protection from moisture and oxygen. Examples of such transparent multilayer barrier coatings and processes can be found, for example, in U.S. Patent Nos. 5,440,446 (Shaw et al.); 5,877,895 (Shaw et al.); 6,010,751 (Shaw et al.); 7,018,713 (Padiyath et al.); and 6,413,645 (Graff et al.).

SUMMARY

~~In one aspect, the~~ The present disclosure features compositions of matter including at least one urea (multi)-urethane (meth)acrylate-silane compound of the formula R_A-NH-C(O)-N(R^4)-R^{11}-[O-C(O)NH-R_S]$_n$. R_A is a (meth)acryl containing group of the formula R^{11}-$(A)_n$, in which R^{11} is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene groups optionally containing one or more catenary oxygen atom, A is a (meth)acryl group comprising the formula X^2-C(O)-C(R^3)=CH_2, *in which* X^2 *is* -O, -S, *or* –NR^3, R^3 *is independently* H, *or* C_1-C_4, *and* n = 1 to 5. Additionally, R^4 is H, C_1 to C_6 alkyl, or C_1 to C_6 cycloalkyl. R_S is a silane containing group of the formula -R^1-[Si(Y_p)(R^2)$_{3-p}$]$_q$, in which R^1 is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene groups optionally containing one or more catenary oxygen atoms, Y is a hydrolysable group, R^2 is a monovalent alkyl or aryl group, and p is 1,2, or 3.

In one aspect, the present disclosure relates to a composition of matter, comprising: at least one urea (multi)-urethane (meth)acrylate-silane compound of the formula: R_A-NH-C(O)-N(R^4)-R^{11}-[O-C(O)NH-R_S]$_n$, wherein: R_A is a (meth)acryl containing group of the formula R^{11}-$(A)_n$, further wherein R^{11} is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene groups optionally containing one or more catenary oxygen atom, A is a (meth)acryl group comprising the formula X^2-C(O)-C(R^3)=CH_2, additionally wherein: X^2 is -O, -S, or –NR^3, R^3 is independently H, or C_1-C_4, and n = 1 to 5; R^4 is H, C_1 to C_6 alkyl, or C_1 to C_6 cycloalkyl; R_S is a silane containing group of the formula -R^1-[Si(Y_p)(R^2)$_{3-p}$]$_q$, wherein: R^1 is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene groups optionally containing one or more catenary oxygen atoms, Y is a hydrolysable group, R^2 is a monovalent alkyl or aryl group, and p is 1,2, or 3.

~~In a related aspect, t~~The present disclosure also features compositions of matter including at least urea (multi)-urethane (meth)acrylate-silane compound of the formula R_S-NH-C(O)-N(R^4)-R^{11}-[O-C(O)NH-R_A]$_n$. R_S is a silane containing group of the formula -R^1-Si(Y_p)(R^2)$_{3-p}$, in which R^1 is a polyvalent alkylene, arylene, alkarylene, or aralkylene

group, said alkylene, arylene, alkarylene, or aralkylene groups optionally containing one or more catenary oxygen atoms, Y is a hydrolysable group, R^2 is a monovalent alkyl or aryl group, and p is 1,2, or 3. Additionally, R^4 is H, C_1 to C_6 alkyl, or C_1 to C_6 cycloalkyl. R_A is a (meth)acryl group containing group of the formula R^{11}-$(A)_n$, in which R^{11} is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene group optionally containing one or more catenary oxygen atom, A is a (meth)acryl containing group of the formula X^2-C(O)-$C(R^3)$=CH_2, in which X^2 is -O, -S, or –NR^3, R^3 is independently H, or C_1-C_4; and n = 1 to 5.

In another aspect, the present disclosure relates to a composition of matter, comprising: at least one urea (multi)-urethane (meth)acrylate-silane compound of the formula: R_S-NH-C(O)-$N(R^4)$-R^{11}-[O-C(O)NH-R_A]$_n$, wherein: R_S is a silane containing group of the formula -R^1-$Si(Y_p)(R^2)_{3-p}$, wherein: R^1 is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene groups optionally containing one or more catenary oxygen atoms, Y is a hydrolysable group, R^2 is a monovalent alkyl or aryl group, and p is 1,2, or 3; R^4 is H, C_1 to C_6 alkyl, or C_1 to C_6 cycloalkyl; R_A is a (meth)acryl group containing group of the formula R^{11}-$(A)_n$, further wherein: R^{11} is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene group optionally containing one or more catenary oxygen atom, A is a (meth)acryl containing group of the formula X^2-C(O)-$C(R^3)$=CH_2, additionally wherein: X^2 is -O, -S, or –NR^3, R^3 is independently H, or C_1-C_4; and n = 1 to 5.

In any of the foregoing embodiments, each hydrolysable group Y is independently selected from an alkoxy group, an acetate group, an aryloxy group, and a halogen. In some particular exemplary embodiments of the foregoing, at least some of the hydrolysable groups Y are alkoxy groups.

~~In another aspect, t~~The present disclosure also describes an article including a substrate selected from a (co)polymeric film or an electronic device, the electronic device further including an organic light emitting device (OLED), an electrophoretic light emitting device, a liquid crystal display, a thin film transistor, a photovoltaic device, or a combination thereof; a base (co)polymer layer on a major surface of the substrate; a base (co)polymer layer on a major surface of the substrate; an oxide layer on the base (co)polymer layer; and a protective (co)polymer layer on the oxide layer, wherein the protective (co)polymer layer comprises the reaction product of at least one of the foregoing urea (multi)-urethane (meth)acrylate-silane precursor compound of the formula R_A-NH-C(O)-N(R^4)-R^{11}-[O-C(O)NH-R_S]$_n$, or R_S-NH-C(O)-N(R^4)-R^{11}-[O-C(O)NH-R_A]$_n$, as described above.

In another aspect, the present disclosure relates to an article, comprising: a substrate selected from a (co)polymeric film or an electronic device, the electronic device further comprising an organic light emitting device (OLED), an electrophoretic light emitting device, a liquid crystal display, a thin film transistor, a photovoltaic device, or a combination thereof; a base (co)polymer layer on a major surface of the substrate; an oxide layer on the base (co)polymer layer; and a protective (co)polymer layer on the oxide layer, wherein the protective (co)polymer layer comprises the reaction product of at least one urea (multi)-urethane (meth)acrylate-silane precursor compound of the formula: R_A-NH-C(O)-N(R^4)-R^{11}-[O-C(O)NH-R_S]$_n$, wherein: R_A is a (meth)acryl containing group of the formula R^{11}-(A)$_n$, further wherein R^{11} is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene groups optionally containing one or more catenary oxygen atom, A is a (meth)acryl group comprising the formula X^2-C(O)-C(R^3)=CH_2, additionally wherein: X^2 is -O, -S, or –NR^3, R^3 is independently H, or C_1-C_4, and n = 1 to 5, R^4 is H, C_1 to C_6 alkyl, or C_1 to C_6 cycloalkyl; R_S is a silane containing group of the formula -R^1-Si(Y_p)(R^2)$_{3-p}$, wherein: R^1 is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene groups optionally containing one or more catenary oxygen atoms, Y is a hydrolysable group, R^2 is a monovalent alkyl or aryl group, and p is 1,2, or 3.

In another aspect, the present disclosure relates to an article, comprising: a substrate selected from a (co)polymeric film or an electronic device, the electronic device further comprising an organic light emitting device (OLED), an electrophoretic light emitting device, a liquid crystal display, a thin film transistor, a photovoltaic device, or a combination thereof; a base (co)polymer layer on a major surface of the substrate; an oxide layer on the base (co)polymer layer; and a protective (co)polymer layer on the oxide layer, wherein the protective (co)polymer layer comprises the reaction product of at least one urea (multi)-

urethane (meth)acrylate-silane precursor compound of the formula: R_S-NH-C(O)-N(R^4)-R^{11}-[O-C(O)NH-R_A]$_n$, wherein: R_S is a silane containing group of the formula -R^1-Si(Y_p)(R^2)$_{3-p}$, wherein: R^1 is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene groups optionally containing one or more catenary oxygen atoms, Y is a hydrolysable group, R^2 is a monovalent alkyl or aryl group, and p is 1,2, or 3; R^4 is H, C_1 to C_6 alkyl, or C_1 to C_6 cycloalkyl; R_A is a (meth)acryl group containing group of the formula R^{11}-(A)$_n$, further wherein: R^{11} is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene group optionally containing one or more catenary oxygen atom, A is a (meth)acryl containing group of the formula X^2-C(O)-C(R^3)=CH_2, additionally wherein: X^2 is -O, -S, or –NR^3, R^3 is independently H, or C_1-C_4, and n = 1 to 5.

In any of the foregoing articles, each hydrolysable group Y is independently selected from an alkoxy group, an acetate group, an aryloxy group, and a halogen. In some particular exemplary embodiments of the foregoing articles, at least some of the hydrolysable groups Y are alkoxy groups.

In additional exemplary embodiments of any of the foregoing articles, the article further includes a multiplicity of alternating layers of the oxide layer and the protective (co)polymer layer on the base (co)polymer layer.

Some exemplary embodiments of the present disclosure provide composite barrier assemblies, for example composite barrier films. Thus, in some exemplary embodiments of the foregoing articles, the substrate is a flexible transparent (co)polymeric film, optionally wherein the substrate comprises polyethylene terephthalate (PET), polyethylene napthalate (PEN), heat stabilized PET, heat stabilized PEN, polyoxymethylene, polyvinylnaphthalene, polyetheretherketone, a fluoro(co)polymer, polycarbonate, polymethylmethacrylate, poly α-methyl styrene, polysulfone, polyphenylene oxide, polyetherimide, polyethersulfone, polyamideimide, polyimide, polyphthalamide, or combinations thereof. In other exemplary embodiments of any of the foregoing composite films, the base (co)polymer layer includes a (meth)acrylate smoothing layer.

In further exemplary embodiments of any of the foregoing articles, the oxide layer includes at least one oxide, nitride, carbide or boride of atomic elements selected from Groups IIA, IIIA, IVA, VA, VIA, VIIA, IB, or IIB, metals of Groups IIIB, IVB, or VB, rare-earth metals, or a combination or mixture thereof. In some exemplary embodiments of any of the foregoing articles, the article further includes an oxide layer applied to the protective (co)polymer layer, optionally wherein the oxide layer includes silicon aluminum oxide.

~~In a further aspect, t~~The disclosure also describes methods of using a composite barrier film as described above in an article selected from a photovoltaic device, a solid state lighting device, a display device, and combinations thereof. Exemplary solid state lighting devices include semiconductor light-emitting diodes (SLEDs, more commonly known as LEDs), organic light-emitting diodes (OLEDs), or polymer light-emitting diodes (PLEDs). Exemplary display devices include liquid crystal displays, OLED displays, and quantum dot displays. Hence, in an additional aspect, the disclosure describes an electronic device incorporating the article as defined herein, wherein the substrate is a (co)polymer film and the electronic device is selected from a solid state lighting device, a display device, and combinations thereof.

~~In an additional aspect, t~~The disclosure also describes a process including: (a) applying a base (co)polymer layer to a major surface of a substrate, (b) applying an oxide layer on the base (co)polymer layer, and (c) depositing on the oxide layer a protective (co)polymer layer, wherein the protective (co)polymer layer includes a (co)polymer formed as the reaction product of at least one of the foregoing urea (multi)-urethane (meth)acrylate-silane precursor compound of the formula R_A-NH-C(O)-N(R^4)-R^{11}-[O-C(O)NH-R_S]$_n$, or R_S-NH-C(O)-N(R^4)-R^{11}-[O-C(O)NH-R_A]$_n$, as previously described. The substrate is selected from a (co)polymeric film or an electronic device, the electronic device further including an organic light emitting device (OLED), an electrophoretic light emitting device, a liquid crystal display, a thin film transistor, a photovoltaic device, or a combination thereof.

In another aspect, the present disclosure relates to a process, comprising: (a) applying a base (co)polymer layer to a major surface of a substrate selected from a (co)polymeric film or an electronic device, the electronic device further comprising an organic light emitting device (OLED), an electrophoretic light emitting device, a liquid crystal display, a thin film transistor, a photovoltaic device, or a combination thereof; (b) applying an oxide layer on the base (co)polymer layer; and (c) depositing on the oxide layer a protective (co)polymer layer, wherein the protective (co)polymer layer comprises the reaction product of at least one urea (multi)-urethane (meth)acrylate-silane precursor compound of the formula: R_A-NH-C(O)-N(R^4)-R^{11}-[O-C(O)NH-R_S]$_n$, wherein: R_A is a (meth)acryl containing group of the formula R^{11}-(A)$_n$, further wherein R^{11} is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene groups optionally containing one or more catenary oxygen atom, A is a (meth)acryl group comprising the formula X^2-C(O)-C(R^3)=CH_2, additionally wherein: X^2 is -O, -S, or –NR^3, R^3 is independently H, or C_1-C_4,

and n = 1 to 5; R^4 is H, C_1 to C_6 alkyl, or C_1 to C_6 cycloalkyl; R_S is a silane containing group of the formula $-R^1-Si(Y_p)(R^2)_{3-p}$, wherein: R^1 is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene groups optionally containing one or more catenary oxygen atoms, Y is a hydrolysable group, R^2 is a monovalent alkyl or aryl group, and p is 1,2, or 3.

In another aspect, the present disclosure relates to a process, comprising: (a) applying a base (co)polymer layer to a major surface of a substrate selected from a (co)polymeric film or an electronic device, the electronic device further comprising an organic light emitting device (OLED), an electrophoretic light emitting device, a liquid crystal display, a thin film transistor, a photovoltaic device, or a combination thereof; (b) applying an oxide layer on the base (co)polymer layer; and (c) depositing on the oxide layer a protective (co)polymer layer, wherein the protective (co)polymer layer comprises the reaction product of at least one urea (multi)-urethane (meth)acrylate-silane precursor compound of the formula: R_S-NH-C(O)-$N(R^4)-R^{11}-[O-C(O)NH-R_A]_n$, wherein: R_S is a silane containing group of the formula $-R^1-Si(Y_p)(R^2)_{3-p}$, wherein: R^1 is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene groups optionally containing one or more catenary oxygen atoms, Y is a hydrolysable group, R^2 is a monovalent alkyl or aryl group, and p is 1,2, or 3; R^4 is H, C_1 to C_6 alkyl, or C_1 to C_6 cycloalkyl; R_A is a (meth)acryl group containing group of the formula $R^{11}-(A)_n$, further wherein: R^{11} is a polyvalent alkylene, arylene, alkarylene, or aralkylene group, said alkylene, arylene, alkarylene, or aralkylene group optionally containing one or more catenary oxygen atom, A is a (meth)acryl containing group of the formula $X^2-C(O)-C(R^3)=CH_2$, additionally wherein: X^2 is -O, -S, or $-NR^3$, R^3 is independently H, or C_1-C_4, and n = 1 to 5.

In some exemplary embodiments of the foregoing process, the at least one urea (multi)-urethane (meth)acrylate-silane precursor compound undergoes a chemical reaction to form the protective (co)polymer layer at least in part on the oxide layer. Optionally, the chemical reaction is selected from a free radical polymerization reaction, and a hydrolysis reaction. In any of the foregoing processes, each hydrolysable group Y is independently selected from an alkoxy group, an acetate group, an aryloxy group, and a halogen. In some particular exemplary embodiments of the foregoing articles, at least some of the hydrolysable groups Y are chlorine.

In some particular exemplary embodiments of any of the foregoing processes, step (a) includes (i) evaporating a base (co)polymer precursor, (ii) condensing the evaporated base

(co)polymer precursor onto the substrate, and (iii) curing the evaporated base (co)polymer precursor to form the base (co)polymer layer. In certain such exemplary embodiments, the base (co)polymer precursor includes a (meth)acrylate monomer.

In certain particular exemplary embodiments of any of the foregoing processes, step (b) includes depositing an oxide onto the base (co)polymer layer to form the oxide layer. Depositing is achieved using sputter deposition, reactive sputtering, chemical vapor deposition, or a combination thereof. In some particular exemplary embodiments of any of