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(54) **Title:** A RESISTIVE EVAPORATOR FOR USE IN THE VACUUM DEPOSITION PROCESSES

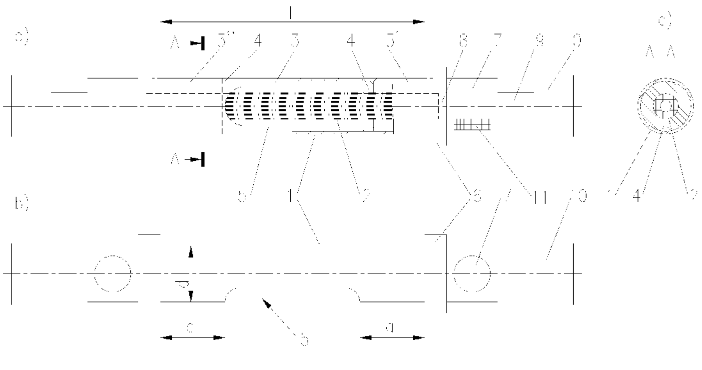

Fig.1

(57) **Abstract:** The invention relates to devices for vacuum evaporation of metals and alloys. It may be used, for example, for depositing comparatively thick coatings onto roll substrates and disperse materials in lengthy processes, as well as for producing free metal foils. The evaporator includes a thin-wall pipe (1) with a porous core (2) symmetrically installed inside the pipe. Thereby a semiclosed space between pipe (1) and porous core (2) is formed. Zone (3) of the said space is an evaporation chamber, which is located in the middle part of the evaporator. A vapour output aperture (5) is made in the pipe opposite the evaporation chamber. The vapour flows through the said aperture (5) and the coating is deposited onto a substrate. In accordance with this invention additional partitions (4) and fluctuation damping chamber (3') and (3") are formed at both sides of the evaporation chambers. In the said fluctuation damping chambers pipe (1) has no apertures for vapour output in the substrate direction. Molybdenum contacts (6) fit in both ends of the pipe and porous core in order to provide reliable electrical and mechanical contact.

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A RESISTIVE EVAPORATOR FOR USE IN THE VACUUM DEPOSITION PROCESSES

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FIELD OF THE INVENTION

The present invention relates to devices for vacuum evaporation of metals and alloys. It may be used, for example, for depositing comparatively thick coatings onto roll substrates and disperse materials in lengthy processes, as well as for producing free metal foils.

BACKGROUND OF THE INVENTION

It is necessary to evaporate considerable amount of the material in order to implement highly productive processes and deposit thick coatings in vacuum. Usually deposited material feeding into the evaporator during the deposition process is used in order to evaporate so big amount of the material. The material may be fed into the evaporator as wires, pellets, powder and other forms. Sometimes the material is fed into the evaporator in a liquid phase.

Vacuum evaporation devices are well known in the field of depositing materials onto various substrates.

Thus, US patent No. 5230923 offers the device of feeding silicon, silicon oxide or mixture of these materials with some additives of other materials for continuous evaporation in order to coat polymeric films. Tin, indium and aluminium are mentioned as other materials. During the deposition process the evaporated material is fed as tablets, small cylinders, wires, powder etc. into the evaporator though its input aperture.

At the opposite end of the evaporator there is an aperture for excess evaporated material withdrawal in order to provide evaporation uniformity. The device is designed for lengthy continuous evaporation of the material. Yet using a moving mechanical device (in the form of an endless belt or pusher) under vacuum conditions for feeding the evaporated material complicates the process considerably and decreases reliability of the device. As special moving aids for withdrawing excess material are not provided, it is evident that operation of the feeding device may be facilitated also by withdrawal of excess material (in spite of the fact that at least a part of this material may be in a melted form). Reliability of this system lengthy operation gives rise to doubt. Slightest solidification of the material near output aperture will cause beginning of the process blocking out. At large, reliability of such device operation under vacuum and comparatively high temperature conditions is unsatisfactory.

A paper at the 51st Annual Technical Conference of the Society of Vacuum Coaters “Wire Fed Evaporation of Copper from Refractory Metal Boats” of I. Ashmanis et al. offers the vacuum evaporation device, which is considered as the prior art (I. Ashmanis, V. Kozlov, E. Yadin, J. Vilks, “Wire Fed Evaporation of Copper from Refractory Metal Boats”, Society of Vacuum Coaters, Proceedings of the 51st Annual Technical Conference”, 2007).

The prior art evaporation device is a unit of two tubular evaporators, which are installed on current-carrying posts. The device also contains the mechanism of copper wire feeding and a system of shields. Each tubular evaporator is a linear structure, which consists of a thin-wall pipe (shield) and porous core and the latter is installed concentrically inside the pipe. The ends of the pipe and porous core are pushed in molybdenum contacts in order to provide reliable electrical and mechanical contact. Copper vapour output apertures are formed in the pipe part, which looks at the substrate. The molybdenum contacts are provided with drill holes in order to form a wire melting chamber and channels for melted copper feeding to the porous core. The evaporator is heated by direct passage of current owing to comparatively high electrical resistance of the evaporator.

Such device operates quite well while copper wire feeding is comparatively high, but when the wire feeding is decreased to
5 – 6 g/min. and lower, the evaporator operation troubles are observed. At low speed of the wire

feeding the evaporator current fluctuation develops and the evaporation rate becomes unstable, it deteriorates uniformity of the deposited coatings. It occurs due to the situation that during the wire melting at decreasing feeding speed to 5 – 7 g/min. the melted metal under the force of surface tension is wrapped into a globule. The globule tears away from the contact and hovers at the copper wire end above the melting chamber. The wire continues to melt and the globule grows. After achievement the size when the gravity force exceeds the force of surface tension the globule tears away from the wire and drops into the melting chamber, further it wets the porous core, flushes along its entire length and evaporates. Meanwhile the wire feeding into the melting chamber continues. As soon as the wire end touches the contact, the wire starts to melt, the melted material tears away from the contact, is wrapped into a globule and the above-described cycle repeats.

It is known that feeding wires of fusible metals (e.g. indium) into the evaporator is problematic due to low melting temperature. In this case the evaporated metal is fed into the evaporator in liquid form. During indium evaporation formation of small indium globules at the metal line end and evaporation fluctuation are sometimes also observed, if metal feeding speed is below 5 – 6 g/min.

The applicant used the offered technical solution for evaporating copper wire of 1.5 mm diameter at the feeding speed 10, 8, 5 and 3 g/min. If value of the evaporator power supply voltage is properly selected, no problems were observed while evaporating copper at wire feeding speed 10 and 8 g/min. Testing of the deposited coating thickness on a polymeric film showed the coating non-uniformity did not exceed ±5%.

After decreasing the copper wire feeding speed to 5 g/min. current fluctuation at average interval about 6 seconds was observed. The globules of 5 – 6 mm in diameter were periodically appearing at the wire end. Testing of the deposited coating thickness on a polymeric film testified that under such operation conditions the coating thickness variation was significant, while thickness non-uniformity of the deposited coating exceeded ±40%. During evaporation of other materials (including indium, silver) the process instability was even higher.

SUMMARY OF THE INVENTION

It is an object of the present invention to expand the evaporator process capabilities by stable evaporation of various metals at a wide range of evaporation rates. The process stability depends on compatibility of the evaporated metal melting temperature and evaporation rate provided by the apparatus. The wide range of evaporation rates of the apparatus expands its applicability.

Expansion of the evaporator application may be also provided by its usage in combination with a magnetron sputtering device. Those qualified in the field well know that some materials are better to be thermally evaporated while others are better sputtered. If necessary coating should be composed of the metals or alloys of these different groups, this invention may be used when one metal of the first group, e.g. copper, is thermally evaporated with the offered boat, while another metal or alloy of the second group, e.g. nichrome, is sputtered with the magnetron sputtering device. In this case the offered technical solution allows better co-ordination of deposition rates from both the evaporation and magnetron sputtering sources.

One more application of the invention may be simultaneous evaporation of copper and indium from two separate thermal evaporators and depositing copper and indium alloy onto one substrate. In this case the offered technical solution allows changing copper and indium ratio in the coating up to ten times, thus determining most appropriate process conditions and manufacturing the material with necessary properties.

The offered evaporator may be also used for coating a variety of substrate materials, including heat-sensitive polymer films without their excessive heating during the deposition process, which also expands application of the apparatus. For this purpose the offered boat design allows achieving a low evaporation rate with correspondingly low heat flow and proportionally low substrate temperature.

BRIEF DESCRIPTION OF DRAWINGS

The devices according to this invention for wire-feeding metal evaporation are shown in Fig. 1 and 2.

Fig. 1 shows the evaporator design, including: a) – side-view, b) - plan view, c) – evaporator cross-section along A-A plane. Fig. 2 shows one of possible layouts of the evaporator installation in a vacuum chamber.

Fig. 3 shows the device according to this invention with feeding fusible metal into the evaporator in a liquefied form.

DETAILED DESCRIPTION OF THE INVENTION

The evaporator includes a thin-wall pipe 1 with a porous core 2 symmetrically installed inside the pipe. Thereby a semiclosed space between pipe 1 and porous core 2 is formed.

Zone 3 of the said space is an evaporation chamber, which is located in the middle part of the evaporator. A vapour output aperture 5 is made in the pipe opposite the evaporation chamber. The vapour flows through the said aperture 5 and the coating is deposited onto a substrate. In accordance with this invention additional partitions 4 and correspondingly fluctuation damping chamber 3' and 3" are formed at both sides of the evaporation chambers. In the said fluctuation damping chambers pipe 1 has no apertures for vapour output in the substrate direction.

Molybdenum contacts 6 fit in both ends of the pipe and porous core in order to provide reliable electrical and mechanical contact. The pipe 1 may be turned about its axis in the contacts 6 in order to direct the vapour flow in any necessary direction.

The molybdenum contacts are provided with drill holes in order to form a melting material chamber 7 and channels 8 for the melted material feeding to the porous core 2. The chamber 7 serves for melting of the evaporated metal wire or for admission of the evaporated metal in the liquefied form. The melted metal is further canalized to the porous core 2.

Thermal bridges 9 are formed in order to provide necessary temperature difference between the melting chamber 7 and an end contact 10. An insert 11 of the material resistant to the evaporated metal melt is placed in the chamber 7 bottom in the point of the evaporated material feeding in order to increase the evaporator life. The evaporator end contacts 10 fit in cooled copper current leads 12 (see Fig. 2) through graphite gaskets (not shown). The current leads 12 are made of one-piece high-melting material, e.g. copper.

Fig. 2 also shows a substrate 16 and layout of the evaporator mounting in a vacuum chamber 17. For the evaporator heating and stable operation a power supply 18 of corresponding output voltage mean-square value is used. Water is fed and drained through channels 19 in order to cool the end contacts 10.

A feeding mechanism with an evaporated material reserve for the whole operation cycle is necessary in order to supply the evaporated material into the evaporator. Fig. 2 shows a mechanism 13 for the evaporated material feeding in the wire form as an example. A spool 14 contains necessary amount of evaporated wire 15. The coating is deposited onto a substrate 16.

Fig. 3 shows the device for feeding fusible metal into the evaporator in a liquefied form. In this case the evaporated metal is fed into the melting chamber 7 in the liquid form. Apart from the above-mentioned elements the evaporator also contains a heated tank 20 with liquefied metal and heated metal pipeline 21 for feeding liquefied metal into the chamber 7 through funnel 22.

The evaporator operates in the following way.

When pressure in the vacuum chamber 17 achieves 0.1 mtorr the evaporator power supply is switched on. Voltage is gradually supplied to the evaporator, which is mounted in the cooled contacts 12. Maximum value of the voltage depends on the evaporator dimensions, evaporated material and necessary evaporation rate. It is determined experimentally during the evaporator installation. After bringing the evaporator to stable operation the wire feeding mechanism is switched on. The wire 15 from the spool 14 arrives to the melting chamber 7, heated, melts and the melted material flushes over the whole length of the porous core 2. The melt fills the core pores and covers the core with a thin layer of liquid metal.

The evaporation process starts. The material is evaporated from the core 2 surface.
The material vapour after multiple reflection from the pipe 1 walls in the central part of the evaporator outflows through the aperture 5 and deposits onto the substrate.
In the damping chambers 3' and 3'' the material also evaporates from the core 2, yet as far as in these zones of the pipe there is no output of the vapour outside the evaporator, the vapour reflects repeatedly from the pipe inside walls and again condenses on the porous core. In this way a dynamic equilibrium is set in these zones when the number of molecules, escaping from the melted material layer on the core, is equal to the number of molecules, returning from the vapour to the core surface, i.e. the evaporation rate is equal to the condensation rate.
When the evaporation rate is fairly high, in our case it is 7 – 10 g/min., the above-mentioned condition in the damping zones continues during the whole evaporation process.
When the evaporation rate is low, the previously described formation of the melting material globules is observed and causes the tendency to the process fluctuation. Yet the damping chambers 3' and 3'' stabilize the process. The stabilization effect may be described in the following way. After the globule separation from the wire it falls into the melting chamber and wets the evaporator core; evaporation from the evaporation chamber 3 starts. The material also evaporates from the core 2 in the damping chambers 3' and 3'', yet as soon as there is no apertures in these zones, the vapour repeatedly reflects from the pipe inside walls and again condenses on the porous core. When the evaporated material amount in the chamber 3 on the core 2 becomes less than in the chambers 3' and 3'', the temperature in the evaporation chamber 3 increases and the evaporated material is pumped from the chamber 3' and 3'' to the chamber 3 by capillary forces, which stabilizes the evaporation rate.
Several evaporators of such type have been manufactured at the applicant's facility. Some of them were designed for evaporating copper with copper wire feeding, others were intended for indium evaporation with metal feeding in a liquid state. The pipe diameter in both evaporators was 20 mm, while the pipe length was 110 mm. The size of the vapour output apertures was 12 x 43 mm. The aperture was made in the pipe central part at the distance of 25 mm from the contacts.
During evaporation copper was fed into the melting chamber in the form of wire 1.5 mm in diameter.
During indium evaporation it was fed into the melting chamber in the melted form from a special reservoir.
Both metals were evaporated in order to be deposited onto polymer films at the speeds of 10, 7, 5 and 3 g/min. Under all said conditions stable uniform evaporation without noticeable process fluctuation was observed.
Check measurements of the coating thickness on polymeric films showed that there were no evaporator operation fluctuations under the said operation conditions. At the feeding speeds of 10, 7 and 5 g/min. thickness non-uniformity did not exceed ±5%. At the feeding speed of 3 g/min. thickness non-uniformity did not exceed ±10%.

What is claimed is:

1. A resistive evaporator for use in the vacuum deposition processes, which comprises an evaporation chamber, a thin-wall tube with apertures for output of the evaporated material vapour, a porous core, which is fixed inside the said thin-wall tube, contacts for electrical current feeding, at least one material melting chamber, a device for evaporated material feeding into the said material melting chamber, a channel for melting material feeding from the material melting chamber into the porous core, characterized in that in order to expend process capabilities of the evaporator and enhance the coating qualities on account of the evaporation rate stabilization, at least one chamber of damping evaporation rate fluctuation is made between one of electrical contacts and the evaporation chamber, the said damping chamber is separated from the evaporation chamber with a partition, which is provided with an aperture for the porous core and liquid material flow.

2. The device in accordance with claim 1, wherein the length of the fluctuation damping chamber is not less than one diameter of the evaporation chamber.

3. The device in accordance with claim 1, wherein the diameter of the fluctuation damping chamber is equal to the diameter of the said thin-wall tube.

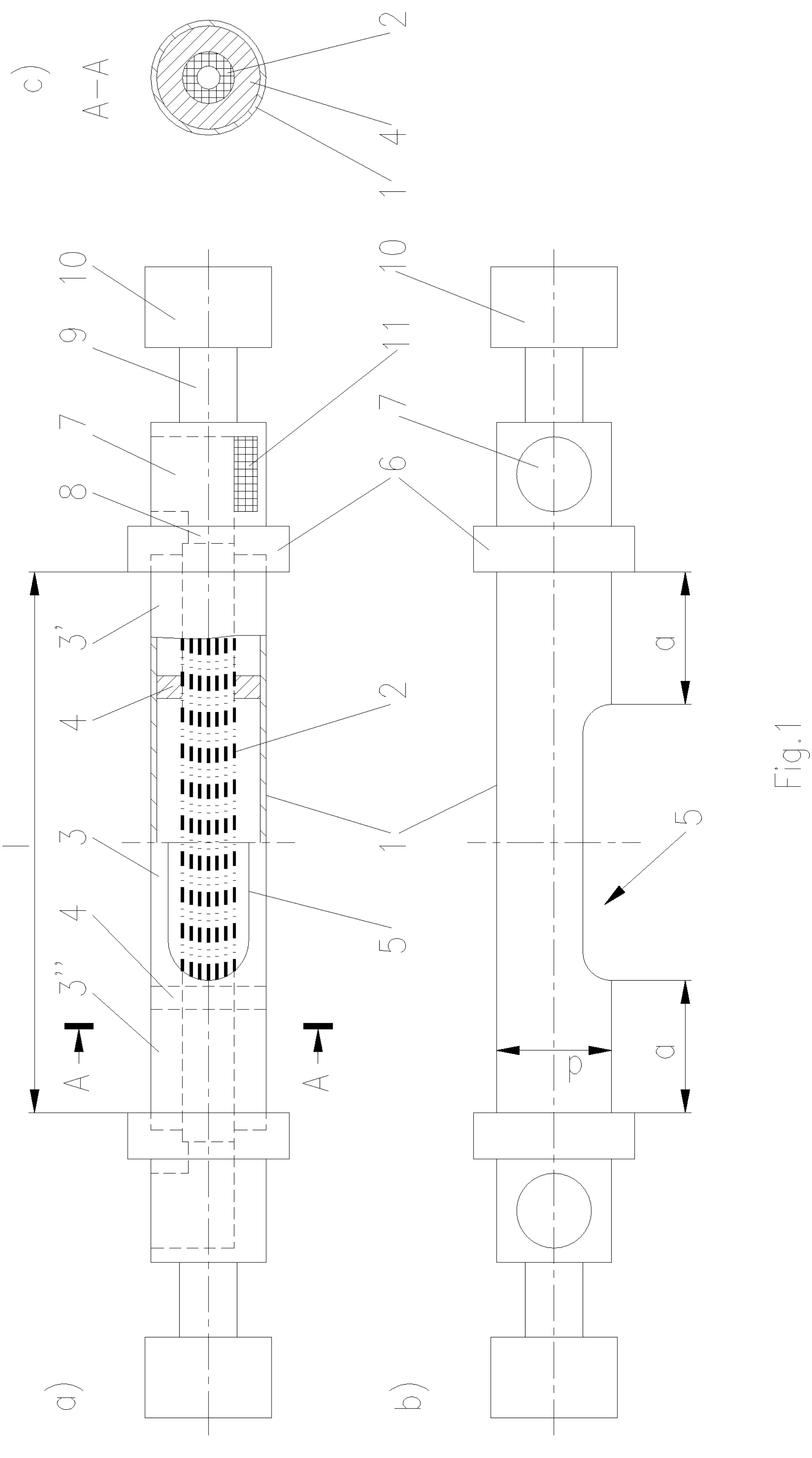

Fig.1

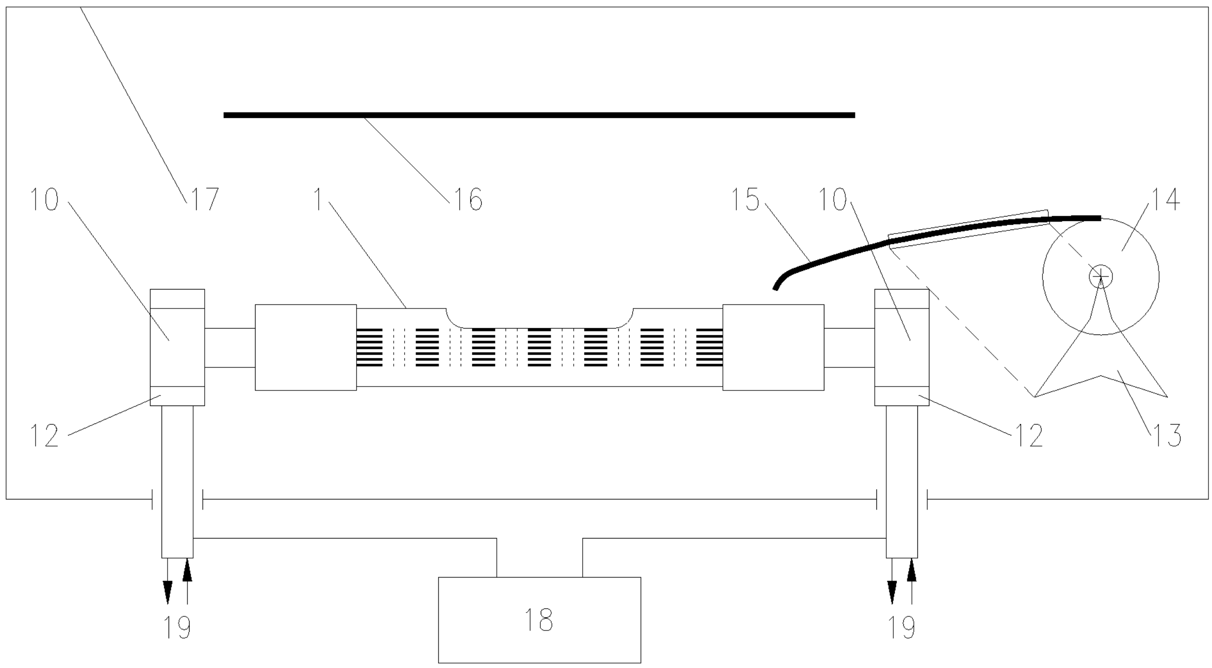

Fig.2

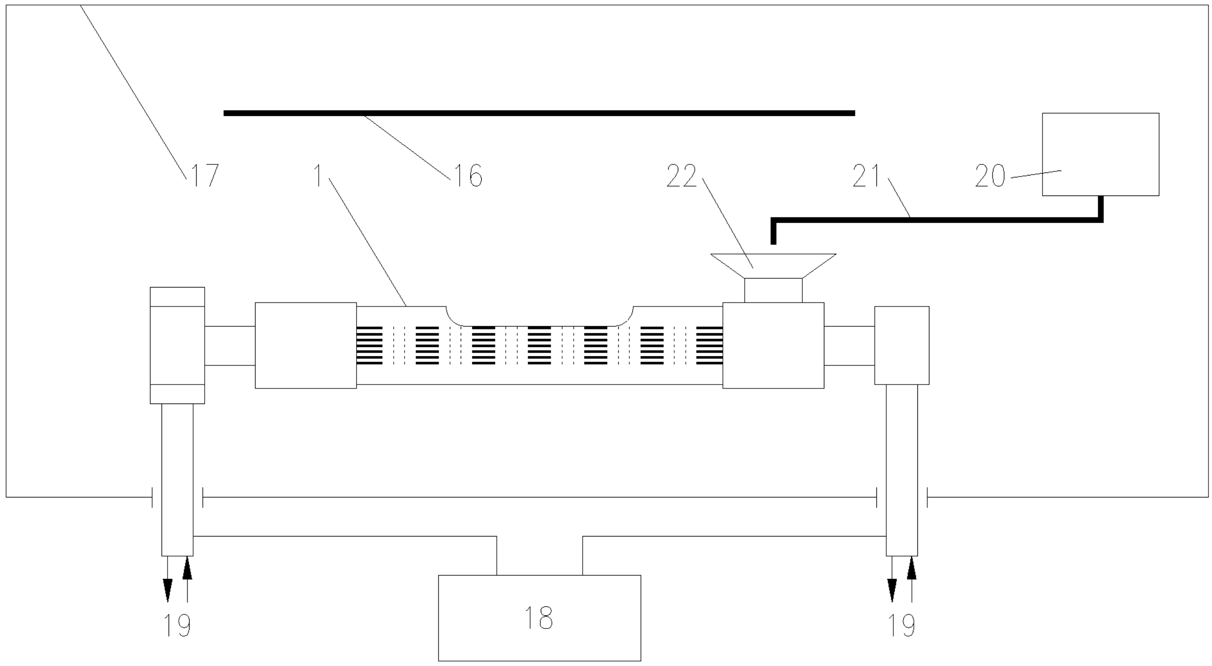

Fig.3