

Method and device for coating substrates

Description

The invention relates to a method for coating a substrate and a device for coating a substrate.

In the prior art, the application of a polymer on the surface of a substrate takes place as follows. The substrate, in particular a wafer, is fixed at the underside on a horizontal rotary plate, the sample holder (engl.: chuck) by means of a vacuum suction system. A predefined quantity of a polymer solution, which is mixed with solvent - referred to below solely as a film layer material, is applied with a metering device via the centre of the wafer. The film layer thickness is dependent on the viscosity of the polymer solution, the rotational speed, the rotational acceleration and the process duration of the spin-coating. The final rotational speed and the process duration are controlled on the spin-coater depending on the desired result and the film layer material is distributed from the delivery point, i.e. the approximately concentric centre of the substrate, towards the radially symmetrical edge of the substrate. Any excess film layer material is spun off from the substrate. As a rule, solvent-containing polymer solutions are used for this. The solvent proportion is intended to serve to reduce the viscosity and thus to assist the uniform distribution of the polymer solution on the wafer. The reduced viscosity accelerates the production of the film layer. As a result of the reduction of the viscosity of the polymer solution extending over all areas of the wafer, a particularly large amount of excess material is spun off over the edge of the substrate. To be able to produce a stable film layer, it is necessary in

spent on baking out the solvent present in the individual film layers increases proportionally.

Conversely, it is of course the case that the thinner the film layer is formed, the baking-out time is reduced accordingly. The thickness of the film layer cannot however be freely selected, but rather is determined by the given demands on such a film layer. Notwithstanding this, it is the case that the process step of baking-out when using solvent-containing polymer solutions is absolutely essential and at all events has the effect of impeding the process flow.

The problem as per embodiments of the present invention, therefore, is to develop the generic devices and methods for coating substrate in such a way that efficient coating is enabled, in particular when used in bonding.

According to an aspect, there is provided a device for coating a substrate with a film layer, characterised in that the device comprises application means for applying a thermoplastic film layer material and distribution means for distributing the film layer material on the substrate for the formation of the film layer, wherein the application means comprise at least one extruder device.

All combinations of at least two features given in the description, in the claims and/or the drawings also fall within the scope of the invention. In the case of value ranges, values lying inside the stated limits are also deemed to be disclosed as limiting values and can be claimed in any combination.

The basic idea of embodiments of the present invention is to use an in particular solvent-free thermoplastic for the coating of a substrate with a film layer, said thermoplastic being applied by means of a device (application means) suitable for applying the thermoplastic.

Embodiments of invention relate in particular to a method and a device, with which coating, preferably spin-coating, of a substrate, in particular a wafer, takes place with an in particular solvent-free thermoplastic.

Embodiments of invention describe in particular a method and a device, which provides for the use of an in particular solvent-free thermoplastic for the production of film layers on substrates. The addition of solvents to reduce the viscosity is preferably thereby completely dispensed with.

Moreover, embodiments of the invention relate in particular to a device with which it is possible to distribute the thermoplastic serving to produce a film layer uniformly on a substrate surface, in particular irrespective of the form in which it is present. Uniform distribution is understood here to mean both the homogeneity of the applied material and also the film layer thickness.

In principle, the use of all known types of thermoplastics is conceivable. According to embodiments of the invention, the following are preferred, individually or in combination:

- bonding adhesives, in particular
 - cycloolefin copolymers
- polyethylene (PE),
- polypropylene (PP),
- polystyrene (PS),
- polyvinyl chloride (PVC),
- polyamide (PA),
- polyimide (PI),
- polymethyl methacrylate
- acrylonitrile butadiene styrene (ABS) with a melting temperature of 220 - 250 °C,
- polyamides (PA) with a melting temperature of 178 - 260 °C,

- polyactides (PLA) with a melting temperature of 150 - 160 °C,
- polymethyl methacrylate (PMMA) with a melting temperature of 105 °C,
- polycarbonate (PC) with a melting temperature of 280 - 320 °C,
- polyethylene terephthalate (PET) with a melting temperature of 250 - 260 °C,
- polyethylene (PE) with a melting temperature of 80 - 100 °C, (PE-LD, 80 °C), (PE-HD, 100 °C), (PE-LLD, 30-90 °C),
- polypropylene (PP) with a melting temperature of 160 - 165 °C, in particular with the addition of small amounts of solvents,
- polystyrene (PS) with a melting point of 240 °C in the case of isotactic PS and 270 °C in the case of syndiotactic PS,
- polyether ether ketone (PEEK) with a melting point of 280 °C,
and/or
- polyvinyl chloride (PVC) with a melting point of 79 °C, in particular with the addition of solvent.

In addition, thermoplastics not yet known today are also intended which in characteristics, i.e. material behaviour etc., have similar properties to the aforementioned film layer materials. These include in particular mechanical properties, especially the melting temperature.

Embodiments of the invention in particular make provision for the use of a solvent-free thermoplastic for producing a film layer on a substrate, in particular a wafer.

Thermoplastic is a plastic which, depending on the ambient parameters such as pressure, temperature, can basically have four different aggregate

states, namely solid, thermoelastic, thermoplastic and liquid. According to embodiments of the invention, thermoplastics are preferably used that do not cross-link and can be liquefied and hardened repeatedly, in particular with arbitrary frequency, in a reversible manner.

The thermoplastic is applied on the surface of a substrate by an application means. The application means is in particular an extruder. In order to bring about, via an extruder device, an application of a thermoplastic (generally: film layer material) that is present in particular in solid form in the extruder device, the aggregate state of the film layer material is changed from solid to liquid by the supply of heat, in particular in the extruder device. This preferably takes place by means of a heat source present in the extruder. As a result of the change in the aggregate state, it is possible to deliver the film layer material via the extruder onto the substrate surface. The quantity of the film layer material to be applied on the substrate surface is dependent on the desired film layer thickness.

The application means comprise in particular an opening via which the thermoplastic exits. The opening can in particular be swept with gases and/or gas mixtures in order to prevent premature oxidation of the thermoplastic. The gases used are preferably

- Noble gases, in particular
 - Ar, He, Kr, Xe,
- Inert gases
 - N₂, CO₂

The extruder operates in particular at a processing temperature between 25 °C and 500 °C, preferably between 50 °C and 500 °C, still more preferably between 100 °C and 500 °C, most preferably between 250 °C and 500 °C, with utmost preference between 300 °C and 500 °C.

The extruder operates in particular at a processing pressure between 1 bar and 1000 bar, more preferably between 10 bar and 1000 bar, most preferably between 100 bar and 1000 bar, with utmost preference between 500 bar and 1,000 bar.

In order to be able to maintain the aggregate state and in particular the viscosity also during the delivery of the film layer material onto the substrate, provision is made according to an embodiment of the invention to supply heat in particular in a narrow temperature range. This temperature range is material-dependent and is derived from the viscosity curve.

Some viscosity curves have a viscosity minimum of the viscosity as a function of the temperature. The limits of the preferred temperature range according to embodiments of the invention are indicated as plus/minus values in relation to this viscosity minimum. The temperature range lies in particular between -50 °C and +50 °C, preferably between -30 °C and +30 °C, still more preferably between -10 °C and +10 °C, still more preferably between -5 °C and +5 °C, most preferably between -1 °C and +1 °C around the temperature value at which the viscosity minimum of the viscosity curve is located. The viscosity minimum of the viscosity curve is preferably a global minimum. If the viscosity curve has a number of minima and if it proves to be expedient, it may be advisable according to embodiments of the invention to select a non-global minimum.

If the viscosity curve does not have a minimum, but rather exhibits a continuous decline of the viscosity with increasing temperature, a temperature is preferably selected at which the viscosity of the thermoplastic is correspondingly low. This temperature preferably lies

above 25 °C, preferably above 50 °C, still more preferably above 100 °C, most preferably above 150 °C, with utmost preference above 250 °C.

By means of a temperature range selected as narrow as possible, the low viscosity of the film layer material present during the application onto the substrate is kept as constant as possible at least at the start of the distribution and the film layer material is distributed homogeneously on the substrate. The addition of solvent for the purpose of reducing the viscosity is for this reason unnecessary throughout the entire process of distributing the film layer material.

The application of the film layer material preferably takes place at a central point, in particular approximately in the concentric centre of the substrate. Following the delivery of the film layer material from the extruder device onto the substrate surface, the film layer material is distributed over the entire area of the substrate (distribution means), especially by rotation means.

Since cooling that starts after the delivery of the thermoplastic onto the substrate could impede the uniform distribution, the sample holder receiving the substrate can be heated according to an embodiment of the invention with a heating device, in particular integrated into the sample holder. In a particular embodiment of the invention, the sample holder is heated to the same temperature as the application means, in particular the extruder, in order for the most part to prevent cooling of the polymer to be applied.

In an embodiment of the heating device, the latter comprises separately controllable heating zones, which in a particularly advantageous embodiment are arranged in an annular manner, in particular

concentrically, on the sample holder or are integrated therein. In particular, partial annular heating of the substrate can thus take place depending on a temperature profile previously prepared for the given case of application. As a result of the separately controllable heating zones, the adjustment of a heating profile, and therefore of a temperature distribution with which the temperature is given as a function of the radial position, is possible.

On the basis of the fact that the flow rate of the solvent towards the radially symmetrical edge increases with widening with a constant rotational speed, the viscosity of the film layer material can be influenced by a differing exposure to heat along concentric sections. The viscosity is preferably kept lower in the centre than towards the edge, in order to promote a more rapid distribution into the radial edge region. The viscosity is preferably reduced towards the edge region, in order to reduce to a minimum excessive spinning-off of film layer material over the lateral edge of the substrate or even to prevent it completely.

According to a further advantageous embodiment, provision is made such that the first substrate and/or the second substrate is rotated during the application of the film layer. The rotational speed of the substrate fixed on the sample holder that is to be applied at the minimum to produce the desired film layer is not solely dependent on the in particular locally controlled heat input and the possibility thus arising of changing the viscosity. On the contrary, an optimum distribution can be brought about by a combination with a rotation speed, without excessive film layer being wasted.

In an embodiment of the invention, the melt flow index (engl.: mass flow rate, MFR) of the film layer material is particularly decisive for the

adjustment of the rotation and/or the temperature, since said melt flow index characterises the flow behaviour and the time when the flowability of the thermoplastic used is reached. The melt flow index is determined for a defined temperature and a defined pressure. The measurement preferably takes place in a capillary rheometer. The sample to be investigated is heated to a defined temperature and pressed by an application of pressure, in particular by a calibration weight, through a capillary. The measured mass per time unit, in particular per 10 minutes, is then a measure for the melt flow index. The unit of the melt flow index is given in $\text{g}/(10 \cdot \text{min})$. The greater the value, the less viscous the thermoplastic. Since the melt flow index applies to a specific temperature and a specific pressure, guidance values are stated here for wide temperature and/or pressure ranges. The melt flow index of the film layer material is in particular greater than $10\text{E-}3 \text{ g}/(10 \cdot \text{min})$, preferably greater than $10\text{E-}1 \text{ g}/(10 \cdot \text{min})$, still more preferably greater than $10 \text{ g}/(10 \cdot \text{min})$, most preferably greater than $100 \text{ g}/(10 \cdot \text{min})$, with utmost preference greater than $1000 \text{ g}/(10 \cdot \text{min})$.

By means of annular heating elements which can be heated separately and in a differentiated manner and which extend around the concentric centre of the sample holder, it is possible to heat the radial edge region of the substrate less intensively, which has a direct influence on the viscosity in these regions. For this purpose, the heating elements are heated in such a way that the heat input becomes less from the concentric centre of the sample holder towards the radially symmetrical edge region, wherein the flow rate is in particular kept constant.

According to embodiments of the invention, an increase in the viscosity in the radially symmetrical edge region of the substrate is preferred, and resulting

therefrom a reduction in the film layer material being spun out over the edge of the substrate.

The creation of associated sets of parameters (formulations) for controlling the rotation, in particular the rotational speed and therefore the centrifugal forces, and the heat input, in particular in preferably separately controlled heating elements of the sample holder, represents an embodiment of the present invention. The thermoplastic properties of the given film layer material are preferably taken into account, in particular by the creation of specific sets of parameters for each film layer material or for each combination of a film layer material and a substrate. The following, in particular typical, sets of parameters and formulations are stated by way of example, but are not limiting.

Rotational speed (rpm)	Acceleration (rpm/s)	Temperature (°C)
100-10000	100-5000	25-500
100-10000	100-5000	100-500
100-5000	100-5000	100-500
100-2500	100-5000	100-500

In particular, in addition to the centrifugal forces, acting Coriolis forces are taken into account in the creation of the formulations. The Coriolis force is directly proportional to the angular speed of the rotating substrate, and directly proportional to the speed of the propagating thermoplastic. It can thus be reduced by a reduction in the angular speed and/or the speed of the propagating thermoplastic. If, for example, the speed of the propagating thermoplastic is increased due to a higher temperature and an associated lower viscosity, the angular speed can be

reduced correspondingly, in order to reduce or to prevent the Coriolis force. In particular, the desired layer thickness is also taken into account, so that the parameters are in particular set in such a way that the requirements for the distribution of the thermoplastic on the substrate are complied with. The parameters can in particular be determined empirically.

A process according to embodiments of the invention for coating substrates with thermoplastic in the semiconductor industry can be improved in particular by the fact that the film layer material is applied, in particular deposited, continuously in a rod-like form, continuously as roll material or as ready-made pads, by means of at least one application means onto the substrate, in particular a wafer. The film layer material is preferably applied in combination with a sample holder forming a plurality of heating zones. The application means then acts as a kind of glue gun. The supply of rods or pads by means of an extruder is also conceivable, as long as the latter can be processed with the extruder.

In an embodiment of the invention, the thermoplastic is fed as a granulate to the application means, in particular to the extruder.

By the use of a thermoplastic comprising in particular a solvent proportion less than 80 %, preferably less than 60 %, still more preferably less than 40 %, much more preferably less than 20 %, most preferably less than 1 %, with utmost preference a solvent-free thermoplastic, the time-intensive baking-out of a solvent at different temperatures is completely eliminated or is at least markedly reduced. Moreover, an increased rotational speed, which serves to reduce the solvent, can be dispensed with. A higher throughput is thus achieved, to which particular

Moreover, the embodiments of invention is based on the idea of developing a method and a device with which it is possible, by means of an application means, in particular an extruder, to implement the application of an in particular solvent-free thermoplastic in a controlled manner for the production of a predefined film layer onto substrates used in the semiconductor industry.

An alternative device according to embodiments of the invention comprises:

- an application means, in particular an extruder device, for the controlled heating and delivery of an in particular solvent-free thermoplastic onto a substrate to be processed,
- a sample holder comprising a multiplicity of heating elements, in particular constituted in an annular form, which can be completely integrated into the sample holder, and
- a heating device with an associated control, which in particular is set up in such a way that the temperature on the application means, in particular on the extruder device, and the heating of the sample holder can be regulated independently of one another.

In particular, a multiplicity of heating elements is disclosed, which can be heated independently of one another, preferably steplessly, and which can also be part of the sample holder. The heating elements can preferably be actively cooled in order that cooling to a desired temperature can take place more quickly. The number of heating elements therefore amounts to at least two heating elements, preferably more than two heating elements, most preferably more than ten heating elements, with utmost preference more than 20 heating elements. In cross-section, the heating elements are in particular constituted rectangular, in order to enable a plane-parallel contact directly or indirectly with the substrate. In principle, however, any other cross-sectional geometry is also conceivable that enables a

claimed contact heat transfer. The heating elements can moreover be spaced apart from one another and/or be isolated, in order to prevent an uncontrolled and undesired release of heat to adjacent heating elements and therefore heating zones.

An individual heating element can also take effect as an independently operating heating zone. Similarly, it is advantageously possible to combine a plurality of heating elements to form a heating zone, i.e. to form groups and to control the latter by means of the control unit.

The heating elements extend in particular over the entire sample holder and are preferably arranged in an annular manner around the concentric centre of the sample holder. The heating elements can be both an integral component of the sample holder and can also comprise individual segments, which are in contact with the underside of the sample holder in a plane-parallel manner and thus enable an indirect heat transfer. The side of the sample holder facing the substrate, which is provided as a contact face with the substrate, is preferably constituted plane-flat.

The method and the device are operated, in particular in an automated manner, with tried and tested formulations, in particular empirically optimised value-collections of parameters (sets of parameters), which are connected functionally and in terms of the process. The use of formulations is therefore particularly important for the device and the method according to embodiments of the invention, because a reproducibility of process sequences can thus be guaranteed, which in turn directly influences the quality of the result to be expected. Moreover, a greater ease of operation of the device according to embodiments of the invention thus arises.

Notwithstanding this, a manual control by a machine operator is also conceivable.

The substrates (first and/or second substrate) are preferably wafers. The wafers are standardised substrates with defined, in particular standardised, diameters. Standardised diameters of 1, 2, 3, 4 inches or 125 mm, 150 mm, 200 mm, 300 mm or 450 mm are preferably selected as diameters of the substrates. The coating of rectangular substrates is however also conceivable.

According to an advantageous embodiment, the aforementioned devices are located at least partially, preferably completely in an evacuable and/or heatable environment, preferably in a process chamber, which in particular can be swept with gas, in order to create ideal conditions for a subsequent bonding process. The method according to embodiments of the invention takes place at least partially, preferably completely, in the bonding chamber, wherein in particular the first substrate is bonded with the second substrate as an additional step at the end. The process chamber can in particular be evacuated to a pressure of less than 1 bar, preferably less than 10^{-3} mbar, still more preferably less than 10^{-4} mbar, most preferably less than 10^{-5} mbar, with utmost preference less than 10^{-6} mbar.

The method according to embodiments of the invention in particular makes provision to place an in particular preheated carrier substrate, preferably a polymer substrate, onto a heatable sample holder and then to adjust it to the temperature of the sample holder. After the adjustment of the temperature has taken place, the application of the thermoplastic (generally: film layer material), in particular a plastomer, takes place by means of the application means, in particular the extruder device, onto the surface of the substrate. The application can in particular take place at the moment

The melt flow index of the film layer material, in particular a thermoplastic, is specific to the film layer material used. Some thermoplastics, also able to be used according to embodiments of the invention, can achieve a flowable state only with the addition of solvent such as for example acetone. These kinds of thermoplastics are also claimed according to embodiments of the invention, since only very small quantities of solvent need to be added (compared to the methods known in the prior art), in order to achieve the flowability/flow rate aimed at according to embodiments of the invention. The thermal input to achieve a flowable state of the film layer material, in particular a thermoplastic, lies in particular in a range from 80 - 280 °C.

The thermal input preferably takes place in such a way that, in the region of the concentric centre on the substrate surface, a temperature is reached at which an optimum melt flow index is present for the film layer material used, which enables the thermoplastic to exit from the extrusion opening in a suitable quantity per unit of time. The heating means are moreover suitable for holding this temperature, in particular in a controlled manner, permanently or constantly between -20 °C and +20 °C, preferably between -10 °C and +10 °C, still more preferably between -5 °C and +5 °C, most preferably between -2 °C and +2 °C, with utmost preference between -1 °C and +1 °C, of the specified or adjusted temperature.

In particular, the heat input in the vicinity of the concentric centre of the substrate is higher than in the radially symmetrical edge region of the substrate, where spinning-off of excess film layer material is prevented as far as possible or at least markedly reduced by a higher viscosity.

The heat input to be adjusted is thus primarily determined by the melt flow index and/or the critical temperature applicable to the film layer

material used, at which critical temperature a thermal decomposition occurs. The range of the heat input can be such that the film layer material used passes through all the aggregate states from the application means, in particular the extruder device, up to the distribution in the radially symmetrical edge region of the substrate.

In an embodiment of the invention, a substrate coated, in particular lacquered, by means of the inventive process or the inventive embodiment, is bonded after the coating, in particular immediately. According to embodiments of the invention, evaporation of a solvent in particular is no longer necessary, which markedly improves the process time between the lacquering and the bonding. The time between the end of the coating and the start of the bonding process is in particular less than 10 minutes, preferably less than 5 minutes, still more preferably less than 3 minutes, most preferably less than 1 minute, with utmost preference less than 30 seconds. Such short time intervals cannot be achieved with evaporation steps and therefore represent a decisive improvement of embodiments of the invention.

In a first embodiment of a process of the invention, the following steps take place, in particular in this sequence.

In the first process step, a substrate, in particular a carrier substrate, is loaded onto an in particular temperature-regulated sample holder.

In a second process step, the substrate is brought to the temperature of the sample holder.

In a third process step, the substrate is accelerated to a preset rotational speed.