devices, the flow profile tends to switch from laminar to turbulent or vice versa, as even minor changes in the fluid flow (in terms of time, velocity, chemical composition, etc.) are likely to affect the flow profile in an unpredictable manner.

Deposition times are mainly limited by long purging periods. In order to optimize deposition speed (in terms of time per deposition cycle, such as 0,5 – 20 seconds per deposition cycle, for example), fluidic flow through the deposition reactors should be as even as possible. In ALD, turbulence is likely to slow evacuation of pulsed chemicals that results in incomplete purge, whereupon the first precursor remains in the reaction space upon delivery of the second precursor thereto. The undesirable situation arises, when the second precursor reacts with the first precursor in a gas phase, which leads to particle formation. At worst scenario, such situation ruins the samples to be coated. In any case, presence of two precursors in the ALD reaction instead of one is likely to result in particle formation, coating non-uniformity and poor quality of the film, with such properties of the film impaired as electrical breakthrough voltage and increase particles.

In this regard, an update in the field of thin-film deposition technology is still desired, in view of addressing challenges associated with avoiding turbulence while providing efficient mixing of precursors in the thin-film deposition reactors.

SUMMARY OF THE INVENTION

Embodiments of the present invention solve or to at least alleviate each of the problems arising from the limitations and disadvantages of the related art. Disclosed herein are various embodiments of a fluid distributing device for a thin film deposition apparatus, a related apparatus, system and method.

Disclosed herein is a fluid distributing device for a thin-film deposition apparatus, comprising an expansion region comprising sub-regions for receiving fluid streams F1, F2 via at least one inlet arranged on each sub-region such that said fluid streams F1, F2 propagate through the sub-regions in directions essentially towards one another, and a transition region, in which fluid streams F1, F2 arriving thereto via the sub-regions combine, wherein each sub-region has an interior with a distance thereacross increasing on a cross-sectional plane between each inlet and the transition region to an expansion width D1 in a direction of fluid flow F1, F2; and wherein the transition region is configured to direct a combined fluid stream into a reaction chamber of the deposition apparatus, such that a flow F established at an entrance to the reaction chamber and propagating through the length of said reaction chamber is laminar.

According to a first aspect, there is provided a thin-film deposition apparatus including: a reaction chamber for accommodating substrates arranged with their side faces adjacent to each other; and a fluid distributing device, comprising an expansion region with sub-regions into which fluid streams F1, F2 are received via at least one inlet arranged on each sub-region such that said fluid streams F1, F2 propagate through the sub-regions in directions essentially

towards one another, and a transition region, in which fluid streams F1, F2 arriving thereto via the sub-regions combine; wherein each sub-region has an interior with a distance thereacross increasing on a cross-sectional plane between each inlet and the transition region to an expansion width D1 in a direction of fluid flow F1, F2; and wherein the transition region is configured to further direct a combined fluid stream into the reaction chamber, such that a flow F established at an entrance to the reaction chamber and propagating through the length of said reaction chamber, between the side faces of the substrates, is laminar.

In an embodiment, the apparatus comprises the fluid distributing device in which a fluidic flow established in the interior of each sub-region at a distance between the inlet and the transition region is laminar.

In an embodiment, the apparatus comprises the fluid distributing device in which the transition region is a channel with an entrance and an exit provided as openings having a width d2, d2’ and a length that extends at the distance D1 corresponding to the expansion width of each sub-region.

In embodiment, the apparatus comprises the fluid distributing device in which the transition region further comprises a constriction zone formed by inclination of lateral surfaces of the channel to a width d3 essentially constant at the distance D1.

In an embodiment, the apparatus comprises the fluid distributing device in which at least a portion of said channel has lateral surfaces inclined at a curvature.

In an embodiment, the apparatus comprises the fluid distributing device in which the sub-regions of the expansion region are disposed at a cross-sectional plane P1 essentially orthogonal to a longitudinal axis *Y* of the deposition apparatus.

In an embodiment, the direction of the fluid streams F1, F2 propagating through the expansion region is essentially perpendicular to the direction of fluid flow F propagating through the reaction chamber.

In an embodiment, the apparatus comprises the fluid distributing device in which the sub-regions of the expansion region are each disposed at cross-sectional planes P1’ and wherein each such plane P1’ is inclined by an angle alpha, α with regard to the cross-sectional plane P1. In embodiment, said cross-sectional planes P1’ are mirror-symmetrical.

In an embodiment, the apparatus comprises the fluid distributing device in which at the transition region each fluid stream F1, F2 makes a turn from the cross-sectional plane P1, P1’ to a cross-sectional plane P2 defined as a plane of symmetry for the sub-regions along the longitudinal axis *Y* of the deposition apparatus.

In an embodiment, the apparatus comprises the fluid distributing device in which the fluid distributing device further comprises a flow-shaping element configured to adjust a flow direction of fluid streams F1, F2 entering the transition region essentially towards the reaction chamber.

In an embodiment, the apparatus comprises the fluid distributing device which further

comprises a mixing arrangement in the transition region.

In an embodiment, the apparatus comprises the fluid distributing device which further comprises a plasma generating arrangement in the fluid distributing device, said plasma generating arrangement being optionally disposed in the transition region of the fluid distributing device.

In an embodiment, the reaction chamber of said apparatus has a constant cross-section throughout its length.

In an embodiment, in said apparatus, the transition region is established by a channel with an entrance opening and an exit opening, and wherein said entrance opening and/or said exit opening have the same cross-section as the reaction chamber.

In an embodiment, an interior of the reaction chamber of said apparatus dimensionally conforms to a predetermined number of substrates received thereinto.

In an embodiment, the apparatus is configured to deposit material on substrate surfaces by establishing a laminar flow F of a precursor fluid through the length of the reaction chamber, wherein the precursor fluid propagates between the side faces of said substrates with essentially uniform velocity at a leading edge.

In an embodiment, in said apparatus, the precursor fluid delivered into the reaction chamber comprises at least one precursor chemical.

In an embodiment, the precursor fluid is delivered into the reaction chamber of said apparatus in a number of sequential pulses.

In an embodiment, the apparatus is configured to deposit a coating film simultaneously on all substrate surfaces.

In an embodiment, the apparatus further comprises an exhaust conduit and an enclosure arranged essentially around said exhaust conduit and receiving fluid flowing from the reaction chamber through the conduit, wherein said exhaust conduit and said enclosure form an exhaust assembly configured to alter a direction of exhaust flow exiting the reaction chamber. In embodiment, in said exhaust assembly, the exhaust conduit and the enclosure form a passage, in which exhaust flow exiting the reaction chamber via the exhaust conduit makes a turn around a wall or walls forming said conduit, while remaining in the enclosure, to be further directed into an exhaust manifold via an aperture arranged on at least one side wall of the enclosure.

In an embodiment, the apparatus is configured as an apparatus for chemical deposition reactions. In embodiment, said apparatus is configured as an apparatus for Atomic Layer Deposition (ALD).

According to a second aspect, there is provided a method for depositing material on substrate surfaces in an apparatus for thin-film deposition, including: obtaining a thin-film deposition apparatus that comprises a reaction chamber for accommodating substrates arranged with their side faces adjacent to each other; and a fluid distributing device that comprises an

expansion region comprising sub-regions and a transition region; establishing a flow of fluid into the sub-regions via at least one inlet arranged on each sub-region such that fluid streams propagate through the sub-regions in directions essentially towards one another, wherein at least one fluid stream comprises at least one precursor; combining fluid streams in the transition region, whereby a precursor fluid is formed comprising at least one precursor, and further directing said precursor fluid into the reaction chamber; and depositing material on substrate surfaces by establishing a laminar flow of precursor fluid at an entrance to the reaction chamber and maintaining said laminar flow upon propagating said precursor fluid between the side faces of the substrates through the length of said reaction chamber, wherein each said sub-region has an interior with a distance thereacross increasing on a cross-sectional plane between each inlet and the transition region to an expansion width in a direction of fluid flow.

According to a third aspect, there is provided use of the above apparatus for depositing thin films of coating material on the substrate surfaces.

According to a fourth aspect, there is provided a thin-film deposition system comprising a number of the above apparatuses for thin film deposition, the apparatuses in said system are connected to one another in sequence and/or in an array.

In an embodiment, the apparatuses are arranged in said system such, as to receive a common precursor compound into at least two apparatuses.

According to a fifth aspect, there is provided a method for uniform distribution of fluids in an apparatus for thin-film deposition, including: obtaining a thin-film deposition apparatus that comprises a reaction chamber for accommodating substrates arranged with their side faces adjacent to each other; and a fluid distributing device that comprises an expansion region with sub-regions and a transition region; establishing a flow of fluid into the sub-regions via at least one inlet arranged on each sub-region such that fluid streams propagate through the sub-regions in directions essentially towards one another; combining fluid streams in the transition region, and directing a combined fluid stream into the reaction chamber such that a flow established at an entrance to the reaction chamber and propagating through the length of said reaction chamber, between the side faces of the substrates, is laminar, wherein each said sub-region has an interior with a distance thereacross increasing on a cross-sectional plane between each inlet and the transition region to an expansion width in a direction of fluid flow; wherein an interior of the reaction chamber dimensionally conforms to a predetermined number of substrates received thereinto; and wherein, at the transition region, each fluid stream makes a turn from the cross-sectional plane to a cross-sectional plane defined as a plane of symmetry for the sub-regions along a longitudinal axis of the deposition apparatus.

The utility of embodiments of the present invention arises from a variety of reasons depending on each particular embodiment thereof. Overall, the invention offers devices and methods for efficient mixing of precursor chemicals in the deposition apparatus and, at the same time, for establishing laminar flow conditions in chemical deposition reactions. Avoiding vorticity in ALD reactions allows for creating high-quality films with improved

thickness uniformity. By establishing and controlling laminar flow profiles, the invention allows for shortening purging periods and for speeding-up the overall production process.

In ALD implementation, laminar flow is maintained during both pulse- and purge phases. Establishing laminar flow conditions in purge phase allows for more efficient removal of fluids, such as gases, from the reaction space and for reducing time periods required for purging a predetermined (reaction chamber) volume, accordingly. Thus, fluid flowing laminar into the reaction space steadily and evenly "pushes away" precursor compounds and/or reaction products remaining, in the gaseous phase, from a preceding pulse.

In solutions that do not support laminar flow (prior art), concentration of said precursor compounds and/or reaction products in the reaction space is typically reduced by "diluting" with inert fluid. However, due to essentially turbulent flow conditions purging of the reaction chamber may last for a very long time (over 1 min, for example). In the apparatus presented hereby laminar flow conditions, established at an entrance to the reaction chamber and maintained upon propagating fluids through said reaction chamber, are close to that observed in laminar plugflow reactors.

The fluid distributing device according to embodiments of the present invention allows for keeping precursor chemicals, that arriving into the reaction chamber from the different sources, separated from one another thus effectively preventing said chemicals from mixing- and/or reacting with each other until they reach a predetermined space in the reactor apparatus. Film formation on the reactor surfaces preceding the reaction chamber is thus avoided. In the apparatus, precursor chemicals are guided straight into the reaction chamber without being allowed to reside on the undesired surfaces (due to untimely / too early mixing).

In embodiments of the apparatus presently disclosed, propagation of precursor compounds through the reaction space occurs one precursor at a time, which is made possible by improved flow velocity characteristics enabled, in turn, by the innovative configuration. The apparatus thus allows for avoiding problems commonly arising in the shower head reactors, for example, and associated with the so called CVD-type reactions (based on directing at least two precursors into the reaction space simultaneously) in the ALD reactors (based on subsequent directing the precursors in the reaction space so that chemicals do not mix).

Upon conducting chemical deposition reactions in the apparatus according to embodiments of the present disclosure, all substrates, such as wafer substrates, in the reaction chamber become deposited with a uniform layer of precursor so that the concentration of precursor is uniform across the individual substrate (side) surface and across the surfaces of all substrates in the reaction space. Due to its capacity to uniformly mix precursor chemicals and spread said mixed chemicals evenly onto all substrates

CLAIMS

1. A thin-film deposition apparatus (200) comprising:

- a reaction chamber (201) for accommodating substrates (10) arranged with their side faces adjacent to each other; and

- a fluid distributing device (100), comprising an expansion region (101) with sub-regions (101-1, 101-2) into which fluid streams (F1, F2) are received via at least one inlet (103) arranged on each sub-region such that said fluid streams (F1, F2) propagate through the sub-regions in directions essentially towards one another, and a transition region (102), in which fluid streams (F1, F2) arriving thereto via the sub-regions (101-1, 101-2) combine;

wherein each sub-region (101-1, 101-2) has an interior with a distance thereacross increasing on a cross-sectional plane between each inlet (103) and the transition region (102) to an expansion width (D1) in a direction of fluid flow (F1, F2); and

wherein the transition region (102) is configured to further direct a combined fluid stream into the reaction chamber (201), such that a flow (F) established at an entrance to the reaction chamber and propagating through the length of said reaction chamber, between the side faces of the substrates (10), is laminar.

2. The apparatus (200) of claim 1, comprising the fluid distributing device (100), in which a fluidic flow established in the interior of each sub-region (101-1, 101-2) at a distance between the inlet (103) and the transition region (102) is laminar.

3. The apparatus (200) of any one of claims 1 or 2, comprising the fluid distributing device (100), in which the transition region (102) is a channel (102A-102B) with an entrance (102A) and an exit (102B) provided as openings having a width (d2, d2') and a length that extends at the distance (D1) corresponding to the expansion width of each sub-region (101-1, 101-2).

4. The apparatus (200) of any preceding claim, comprising the fluid distributing device (100), in which the transition region (102) further comprises a constriction zone (104) formed by inclination of lateral surfaces (112, 121) of the channel (102A-102B) to a width (d3) essentially constant at the distance (D1).

5. The apparatus (200) of any preceding claim, comprising the fluid distributing device (100), in which at least a portion of the channel (102A-102B) has lateral surfaces inclined at a curvature.

6. The apparatus (200) of any preceding claim, comprising the fluid distributing device (100), in which the sub-regions (101-1, 101-2) of the expansion region (101) are disposed at a cross-sectional plane (P1) essentially orthogonal to a longitudinal axis (*Y*) of the deposition apparatus.

7. The apparatus (200) of any preceding claim, comprising the fluid distributing device (100), in which the direction of the fluid streams (F1, F2) propagating through the expansion region (101) is essentially perpendicular to the direction of fluid flow (F) propagating through the reaction chamber (201).

8. The apparatus (200) of any preceding claims 1-5, comprising the fluid distributing device (100), in which the sub-regions (101-1, 101-2) of the expansion region (101) are each disposed at cross-sectional planes (P1') and wherein each such plane (P1') is inclined by an angle (alpha, α) with regard to the cross-sectional plane (P1).

9. The apparatus (200) of claim 8, comprising the fluid distributing device (100), in which the cross-sectional planes (P1') are mirror-symmetrical.

10. The apparatus (200) of any preceding claim, comprising the fluid distributing device (100), in which, at the transition region (102), each fluid stream (F1, F2) makes a turn from the cross-sectional plane (P1, P1') to a cross-sectional plane (P2) defined as a plane of symmetry for the sub-regions (101-1, 101-2) along the longitudinal axis (*Y*) of the deposition apparatus.

11. The apparatus (200) of any preceding claim, comprising the fluid distributing device (100), in which the sub-regions (101-1, 101-2) have height (h1) essentially constant across the interior thereof.

12. The apparatus (200) of any preceding claim, comprising the fluid distributing device (100) that further comprises a flow-shaping element (105) configured to adjust a flow direction of fluid streams (F1, F2) entering the transition region (102) essentially towards the reaction chamber (201).

13. The apparatus (200) of any preceding claim, comprising the fluid distributing device (100) that further comprises a mixing arrangement (106) in the transition region (102).

14. The apparatus (200) of any preceding claim, further comprising a plasma generating arrangement (107) in the fluid distributing device (100), said plasma generating arrangement being optionally disposed in the transition region (102) of the fluid distributing device.

15. The apparatus (200) of any preceding claim, wherein the reaction chamber (201) has a constant cross-section throughout its length.

16. The apparatus (200) of any preceding claim, wherein the transition region (102) is established by a channel (102A-102B) with an entrance opening (102A) and an exit opening (102B), and wherein said entrance opening and/or said exit opening have the same cross-section as the reaction chamber (201).

17. The apparatus (200) of any preceding claim, wherein an interior of the reaction chamber (201) dimensionally conforms to a predetermined number of the substrates (10) received thereinto.

18. The apparatus (200) of any preceding claim, configured to deposit material on substrate surfaces by establishing a laminar flow (F) of a precursor fluid (12) through the length of the reaction chamber (201), wherein the precursor fluid propagates between the side faces of said substrates (10) with essentially uniform velocity at a leading edge.

19. The apparatus (200) of any preceding claim, wherein the precursor fluid (12) delivered into the reaction chamber comprises at least one precursor (12X, 12A, 12B, 12C, 12D, 12E, 12F, 12G).

20. The apparatus (200) of any preceding claim, wherein the precursor fluid (12) is delivered into the reaction chamber in a number of sequential pulses.

21. The apparatus (200) of any preceding claim, configured to deposit a coating film simultaneously on all substrate surfaces.

22. The apparatus (200) of any preceding claim, further comprising an exhaust conduit (41) and an enclosure (42) arranged essentially around said exhaust conduit (41) and receiving fluid flowing from the reaction chamber (201) through the conduit (41), wherein said exhaust conduit (41) and said enclosure (42) form an exhaust assembly configured to alter a direction of exhaust flow (Fex) exiting the reaction chamber (201).

23. The apparatus of claim 22, wherein the exhaust conduit (41) and the enclosure (42) form a passage, in which exhaust flow (Fex) exiting the reaction chamber (201) via the exhaust conduit (41) makes a turn around a wall or walls forming said conduit (41), while remaining in the enclosure (42), to be further directed into an exhaust manifold (40) via an aperture (42A) arranged on at least one sidewall of the enclosure (42).

24. The apparatus (200) of any preceding claim configured as an apparatus for chemical deposition reactions.

25. The apparatus (200) of any preceding claim configured as an apparatus for Atomic Layer Deposition (ALD).

26. A method for depositing material on substrate surfaces in an apparatus for thin-film deposition, comprising:

- obtaining a thin-film deposition apparatus (200) that comprises a reaction chamber (201) for accommodating substrates (10) arranged with their side faces adjacent to each other; and a fluid distributing device (100) that comprises an expansion region (101) comprising sub-regions (101-1, 101-2) and a transition region (102);

- establishing a flow of fluid (F1, F2) into the sub-regions (101-1, 101-2) via at least one inlet (103) arranged on each sub-region such that fluid streams (F1, F2) propagate through the sub-regions in directions essentially towards one another, wherein at least one fluid stream (F1, F2) comprises at least one precursor (12X, 12A, 12B, 12C, 12D, 12E, 12F, 12G);

- combining fluid streams (F1, F2) in the transition region (102), whereby a precursor fluid is formed comprising at least one precursor (12X, 12A, 12B, 12C, 12D, 12E, 12F, 12G), and further directing said precursor fluid into the reaction chamber (201); and

- depositing material on substrate surfaces by establishing a laminar flow (F) of precursor fluid at an entrance to the reaction chamber and maintaining said laminar flow upon propagating said precursor fluid between the side faces of the substrates (10) through the length of said reaction chamber,

wherein each said sub-region (101-1, 101-2) has an interior with a distance thereacross increasing on a cross-sectional plane (P1, P1') between each inlet (103)

and the transition region (102) to an expansion width (D1) in a direction of fluid flow (F1, F2).

27. The method of claim 26, wherein precursor fluid propagates between the substrates (10) with essentially uniform velocity at a leading edge.

28. Use of the apparatus (200), as defined in any one of claims 1-25 for depositing thin films of coating material on substrate surfaces.

29. A thin-film deposition system (500A, 500B, 500C, 500D) comprising a number of apparatuses (200), as defined in any one of claims 1-25, connected to one another in sequence and/or in an array.

30. The system of claim 29, in which the apparatuses (200) are arranged such, as to receive a common precursor compound (12X, 12A, 12B, 12C, 12D, 12E, 12F, 12G) into at least two apparatuses.

31. A method for uniform distribution of fluids in an apparatus for thin-film deposition, comprising:

- obtaining a thin-film deposition apparatus (200) that comprises a reaction chamber (201) for accommodating substrates (10) arranged with their side faces adjacent to each other; and a fluid distributing device (100) that comprises an expansion region (101) with sub-regions (101-1, 101-2) and a transition region (102);

- establishing a flow of fluid (F1, F2) into the sub-regions (101-1, 101-2) via at least one inlet (103) arranged on each sub-region such that fluid streams (F1, F2) propagate through the sub-regions in directions essentially towards one another;

- combining fluid streams (F1, F2) in the transition region (102), and

- directing a combined fluid stream into the reaction chamber (201) such that a flow (F) established at an entrance to the reaction chamber and propagating through the length of said reaction chamber, between the side faces of the substrates (10), is laminar,

wherein each said sub-region (101-1, 101-2) has an interior with a distance thereacross increasing on a cross-sectional plane (P1, P1') between each inlet

(103) and the transition region (102) to an expansion width (D1) in a direction of fluid flow (F1, F2);

wherein an interior of the reaction chamber (201) dimensionally conforms to a predetermined number of substrates (10) received thereinto; and

wherein, at the transition region (102), each fluid stream (F1, F2) makes a turn from the cross-sectional plane (P1, P1') to a cross-sectional plane (P2) defined as a plane of symmetry for the sub-regions (102-1, 102-2) along a longitudinal axis (*Y*) of the deposition apparatus.