and at least some of the second turning guides are adapted to support the substrate during a change in a direction of travel of the substrate toward the first precursor zone. In some embodiments, more than two precursor zones are provided, all precursor zones being isolated from one another. The substrate transport mechanism may include a payout spool and a take-up spool for roll-to-roll processing of the substrate.

[0008] A method of thin film deposition, according to one embodiment, includes introducing an inert gas into an isolation zone that is interposed between first and second precursor zones, introducing first and second precursor gases into the respective first and second precursor zones, and then guiding a flexible substrate back and forth between the first and second precursor zones and through a series of flow-restricting passageways of the isolation zone, so that the substrate transits through the first and second precursor zones multiple times. The method further includes generating pressure differentials between the isolation zone and the first precursor zone and between the isolation zone and the second precursor zone, the pressure differentials being sufficient to inhibit migration of the first and second precursor gases out of the respective first and second precursor zones and mixing of the first and second precursor gases within one of the zones, thereby essentially preventing reactions within the zones between nonadsorbed amounts of the first and second precursor gases. The pressure differential may be achieved, for example, by differential injection of gases into the various zones or by differential pumping or throttling of exhaust gases from the various zones. In some embodiments, an inert gas is injected into some or all of the passageways. As the substrate transits through the first precursor zone a monolayer of the first precursor gas is adsorbed to the surface of the substrate, and on a subsequent transit of the substrate through the second precursor zone the second precursor gas reacts with the adsorbed first precursor at the surface of the substrate, to thereby deposit a thin film on the substrate. Many layers of material may be deposited by guiding the substrate along a serpentine path that traverses between the first and second precursor zones many times.

[0009] In some embodiments of the method and system, the substrate is transported through three or more precursor zones, all isolated from one another by the isolation zone. One or more of the turning guides, precursors, precursor zones, isolation fluid, or isolation zone may be heated.

[0010] In some embodiments, the isolation and precursor zones may be operated at approximately atmospheric pressures, while in others the pressure may range from relatively low vacuum pressures (e.g. 0,13 Pa (1 millitorr)) to positive pressures of 667 to 2000 hPa (500 to 1500 Torr (approx. 1-2 atmospheres)).

[0011] In some embodiments of the method and system, the flexible substrate may be advanced continuously along a serpentine path in a first direction to complete a first pass, and subsequently rewound along the serpentine path in a second direction opposite the first direction to complete a second pass.

[0012] Embodiments of the method may also include the steps of switching precursors during or between passes, introducing dopants into one or more precursor zones, and/or introducing a radical into one or more of the precursor zones. A length or duration of some of the transits through the precursor zones may be adjusted, in some embodiments, by movably mounted turning guides or zone dividers.

[0013] Systems and methods for trapping exhaust precursor gases for disposal, recycling, or reclaim are also disclosed.

Brief Description of the Drawings

[0014] FIG. 1 is a schematic cross-sectional view illustrating a system and method for ALD on a flexible substrate, in accordance with a first embodiment;

[0015] FIG. 2 is a schematic cross-sectional view illustrating a system and method utilizing ALD for coating layers of different materials onto a flexible substrate, in accordance with a second embodiment;

[0016] FIG. 3 is a schematic cross-sectional view illustrating a system and method for ALD in which a substrate is moved through a linear multi-stage ALD reactor, in accordance with a third embodiment; and

[0017] FIG. 4 is a schematic cross-sectional view illustrating a system and method for ALD on a flexible substrate according to a fourth embodiment, including a precursor recovery and recycling system.

Detailed Description of Preferred Embodiments

[0018] In accordance with embodiments described herein, a flexible substrate, such as a plastic or metallic web or filament, for example, is threaded between adjacent zones each having a different precursor chemical or isolation fluid present therein. As the substrate is advanced, each segment of the substrate is preferably resident in the precursor zones long enough to accomplish the requisite adsorption and reaction of precursor chemicals on the substrate surface. An isolation zone interposed between the precursor zones prevents mixing of the different precursor gases. The substrate is moved through the zones to achieve a thin film coating consistent with the coatings deposited by conventional ALD processes. In addition to enabling the deposition of a highly conformal thin film coating on web materials and on other flexible elongate substrates, systems and methods according to the embodiments described herein may avoid the need to deliver into a common reaction chamber a sequence of precursor and purge gas pulses in alternating succession, as is done in a conventional traveling wave-type ALD reactor.

[0019] Among other possible benefits, certain systems and methods disclosed herein may facilitate the deposition of barrier layers and transparent conductors on flex-