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(54) GAS PHASE SYNTHESIS OF METHYLENE LACTONES USING OXYNITRIDE CATALYST

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C07D 307/26	(2006.01)
C07D 307/34	(2006.01)

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(58) **Field of Classification Search** 549/295, 549/326

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,313,318	B1	11/2001	Coulson et al.	
6,723,790	B1	4/2004	Brandenburg et al.	
2006/0025604	A1 *	2/2006	Hutchenson et al.	549/263
2006/0025609	A1 *	2/2006	Hutchenson et al.	549/263

FOREIGN PATENT DOCUMENTS

JP	10298172	* 11/1998
WO	WO 9952628	10/1999
WO	WO 03/053913	7/2003

OTHER PUBLICATIONS

M. J. Climent et al., Catalysis Letter, 59 (1999) 33-38.

P. Grange et al., Applied Catalysis A: General 114 (1994) L191-L195.

P. L. Grange et al., Applied Catalysis A: General, 137 (1996) 9-23.

Gang Yang et al., On Configuration of exchanged La3+ on ZSM-5: a theoretical approach to the Improvement in hydrothermal stability of La-modified ZSM-5 zeolite, Journal of Chemical Physics (2003), 119 (18), 9765-9770.

* cited by examiner

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(57) ABSTRACT

Process for converting certain lactones to their alpha-methylene substituted forms using an oxynitride catalyst or a composite oxynitride catalyst incorporating lithium, sodium, potassium, rubidium, cesium, magnesium, calcium, strontium, or barium or combinations thereof.

6 Claims, No Drawings

GAS PHASE SYNTHESIS OF METHYLENE LACTONES USING OXYNITRIDE CATALYST

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority under 35 U.S.C. §119 from U.S. Provisional Application Ser. No. 60/591,519, filed Jul. 27, 2004.

FIELD OF INVENTION

The invention pertains to a method of producing unsubstituted and substituted alpha-methylene lactones by a gas phase reaction of starting lactones with formaldehyde in the presence of an oxynitride catalyst or oxynitride composite catalyst.

BACKGROUND

Alpha-methylene-gamma-butyrolactone and methyl alpha-methylene-gamma-butyrolactone are useful monomers in the preparation of both homopolymers and copolymers. In addition, the alpha-methylene-gamma-butyrolactone group is an important structural feature of many sesquiterpenes of biological importance.

U.S. Pat. No. 6,313,318 describes a method for converting certain starting lactones to alpha-methylene substituted lactones using a so-called basic catalyst that is made by treating silica with an inorganic salt of Ba, Mg, K, Cd, Rb, Na, Li, Sr, and La. A problem with silica-based catalysts is that they are hydrothermally unstable under reaction conditions involving temperatures above about 250° C. In addition, regeneration cycles involving air produce water at high temperature, and the water can change the porosity and activity of the catalyst

The prior art in this area involves the use of supported catalysts on silica, which are known to be hydrothermally unstable (see for instance, WO9952628A1). Under reaction conditions, or after repeated regeneration cycles, a hydrothermally unstable material will show catalytic performance that will deteriorate with time.

Aluminum phosphorous oxynitrides are a relatively new category of materials which may have unique properties for base catalyzed chemistry. These materials are believed to have adjustable acid/base properties. The aluminum phosphorus oxynitrides, which were first described by M. J. Climent (M. J. Climent et al., Catalysis Letter, 59 (1999) 33–38; P. Grange et al., Applied Catalysis A: General 114 (1994) L191–L196; P. L. Grange et al., Applied Catalysis A: General, 137 (1996) 9–23), have been shown to be active for various base catalyzed condensation reactions (e.g., arylsulfones with substituted benzaldehydes). Structural information is not available. However, depending on the nitridation temperature and other conditions, and therefore degree of incorporation of nitrogen into the structure of these materials, it was shown that the relative proportion of acidic and basic sites in the catalyst could be adjusted. However, the use of these materials for lactone conversion has not been described, either as the oxynitrides or as composite catalysts in which various Group I and/or Group II elements are incorporated into the oxynitride.

Although a phosphorus oxynitride system might be expected to possess a significant advantage in hydrothermal stability compared to conventional silica catalysts, the catalytic activity of such a material for lactone conversion reactions cannot be predicted because of the unpredictable nature of catalysis in general.

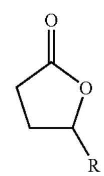
It would be advantageous to have a catalyst that is hydrothermally stable at high temperatures and whose activity does not decay with time on stream (TOS) or after several high temperature oxidizing regenerations.

SUMMARY OF THE INVENTION

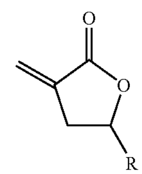
This invention relates to the discovery that the phosphorus oxynitrides and oxynitride composites (as defined below) are surprisingly active for lactone conversion chemistry, with the advantage that they should possess superior hydrothermal stability compared to prior art supported silica catalysts.

In its first aspect, the present invention is a process for preparing a reaction product comprising an alpha-methylene lactone of the Formula II, said process comprising reacting a lactone of the Formula I with formaldehyde,

I



II



wherein R is selected from the group consisting of hydrogen, methyl, ethyl, and straight or branched C_3–C_5 alkyl;

at a temperature in the range of from about 150° C. to about 450° C. in the presence of an oxynitride catalyst of the nominal formula

$$Al_1Si_xP(O_{(4+2x)-y)})N_{2/3y}$$

wherein;

x=0 to 1, and

y=0.001 to 2.

In its second aspect the invention involves the same reaction wherein the oxynitride catalyst is made by a process comprising:

(a) combining $AlCl_3$ or aluminum alkoxides containing 1–20 carbon atoms with water;

(b) adding H_3PO_4 to the product of step (a);

(c) optionally adding silicon alkoxide to the product of step (b);

(d) adding NH_4OH to the product of step (b), or to the product of step (c) if step (c) is performed;

(e) drying the product of step (d);

(f) optionally washing the product of step (e); and

(g) heating the product of step (e) or (f) in NH_3.

In its third aspect, the invention involves the same reaction wherein the catalyst is a composite catalyst that is a reaction composite of the oxynitride catalyst and certain elements selected from Group I and/or Group II of the Periodic Table, made by a process comprising:

(a) contacting (i) the oxynitride catalyst with (ii) a solution comprising a solvent and a compound of at least one element selected from the group consisting of lithium, sodium, potassium, rubidium, cesium, magnesium, calcium, strontium and barium;

(b) drying the product of step (a) to remove at least a portion of said solvent;

(c) heating the product of step (b) to a temperature in the range of 350° C. to 550° C. to produce a catalyst precursor; and

(d) flushing at a preselected flow rate an oxygen-containing gas over said catalyst precursor either during step (c), or after step (c) while the temperature is still in the range of 350° C. to 550° C. to produce the composite catalyst in which the at least one element is present in said composite catalyst in an amount from about 0.1% to about 40% by weight of the combined weight of the oxynitride catalyst and the element.

Catalysts used in the present invention might be expected to confer an advantage over silica-based catalysts in terms of hydrothermal stability of the present phosphorus oxynitrides on the theory that any enhancement of the lattice energy of a solid will yield a thermally and hydrothermally stable material. In terms of their fundamental inorganic properties, phosphate systems are more ionic compared to the silicon oxides by virtue of the phosphate group relative to the oxygen anion. This will in turn strengthen the interactions between the positively and negatively charged species in the lattice, stabilizing the structure. This explanation has been applied to the incorporation of La^{3+} in zeolitic structures (Yang, Gang; Wang, Yan; Zhou, Danhong; Zhuang, Jianqin; Liu, Xianchun; Han, Xiuwen; Bao, Xinhe, "On configuration of exchanged La3+ on ZSM-5: a theoretical approach to the improvement in hydrothermal stability of La-modified ZSM-5 zeolite" Journal of Chemical Physics (2003), 119 (18), 9765–9770).

DETAILED DESCRIPTION OF THE INVENTION

The following terms generally are abbreviated as follows:

alpha-methylene-gamma-butyrolactone is abbreviated MBL;

gamma-butyrolactone is abbreviated GBL;

gamma-valerolactone is abbreviated GVL;

alpha-methylene-gamma-valerolactone is abbreviated MVL;

gamma-methyl alpha methylene gamma butyrolactone is abbreviated MeMBL;

gas chromatography is abbreviated GC;

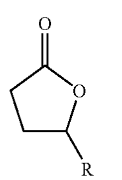
mass spectroscopy is abbreviated MS;

time on stream is sometimes abbreviated TOS; and

standard cubic centimeters in abbreviated sccm.

The process of the present invention concerns a gas phase methylenation of lactones of Formula I to yield alpha-methylene lactones of Formula II.

I



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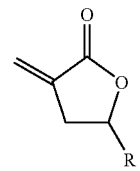
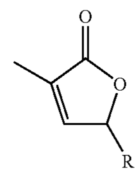
II



Specifically, lactone of Formula I is reacted with formaldehyde to give a reaction product comprising alpha methylene lactones of Formula II. The substituent —R group is selected from the group consisting of hydrogen, methyl, ethyl, and straight or branched C_3–C_5 alkyl. Sometimes produced is an internal isomer of the lactone of Formula II, represented by Formula III, below.

III



In a preferred embodiment, the lactone of Formula I is gamma-butyrolactone (R is H) and the alpha-methylene lactone of Formula II is alpha-methylene-gamma-butyrolactone. In another preferred embodiment, the lactone of Formula I is methyl gamma-butyrolactone (R is methyl) and the alpha-methylene lactone of Formula II is gamma-methyl alpha-methylene gamma-butyrolactone.

The process of the present invention is carried out in the gas phase, at a temperature in the range of from about 150° C. to about 450° C. A temperature in the range of from about 250° C. to about 400° C. is preferred. A temperature in the range of from about 300° C. to about 340° C. is most preferred.

The reaction can be carried out at pressures ranging from about 0.1 MPa to about 1.0 MPa, with a preferred range of from about 0.1 MPa to about 0.5 MPa. Contact time with the catalyst can be selected to achieve desired yields and selectivities. Contact time can be manipulated by increasing or decreasing flow rates over the catalyst.

The formaldehyde may be supplied to the reaction in the form of an aqueous solution (formalin), a hemiacetal of an alcohol, a low molecular weight polyformaldehyde or formaldehyde trimer (trioxane). Formalin is preferred, because it is the lowest cost source of formaldehyde. The use of the trimers and oligomers, however, reduces the need to remove water from the process. Anhydrous formaldehyde can also be used. Hemiacetals work effectively, but require separate steps to release the formaldehyde from the alcohol and to recover and recycle the alcohol.

The oxynitride catalyst used in the present invention is a mixed phase material that may be represented by the nominal formula:

$$Al_1Si_xP(O_{(4+2x)-y)})N_{2/3y},$$

wherein

x=0 to 1, and

y=0.001 to 2.

The catalyst can be made by a process (is obtainable by a process) that comprises the steps of:

(a) combining $AlCl_3$ or aluminum alkoxides containing 1–20 carbon atoms with water;

(b) adding H_3PO_4 to the product of step (a);

(c) optionally adding silicon alkoxide to the product of step (b);

(d) adding NH_4OH to the product of step (b), or to the product of step (c) if step (c) is performed;

(e) drying the product of step (d);

(f) optionally washing the product of step (e); and

(g) heating the product of step (e) or (f) in NH_3.

The relative number of acid and base sites on the catalyst can be adjusted by varying the time and temperature of step (g). The nitridation step in NH_3 introduces nitrogen into the lattice of the oxide, presumably through direct substitution of oxygen. This nitride formation (nominal N^{3-}) introduces basic sites on the catalyst surface.

The alkoxides of aluminum used in steps (a) or of silicon in step (c) may include any alkoxide that contains from 1 to 20 carbon atoms and preferably 1 to 5 carbon atoms in the alkoxide group. C_1–C_4 alkoxides such as aluminum n-butoxide and aluminum isopropoxide may be used. Tetraethylorthosilicate is an example of a silicon alkoxide for step (c), although other alkoxides containing silicon such as tetramethoxysiloxane can be used.

Commercially available alkoxides can be used. However, other routes can prepare inorganic alkoxides. Examples include alkoxides prepared by the direct reaction of zero valent metals with alcohols in the presence of a catalyst. Many alkoxides can be formed by reaction of metal halides with alcohols. Alkoxy derivatives can be synthesized by the reaction of the alkoxide with alcohol in a ligand interchange reaction. Direct reactions of metal dialkylamides with alcohol also form alkoxide derivatives. Additional examples are disclosed in "Metal Alkoxides" by D. C. Bradley et al., Academic Press, (1978).

For step (a), aluminum chloride is preferred. For step (c), tetraethylorthosilicate is preferred.

For step (e), the drying may be performed in air or an inert gas such as nitrogen, helium or argon.

In another embodiment, the oxynitride catalyst may be used to form a composite catalyst that is a reaction product of certain catalytic Group I and/or Group II elements of the Periodic Table and the oxynitride catalyst. Such catalysts can be made by (are obtainable by) a process that comprises the steps of:

(a) contacting (i) the oxynitride catalyst with (ii) a solution comprising a solvent and a compound of at least one element selected from lithium, sodium, potassium, rubidium, cesium, magnesium, calcium, strontium and barium;

(b) drying the product of step (a) to remove at least a portion of said solvent;

(c) heating the product of step (b) to a temperature in the range of 350° C. to 550° C. to produce a catalyst precursor; and

(d) flushing at a preselected flow rate an oxygen-containing gas over said catalyst precursor either during step (c), or after step (c) while the temperature is still in the range of 350° C. to 550° C. to produce the composite catalyst, in which the at least one element is present in said composite catalyst in an amount from about 0.1% to about 40% by weight of the combined weight of the oxynitride catalyst and the element.

The inclusion of an appropriate Group I and/or Group II element into the oxynitride catalyst may cause a shift in the relative number of acid and base sites.

Organic compounds such as the carboxylates, such as acetate, propionate, butyrate, and 2-ethylhexanoate of a catalytic element selected from the group consisting of lithium, sodium, potassium, rubidium, cesium, magnesium, calcium, strontium and barium are dissolved in aqueous or non-aqueous solvent and contacted with the oxynitride catalyst. Organic compounds containing acetates are preferred. Other organic anions such as acetylacetonates can be used. The amount of organic compound should be chosen to provide to the final composite catalyst from 0.1 wt % to 40 wt % of the element relative to the combined weight of the oxynitride catalyst plus the element (as opposed to the compound of which the element is a part). The resulting material is allowed to dry, preferably in a nitrogen environment for an extended time. The purpose of the drying is to remove at least a portion of the solvent in which the organic compound is dissolved.

Organic compounds such as the alkoxides can also be used. Organic alkoxides of an element selected from the group consisting of lithium, sodium, potassium, rubidium, cesium, magnesium, calcium, strontium, and barium can contain from one to 20 carbon atoms and preferably 1 to 5 carbon atoms in the alkoxide group. The organic alkoxide should be soluble in the solvent. Most alkoxides can be dissolved in non-aqueous solutions such as ethanol, propanol, or isopropyl alcohol. Subsequent methods for introducing the element and drying are the same.

The dried material is then heated (for example in an alumina boat placed in a tube furnace) at an ambient temperature of 350° C. to 550° C. (The temperature of the catalyst material may be somewhat higher because of exothermic reactions taking place on the material.) A temperature between 450° C. and 550° C. is preferred. Either during the heating or subsequent to it, but at the same temperature, the material is flushed with an oxygen-containing gas (e.g. air), which is believed to burn off organic residues formed during the heating step. In a tube furnace, an airflow rate of at least 110 cc/min in a 3 cm diameter tube furnace, which corresponds to a linear velocity of 15.6 cm/min was found to be acceptable. Use of sufficiently high airflow rates are preferred to produce a high surface area material. In a tube furnace, the material can be heated at a rate of 5° C./min to 120° C., and can be exposed to this temperature for 4 hours. It can be heated subsequently at a rate of 5° C./min to approximately 450° C. and held at this temperature for 16 hours. Other equipment can be used to perform the heating step. Such equipment includes fluidized bed and rotary calcination equipment.

Heating can be accomplished in air or in a combination of an inert gas such as nitrogen, argon, or krypton for parts of the cycle, followed by air. An initial drying step at 120° C. in nitrogen, another inert gas, or air is preferred for a period of 30 minutes to 24 hours. Following this drying step, the catalyst can be heated in air or nitrogen to a temperature of 350° C. to 550° C. For acetate precursors, 450° C. to 550° C. is required. Heating times can range from 30 minutes to 48 hours. The final heating step preferably is performed in air for at least 30 minutes.

In some cases, reaction conditions may result in a decrease of catalyst efficiency. In these situations it may be useful to periodically reactivate the catalyst. For example, contacting the present catalysts, when activity drops below an acceptable level, with oxygen at elevated temperatures may have the effect of reactivating the catalyst. Contact temperatures with oxygen may range from about 225° C. to about 500° C., with temperatures of about 250° C. to about 425° C. being preferred.

Thermal and hydrothermal stability are required for the catalyst to withstand one or repeated regeneration cycles without permanently degrading catalyst performance.

Selectivities and yields of product may be influenced by the total contact time with the catalyst. As stated previously, yields and selectivities may be increased by adjusting gas and liquid flow rates.

Separation and/or purification of the desired products, including MBL or MeMBL, from unreacted starting lactone and/or reaction byproducts may be performed by processes known in the art. A particularly suitable method to recover the desired product is to polymerize MBL in GBL solution, or MeMBL in GVL solution, using standard free-radical polymerization, isolate the polymer by precipitation, and then thermally depolymerize back to MBL or MeMBL, as the case may be, by heating under vacuum. Separation of the MeMBL from the internal isomer of Formula III can be accomplished by the polymerization of MeMBL. An appropriate polymerization technique is taught in U.S. Pat. No. 6,723,790. Finally, MBL can be separated from GBL by melt crystallization. Another effective method is liquid-liquid extraction.

Non-limiting reactors suitable for the process of the instant invention include a tubular reactor, fluidized bed reactor, fixed bed reactor, and transport bed reactor. The process can be run in either batch or continuous mode as described, for example, in H. Scott Fogler, *Elements of Chemical Reaction Engineering,* 2nd Edition, Prentice-Hall Inc, CA, 1992.

The reaction can be carried out by passing solutions of the formaldehyde and lactone over the catalyst at elevated temperatures.

EXAMPLES

Catalyst 1:

$Al_1\ Si_x\ P\ (O_{(4+2x)-y)})N_{2/3\ y}$, x=0, y is approximately 0.39 (prepared using 800° C. Nitridation Conditions, 16 hours)

115.88 g (0.86 moles) of aluminum trichloride (Alfa Aesar, 8848) was hydrolyzed with 322 g of water and left in solution overnight. One half of this hydrolyzed solution was used. 28.6 ml of 86% H_3PO_4 (J T Baker) was stirred into this half of the solution and was stirred well. After adding 116 ml of ammonium hydroxide (20–30%, EM Science) the material turned into a thick gel. After aging overnight, the material was dispersed with 300 ml of isopropyl alcohol (EM Sciences, Omnisolve), filtered and washed with two 100 ml portions of isopropyl alcohol.

The material was nitrided by placing the material in a tube furnace and heated in anhydrous ammonia. 7.486 g of the solid described above was loaded in an alumina boat, which was placed into a tube furnace and purged in N_2 for 40 minutes (100 sccm N_2). The sample was heated to 70° C. in nitrogen and allowed to soak for 1 hour and then to 500° C. in N_2 for 4 hours. The N_2 was replaced with 100 sccm anhydrous NH_3 and the powder was heated to 800° C., and allowed to soak at that temperature (in NH_3) for 8 hours. After replacing the NH_3 with 100 sccm N_2, the sample was cooled to 500° C. and held at that temperature for 12 hours. The cycle was repeated: the N_2 was replaced with 100 sccm NH_3 and the powder was heated to 800° C. under NH_3 for 8 hours, for a total heating time in NH_3 of 16 hours at 800° C. After switching the gas stream to 200 sccm N_2, the sample was allowed to slowly cool to room temperature.

The final product was analyzed for nitrogen content by Micro-Analysis Inc., Wilmington Del. In this analysis, a Perkin Elmer 2400 CHN analyzer was used which uses a combustion method to convert the sample elements to simple gases (CO_2, H_2O, and N_2). The sample was first oxidized in a pure oxygen environment; the resulting gases were then controlled to exact conditions of pressure, temperature and volume. Finally, the product gases were separated under steady-state conditions and were measured as a function of thermal conductivity. Using this analysis, the final material contained 2.94 wt % nitrogen.

Catalyst 2:

$Al_1\ Si_x\ P\ (O_{(4+2x)-y)})N_{2/3\ y}$, x=0, y is approximately 0.19 (prepared using 650° C. Nitridation Conditions, 5 hours)

The same procedure as described for catalyst 1 was used, except that a different nitridation protocol was used.

The material was nitrided by placing the material in a tube furnace and heated in anhydrous ammonia. 10.00 g of the solid described above was loaded in an alumina boat, which was placed into a tube furnace and purged in N_2 for 40 minutes (100 sccm N_2). The sample was heated to 500° C. in N_2 for 2 hours. The N_2 was replaced with 100 sccm anhydrous NH_3 and the powder was heated to 650° C., and allowed to soak at that temperature (in NH_3) for 5 hours. After switching the gas stream to 200 sccm N_2, the sample was allowed to slowly cool to room temperature.

The final product was analyzed for nitrogen content by Micro-Analysis Inc., Wilmington Del., as previously described. Using this analysis, the final material contained 1.40 wt % nitrogen.

Catalyst 3:

$Al_1\ Si_x\ P\ (O_{(4+2x)-y)})N_{2/3\ y}$

X=0, y is approximately 0.13

(washed sample, prepared using 650° C. Nitridation Conditions, 5 hours)

The same procedure as described in Catalyst 2 was used. Prior to the nitridation step, 75 g of the dried gel was slurried with water and filtered as a washing step. After drying in nitrogen, the material was subjected to the nitridation procedure as described for catalyst 2.

The material was nitrided by placing the material in a tube furnace and heated in anhydrous ammonia. 10.04 g of the solid described above was loaded in an alumina boat, which was placed into a tube furnace and purged in N_2 for 40 minutes (100 sccm N_2). The sample was heated to 500° C. in N_2 for 2 hours. The N_2 was replaced with 100 sccm anhydrous NH_3 and the powder was heated to 650° C., and allowed to soak at that temperature (in NH_3) for 5 hours. After switching the gas stream to 200 sccm N_2, the sample was allowed to slowly cool to room temperature.

The final product was analyzed for nitrogen content by Micro-Analysis Inc., Wilmington Del. In this analysis, a Perkin Elmer 2400 CHN analyzer was used which uses a combustion method to convert the sample elements to simple gases (CO_2, H_2O, and N_2). The sample was first oxidized in a pure oxygen environment; the resulting gases were then controlled to exact conditions of pressure, temperature and volume. Finally, the product gases were separated under steady-state conditions and are measured as a function of thermal conductivity. Using this analysis, the final material contained 0.99 wt % nitrogen.

Catalyst 4:

$Al_1\ Si_x\ P\ (O_{(4+2x)-y)}N_{2/3\ y}$

x=1, y is approximately 0.19

115.88 g (0.86 moles) of aluminum trichloride (Alfa Aesar, 8848) was hydrolyzed with 322 g of water and left in solution overnight. One half of this hydrolyzed solution was used. 28.6 ml of 86% H_3PO_4 (J T Baker) was stirred into this half of the solution and was stirred well. 90 g (0.432 moles) of tetraethoxylsilane (TEOS) was added along with 100 ml of anhydrous ethanol.

After adding about 100 ml ammonium hydroxide (20–30%, EM Science) the material turned into a flaky white precipitate. An additional 25 ml of ammonium hydroxide was added to raise the pH. The material was dried for 48 hours under nitrogen.

The material was nitrided by placing the material in a tube furnace and heated in anhydrous ammonia. 10.01 g of the solid described above was loaded in an alumina boat, which was placed into a tube furnace and purged in N_2 for 12 hours (100 sccm N_2). The sample was heated to 500° C. in N_2 for 2 hours. The N_2 was replaced with 100 sccm anhydrous NH_3 and the powder was heated to 650° C., and allowed to soak at that temperature (in NH_3) for 5 hours. After switching the gas stream to 100 sccm N_2, the sample was allowed to slowly cool to room temperature.

The final product was analyzed for nitrogen content by Micro-Analysis Inc., Wilmington Del., as described previously. Using this analysis, the final material contained 1.47 wt % nitrogen.

Catalyst 5: Approximately 15.5 wt % Rb on Material of Catalyst 1

About 77.5% of a solution derived from 1.27 g of rubidium acetate (Alfa Aesar, 99.8%, #12890) was dissolved in 2.5 g of water and was impregnated into 3 g of Catalyst 1. The material was allowed to dry for at least 12 hours in a nitrogen environment. The material was loaded into an alumina boat and heated in a tube furnace. The internal diameter of the tube furnace was 10 cm. The airflow rate was greater than 1220 cm^3/min, which corresponds to a linear velocity of greater than 15.6 cm/min. Use of this higher airflow is important to produce a high surface area material. The material was heated at a rate of 5° C./min to 120° C., and the 120° C. temperature was maintained for four hours. It was subsequently heated at a rate of 5° C./min to approximately 450° C. (as measured by a thermocouple placed approximately 0.5 cm over the catalyst bed) and was held at this temperature for 16 hours.

Catalyst 6: 20 wt % Rb Supported on Material of Catalyst 3

1.69 g rubidium acetate (Alfa Aesar, 99.8%, #12890) was dissolved in 2.5 g of water and was impregnated into 4 g of Catalyst 1.

The material was allowed to dry for at least 12 hours in a nitrogen environment. The material was loaded into an alumina boat and heated in a tube furnace. The internal diameter of the tube furnace was 10 cm. The airflow rate was greater than 1220 cm^3/m in, which corresponds to a linear velocity of greater than 15.6 cm/min. Use of this higher airflow is important to produce a high surface area material. The material was heated at a rate of 5° C./min to 120° C., and the temperature was maintained for four hours. It was subsequently heated at a rate of 5° C./min to approximately 450° C. (as measured by a thermocouple placed approximately 0.5 cm over the catalyst bed) and was held at this temperature for 16 hours.

Example of Vapor Phase Reaction

Solutions containing gamma-valerolactone in formalin (37% aqueous formaldehyde), at various feed ratios, were fed to a vaporizer (held at 200° C.) followed by the introduction of nitrogen, to carry the vapor through a ¼ inch tubular reactor containing a catalyst heated to the appropriate reaction temperature. In the following examples, nitrogen flow rate was 24 cc/min., liquid feed rate was 1 ml/hr, formaldehyde to GVL molar ratio was 4:1 and the catalyst volume was 2 cc. The TOS (hours) was typically 0.5 to 5 hours. The reactor effluent was condensed in a cold trap and analyzed off-line by GC-MS using an internal standard. Conversion is based on the weight percent of GVL converted and selectivity was based on the weight fraction of each compound relative to the amount of GVL converted.

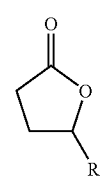
TABLE 1

Reaction Data			
Catalyst	TOS (h)	% GVL Conversion	% Selectivity to MeMBL Isomers
1	0.5	9.25	>90
	2	2.92	>90
2	0.5	18.06	>90
	2	8.78	>90
3	0.50	26.52	>90
	2.00	6.44	>90
	5.00	4.27	>90
4	1.00	10.71	>90
	2.00	6.50	>90
	5.00	4.24	>90
5	0.5	10.00	>90
	2	5.01	>90
6	0.5	15.85	>90
	2	8.63	>90
	5	4.82	>90

The data in Table 1 show that reactions done in accordance with the process of the present invention yield the desired products with adequate conversion and high selectivity.

What is claimed is:

1. A process for preparing a reaction product comprising an alpha-methylene lactone of the Formula II, said process comprising reacting a lactone of the Formula I with formaldehyde,



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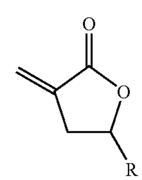

II

wherein R is selected from the group consisting of hydrogen, methyl, ethyl, and straight or branched C_3–C_5 alkyl;

at a temperature in the range of from about 150° C. to about 450° C. in the presence of an oxynitride catalyst of the nominal formula

$$Al_1Si_xP(O_{(4+2x)-y)})N_{2/3y}$$

wherein;

X=0 to 1, and

Y=0.001 to 2.

2. The process of claim 1 wherein the catalyst is made by a process that comprises the steps of:

(a) combining $AlCl_3$ or aluminum alkoxides containing 1–20 carbon atoms with water;

(b) adding H_3PO_4 to the product of step (a);

(c) optionally adding silicon alkoxide to the product of step (b);

(d) adding NH_4OH to the product of step (b), or to the product of step (c) if step (c) is performed;

(e) drying the product of step (d);

(f) optionally washing the product of step (e); and

(g) heating the product of step (e) or (f) in NH_3.

3. A process for preparing a reaction product comprising an alpha-methylene lactone of the Formula II, said process comprising reacting a lactone of the Formula I with formaldehyde,

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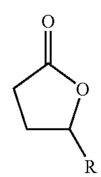

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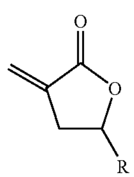

wherein R is selected from the group consisting of hydrogen, methyl, ethyl, and straight or branched C_3–C_5 alkyl;

at a temperature in the range of from about 150° C. to about 450° C. in the presence of a composite catalyst made by a process that comprises:

(a) contacting (i) an oxynitride catalyst of the nominal formula

$$Al_1Si_xP(O_{(4+2x)-y)})N_{2/3y}$$

wherein;

X=0 to 1, and

Y=0.001 to 2,

with (ii) a solution comprising a solvent and a compound of at least one element selected from the group consisting of lithium, sodium, potassium, rubidium, cesium, magnesium, calcium, strontium and barium;

(b) drying the product of step (a) to remove at least a portion of said solvent;

(c) heating the product of step (b) to a temperature in the range of 350° C. to 550° C. to produce a catalyst precursor; and

(d) flushing at a preselected flow rate an oxygen-containing gas over said catalyst precursor either during step (c), or after step (c) while the temperature is still in the range of 350° C. to 550° C. to produce the composite catalyst in which the at least one element is present in said composite catalyst in an amount from about 0.1% to about 40% by weight of the combined weight of the oxynitride catalyst and the element.

4. The process of claim 3 wherein the oxynitride catalyst is made by a process that comprises the steps of:

(a) combining $AlCl_3$ or aluminum alkoxides containing 1–20 carbon atoms with water;

(b) adding H_3PO_4 to the product of step (a);

(c) optionally adding silicon alkoxide to the product of step (b);

(d) adding NH_4OH to the product of step (b), or to the product of step (c) if step (c) is performed;

(e) drying the product of step (d);

(f) optionally washing the product of step (e); and

(g) heating the product of step (e) or (f) in NH_3.

5. A composite catalysts for preparing a reaction product comprising an alpha-methylene lactone of the Formula II, said process comprising reacting a lactone of the Formula I with formaldehyde,

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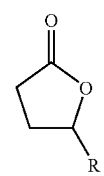
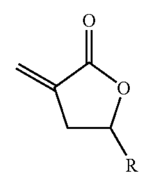


II



wherein R is selected from the group consisting of hydrogen, methyl, ethyl, and straight or branched C_3–C_5 alkyl;

at a temperature in the range of from about 150° C. to about 450° C., said composite catalyst made by a process that comprises:

(a) contacting (i) an oxynitride catalyst of the nominal formula

$$Al_1Si_xP(O_{(4+2x)-y)})N_{2/3y}$$

wherein;

X=0 to 1, and

Y=0.001 to 2,

with (ii) a solution comprising a solvent and a compound of at least one element selected from the group consisting of lithium, sodium, potassium, rubidium, cesium, magnesium, calcium, strontium and barium;

(b) drying the product of step (a) to remove at least a portion of said solvent;

(c) heating the product of step (b) to a temperature in the range of 350° C. to 550° C. to produce a catalyst precursor; and

(d) flushing at a preselected flow rate an oxygen-containing gas over said catalyst precursor either during step (c), or after step (c) while the temperature is still in the range of 350° C. to 550° C. to produce the composite catalyst in which the at least one element is present in said composite catalyst in an amount from about 0.1% to about 40% by weight of the combined weight of the oxynitride catalyst and the element.

6. The composite catalysts of claim **5** wherein the oxynitride catalyst is made by a process that comprises the steps of:

(a) combining $AlCl_3$ or aluminum alkoxides containing 1–20 carbon atoms with water;

(b) adding H_3PO_4 to the product of step (a);

(c) optionally adding silicon alkoxide to the product of step (b);

(d) adding NH_4OH to the product of step (b), or to the product of step (c) if step (c) is performed;

(e) drying the product of step (d);

(f) optionally washing the product of step (e); and

(g) heating the product of step (e) or (f) in NH_3.

* * * * *