rhodamine-hydroxamate and triphosgene.



Scheme S4. Sensing mechanisms of rhodamine-hydrazide for triphosgene.

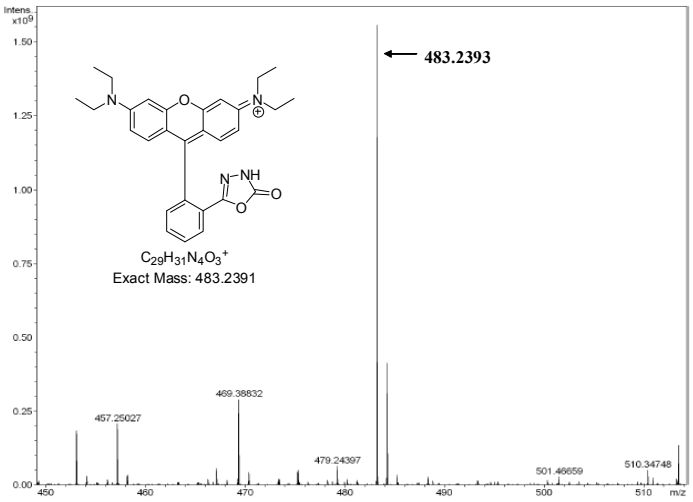


Fig. S14 HRMS confirmation of the genesis of proposed colored species in the reaction between rhodamine-hydrazide and triphosgene.

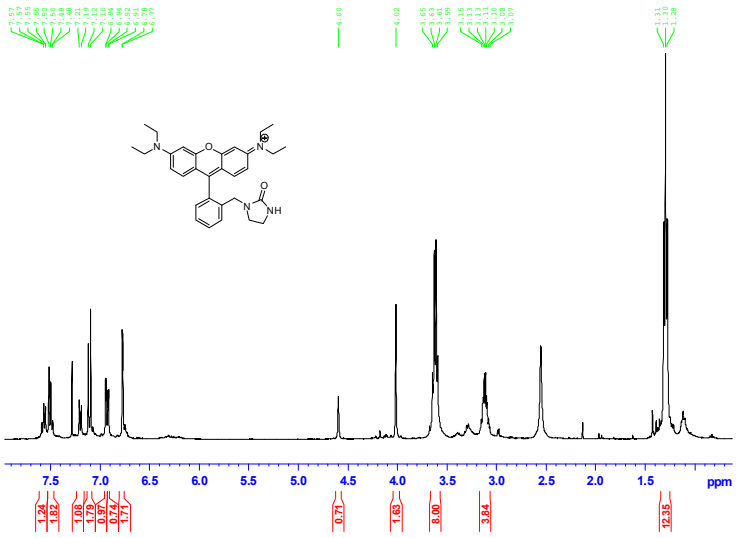


Fig. S15 ^{1}H-NMR spectrum of compound **2**.

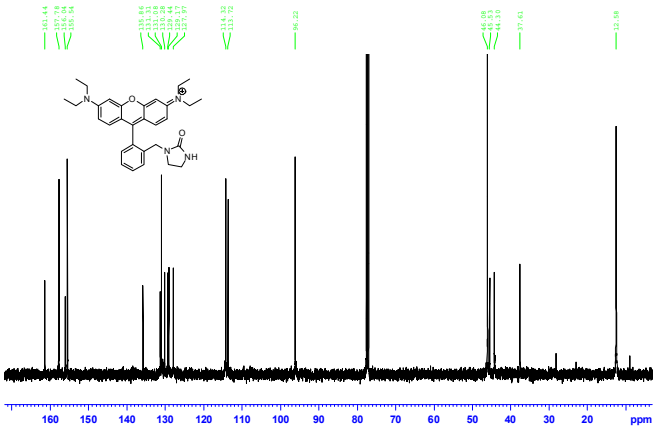


Fig. S16 ^{13}C-NMR spectrum of compound **2**.

Visualization of gaseous phoegene with dRB-EDA absorbed paper stripes

Paper strips were cutted from filter paper in the size of 2cm x 1cm. The stripes were immersed in methylene dichloride containing dRB-EDA (1 mg ml^{-1}) and TEA (3%, v/v), and then placed in the air to evaporate the solvent.

Detection of gaseous phoegene with dRB-EDA absorbed paper strips: The resultant paper stripes were respectively placed in three flasks (250 mL). To the flasks were seperately added phenanthridine (20 mg), triphosgene (20 mg), or phenanthridine (20 mg) and triphosgene (20 mg). The flasks were sealed and then pictured at about 20-30 seconds after addition of the reagent(s).

Detection limit of dRB-EDA absorbed paper strips for gaseous phoegene

To three flasks (250 mL) containing a dRB-EDA absorbed paper strip were seperately added different amount of phenanthridine and triphosgene, 0.2 mg of phenanthridine and 0.2 mg of triphosgene in flask A, 2 mg of phenanthridine and 2 mg of triphosgene in flask B, and 20 mg of phenanthridine and 20 mg of triphosgene in flask C. The flasks were sealed and then pictured at about 20-30 seconds after addition of the reagent(s).

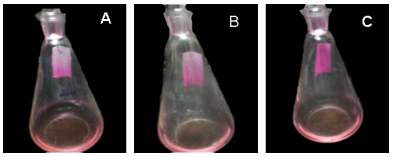


Fig. S17 Visual detectionof gaseous phoegene with dRB-EDA absorbed paper strips. The concentration of phosgene used in the assay was estimated to be 0.8 mg/L (A), 8 mg/L (B) and 80 mg/L (C).

Visualization of gaseous phoegene with dRB-EDA absorbed silica gel column

Silica gel (40 g) were mixed with methylene dichloride (40 ml) containing dRB-EDA (1 mg ml^{-1}) and TEA (5 ml). The mixture were evaporated to remove the solvent in vacuuo, and the resultant silica gel was loaded in to several glass tubes.

Detection of gaseous phosgene: The dRB-EDA absorbed silica gel column with an aspirator connected in one end was placed in a flask (250 mL) containing phenanthridine (2 mg) and triphosgene (2 mg)[5]. The gaseous phosgene were passed through the column by the aspiration for 10 seconds. The silica gel column was pictured in parallel with anothe silica gel column where air was passed through by aspiration.

Detection of triphosgene in solution: The dRB-EDA absorbed silica gel column were loaded with methylene chloride containing various amount of triphosgene as indicated in Fig S19.

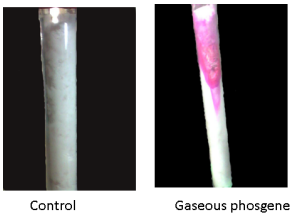


Fig. S18 Detection of gaseous phosgene with dRB-EDA absorbed silica gel column

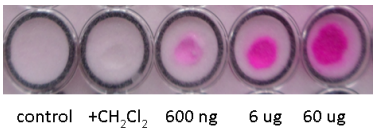


Fig. S19 Detection of phosgene in solution with dRB-EDA absorbed silica gel column

References

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