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CONDITIONED ATMOSPHERE FURNACE MUFFLE

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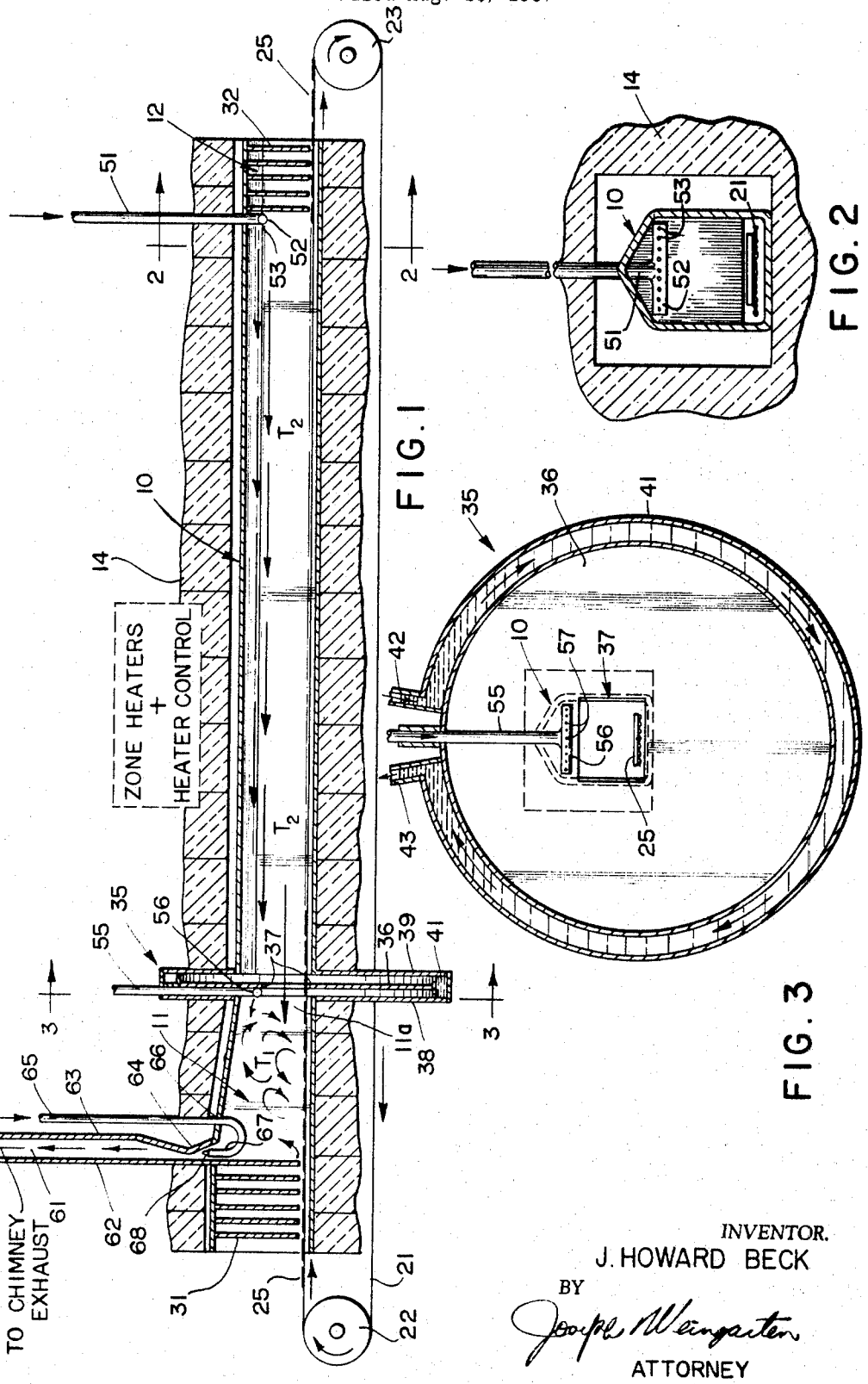

FIG. 1

FIG. 2

FIG. 3

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CONDITIONED ATMOSPHERE FURNACE MUFFLE

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ABSTRACT OF THE DISCLOSURE

An elongate furnace muffle formed with a venturi section at one end arranged to provide relatively smooth nonturbulent axial gas flow over the work in process. Gas introduced under pressure into the venturi section establishes the desired laminar axial gas flow but may also be used to provide substantial gas agitation for specific purposes in a limited region of the muffle.

Field of the invention

The present invention relates in general to furnaces having particular utility in the processing of thick-film microelectronic or integrated circuit elements and related devices where exceedingly close control of temperature and atmosphere is essential to successful performance. It is a feature of the present invention that nonturbulent or laminar gas flow may be established throughout a relatively lengthy muffle whereby products transported therethrough will not be subject to significant temperature variations axially or transversely of the direction of motion. As will be seen, nonturbulent gas flow is achieved over a substantial length of the furnace muffle by means of the introduction of high pressure gas in a venturi-like section of the structure and that this high pressure gas in turn may be used to create a limited region of turbulent flow which may be used to advantage in the processes under consideration.

Discussion of the prior art

The mass production of integrated circuit elements has been limited by many problems resulting from uneven heat treatment in the furnace used to reduce the various wet inks to conductive and resistive lines and areas on a ceramic substrate. One difficulty which has hampered volume production has been the inability to maintain temperature uniformity in a region of gas flow chiefly due to the fact that eddies in the gas stream resulted in significant temperature variations, both in the direction of transport through the furnace and transversely across the conveyor belt. Significant temperature differences in any direction result in product variances which are intolerable with the result that yields have been relatively low, while the cost of the product has been high. While many efforts have been made to achieve temperature uniformity in an atmosphere of flowing gas, discontinuities, pressure variations and the like have always resulted in substantial quality variations from piece to piece. In addition to the foregoing, problems have risen in prior furnaces in the disposal of the injurious, if not poisonous fumes generated during the drying and firing processes. Exhaust fans ordinarily used to vent fumes through an external stack normally add turbulence in the gas stream and tend to increase the variation of temperature in the system. In summary, prior art furnaces used for such processes have represented design by compromise to achieve reasonable utility.

Summary of the invention

The present invention concerns a furnace for heat treatment of specific products, such as integrated circuits, having an elongate tubular muffle with a product input

end flared outwardly in the form of a venturi. Relatively high pressure gas is introduced at the venturi throat, the action of which is to draw low pressure gas from the opposite end of the muffle over the work substantially without turbulence. A second venturi and gas input arrangement at the product input end of the muffle exhausts gas drawn through the length of the muffle as aforesaid, gas introduced at the throat of the first-mentioned venturi and such vapors as may be emitted from the work in process. Axial sections of the muffle may be maintained at different temperatures and turbulent gas flow in the venturi section may be utilized to enhance the treatment of products in that limited area.

Description of the drawing

FIG. 1 is an axial cross sectional view of a furnace embodying the novel features of this invention; some of the more conventional structural aspects being shown in fragmentary and diagrammatic form;

FIG. 2 is a cross sectional view of the novel furnace taken along the plane 2—2 of FIG. 1 illustrating the gas input arrangement at the exit-end of the furnace muffle; and

FIG. 3 is a cross sectional view of the novel furnace taken along the plane 3—3 of FIG. 1 illustrating the gas jets in the venturi section of the muffle.

Description of the preferred embodiment

With reference now to the drawing and more particularly to FIG. 1 thereof, there is shown in cross sectional view a furnace particularly adapted to the firing of relatively small distinct elements, such as integrated circuits in a precisely conditioned atmosphere. Generally speaking, the furnace of the present invention is comprised of an elongate muffle **10** having an open input-end **11** and an open exit-end designated by the reference numeral **12**. The cross sectional shape of the muffle **10** in the central region is clearly shown in FIGS. 2 and 3, and as is apparent, the muffle is formed with three flat sides and a "peaked" upper portion. In the input region **11**, the muffle is of substantially rectangular cross-section, flaring outwardly in the vertical dimension to define a venturi with a throat or constriction **11***a* for purposes to be set forth below. The muffle is preferably made of a material which is chemically resistant to the fumes and vapors present in high temperature fabrication of products such as integrated circuits. A suitable material is quartz; although high temperature stainless steels such as Inconel may be also employed in some applications.

Although the various detailed features of the present invention are closely related to and embodied in the structure of the muffle **10**, certain aspects of a complete furnace embodying this muffle should be described. In particular, muffle **10** is enclosed within a suitably insulated structure built up, for example, of fire brick **14**. The muffle **10** may remain in a horizontal position, or if desired it may be tilted slightly, with the input-end **11** raised a few degrees to enhance axial gas flow. Since the means for bringing the muffle zones to suitably precise operating temperatures, such as heating coils, temperature sensors and control means therefor, are conventional and readily available in the art, these have not been shown in the drawing, other than diagrammatically, for the sake of clarity.

As shown in FIGS. 1, 2 and 3, a conveyor belt **21**, which may be made of flexible stainless steel mesh or hinged links, passes lengthwise through muffle **10** close to the lower flat wall. The conveyor is driven by a pair of rotatable pulleys **22** and **23**, turned by a source of power (not shown) and transports the work pieces in process into, through and out of the furnace in conventional fashion; the process speed being dependent upon

the parameters of the items being fired, process temperatures, and the axial length of the furnace. For the purpose of illustrating typical furnace operation the conveyor belt is shown in each of the figures as supporting a plurality of integrated circuit elements **25**, each being essentially a ceramic substrate having a circuit pattern of conductors, resistors and the like imprinted thereon with appropriate inks as established in that art. This will be discussed in somewhat further detail below.

The manner in which the individual microelectronic circuit elements **25** are deposited upon conveyor belt **21** at the input-end and removed from the conveyor belt **21** at the output-end does not constitute an element of the present invention. For completeness, however, it should be mentioned that various automatic machinery is available for placing the elements on the conveyor and removing the completed products at the output for further processing elsewhere. For an understanding of the present invention it will be sufficient to recognize that with the conveyor belt in operation, motion being in the direction of the arrows, the integrated circuit elements are conveyed axially through the furnace from the input-end to the output-end at a uniform speed and are thus exposed to the various process temperature zones and other conditions which exist in the muffle in the path of motion. More specifically, the various work pieces being processed in passage through muffle **10** are exposed not only to various elevated temperatures but also to an atmosphere of gas which flows continuously from the exit-end to the input-end. For the purpose of confining the flow of the process gases to the region within the muffle, both the input and exit ends have been provided with gas barriers **31** and **32** which essentially consist of a series of transverse parallel metal plates extending from the upper inner surface of the muffle to a point just out of contact with the work pieces being transported on conveyor belt **21**.

For the furnace shown in the drawing, two distinct process temperature zones have been provided along the axial dimension of the muffle. As shown, the input section **11** is operated at a temperature T_1, while the longer section to the right is operated at temperature T_2. The exact temperature levels are of course dependent upon the process requirements. In typical use for integrated circuit processing, the input section **11** would be maintained at a temperature T_1 suited to burning out the liquid vehicles and solvents in the various inks used. Temperature T_2 would be higher and would serve to fire the metallic constituents of the inks to the desired finish.

In order to maintain the two sharply defined temperature regions, a transverse heat barrier designated generally by the reference numeral **35** is inserted between muffle sections. Structurally the heat barrier consists of three relatively large diameter circular parallel plates of material of high thermal conductivity joined at their peripheries by a circular pipe **41**. The central plate **36** is formed with rectangular central opening **37** through which the conveyor belt and work pieces may pass. Outer plates **38** and **39** are rigidly secured to and are formed with openings equal in size to their respective muffle sections. Pipe **41** is provided with inlet and outlet ports **42** and **43** respectively through which a coolant such as water under pressure may be circulated. Heat flowing from the adjacent sections of the muffle through plates **38** and **39** will be dissipated by the coolant, while central plate **36** will inhibit thermal energy interchange between muffle sections by radiation. In operation with a coolant flowing, the heat barrier **35** will maintain a sharp temperature gradient across its small axial dimension, while conventional operation may be restored simply by discontinuing the flow of cooling medium. A similar heat barrier is the subject of United States Patent No. 3,041,056 dated June 26, 1962, and reference is made to that patent for further details of design and operation.

With the foregoing structural features of the furnace and the furnace muffle in view, the arrangement for controlling the gas atmosphere will now be described in detail. Turning first to FIGS. **1** and **2**, the mechanism for introducing a specific gas into the exit-end of the muffle is illustrated. More specifically the arrangement consists of a gas inlet tube **51** which extends inwardly through fire brick **14** and through a suitable opening in the upper portion of muffle **10** where it is terminated by a horizontal connecting tube **52** having closed ends and formed with a series of gas ports **53** directed toward the input end **11**. As is thus evident, gas entering the upper portion of tube **51** will flow outwardly toward the forward end of the muffle through ports **53**.

At the input-end of the muffle a generally similar gas flow structure is provided in the form of a gas input tube **55** which extends radially inward through gas barrier **35** and is terminated as indicated best in FIG. **3** in a transverse tube **56** having closed ends and a plurality of gas ports **57** which face forwardly into muffle input section **11**. The center plate **36** of the gas barrier lies immediately to the right of transverse tube **56**, at the venturi throat **11***a*.

As shown in FIG. 1, input section **11** of muffle **10** is provided at its forward end, just inwardly of gas baffles **31** with a vertical gas exhaust section **61** made up of a forward flat wall **62** and a shaped wall **63** arranged to define a second venturi throat **64**. A gas line **65** extends downwardly into muffle **66** and curves upwardly at **67**. terminating in a jet **68** pointed into venturi throat **64**.

In the processing of integrated circuit elements, critically controlled temperatures and atmospheres are absolutely essential to successful results. In the production of integrated circuit elements the substrate may consist of a high density ceramic, such as aluminum oxide, porcelain, beryllia, or the like. This base material is coated, usually by automatic screening machinery, with thick-film resistor and/or conductor compositions, which are ordinarily mixtures of powdered metal and/or glass particles suspended within a liquid organic vehicle. By whatever process used in their preparation the integrated circuit elements **25** at the time of deposit upon the input end of conveyor **21** have a number of wet ink lines and areas on the upper surface thereof. These inks are to be burned-out and then fired.

In the input section **11** of the muffle shown in FIG. 1 the temperature T_1 to which the elements **25** are subjected is sufficient to burn-out the inks prior to their passage through the heat barrier to the higher firing temperature T_2 zone. It is with this process technology in view that the gas atmospheres and gas flow in the furnace shown in FIG. **1** will now be discussed.

Considering first the process of firing at temperature T_2, it is absolutely essential that local temperature variations be avoided both axially and transversely of the conveyor belt. Gas eddies and turbulent gas flow in any form has the property of creating substantial temperature variation, while laminar, non-turbulent flow results in the virtual elimination of temperature gradients in a well constructed furnace.

In the furnace of the present invention laminar gas flow is achieved in the muffle between gas ports **53** and the opening **37** in the central plate **36** of the heat barrier by connecting tube **51** to a source of gas at relatively low pressure. Indeed, the gas may be air at atmospheric pressure, preheated to temperature T_2 and dried to avoid adverse effects in the furnace. The gas entering the muffle through ports **53** is drawn toward section **11** by the action of gas introduced through ports **57** at the venturi constriction, at relatively high pressure through tube **55**. The fact that gas is introduced through tube **51** with little or no positive pressure while gas at high pressure is introduced forwardly through ports **57** results in smooth, laminar gas flow throughout the entire length of muffle **10** between ports **53** and the opening **37**. This atmosphere

is ideally suited to the processing of micro-electronic elements **25** at firing temperature T_2.

At this point it should be observed that the high pressure gas introduced through ports **57** toward the forward end of the muffle is relatively turbulent in region **11** (as indicated by the curved arrows on the drawing). This agitation of gas is quite useful in burning-out the inks at temperature T_1 and also serves to prevent carburization at the surface of the integrated circuit substrates **25**.

Turning now to the vertical venturi defined by throat **64** between plates **62** and **63**, it will be observed that high pressure gas entering through tube **65** and directly upwardly through nozzle **68** has the effect of exhausting gas and vapor contained in muffle section **11**. As indicated in FIG. 1, the exhaust region **61** is preferably connected to a chimney or stack which is vented away from all personnel since the hydrocarbon vapors of the drying vehicles in muffle section **11** may be injurious or even poisonous. The combined action of the vertical venturi and gas baffles **31** precludes gas exhaust through the open input-end of the muffle.

In the processing of thick-film integrated circuits, dry air may be used as the gas introduced through all three tubes **51**, **55** and **65**. As previously described, the gas introduced through tube **51** may be preheated to temperature T_2 to eliminate local temperature profiles while the gases introduced through tubes **55** and **65** may be somewhat cooler. It is of interest to note that through the selective use of varied gas pressures, both laminar and turbulent flow may be achieved in closely adjacent sections of the muffle, each type of flow serving a highly useful purpose.

Gas entering through tube **51** serves to maintain temperature uniformity and provides the proper chemical environment during the firing process of temperature T_2; gas entering through tube **55** serves to draw the gas forward from ports **53** and also to provide turbulent burnout in the input section; and gas entering through tube **65** serves to exhaust all fumes from the muffle and to reduce back pressure in the region **11** which might otherwise be present as a result of high pressure gas entry through ports **57**. Gas flow in the specified direction thus prevents flow of vapors of the volatile binders and decomposition products into the region of temperature T_2 where contamination of the product might result.

While the invention has herein been described for the processing of thick film integrated circuit elements in two temperature zones under dry air, it should be mentioned that this furnace may be used for heat treatment of various other products. The gases which are introduced may be varied and may be chemically active or inert, or dry or moist, the temperatures in the respective zones may be changed or may be made equal, and the speed and other controls may be altered to achieve a desired purpose. Thus, this invention is to be construed only in accordance with the scope of the appended claims.

What is claimed is:

1. A furnace adapted for the continuous heat treatment of specific products comprising:

an elongate tubular muffle having product input and exit ends;

a conveyor extending axially through said muffle for transporting said products therethrough;

and gas input and exhaust means disposed respectively at said exit and input ends for providing substantially uniform laminar axial gas flow over said conveyor; said gas exhaust means including a section of said muffle formed and arranged as a venturi flaring outwardly toward said input end.

2. A furnace in accordance with claim **1** and including:

means for providing gas at relatively low pressure to gas input means, and

means for providing gas at relatively high pressure to said venturi section of said muffle in said exhaust means.

3. A furnace in accordance with claim **2** wherein said gas provided to said gas input means is at a first temperature while said gas provided at said exhaust means is at a second and different temperature.

4. A furnace in accordance with claim **3** wherein the temperature maintained in said muffle in the region of said venturi section is different than the temperature maintained throughout a substantial axial section of said muffle in the region between said venturi and said gas input means.

5. A furnace in accordance with claim **4** wherein said gas provided at said exhaust means is arranged to cause turbulence in said venturi section.

6. A furnace adapted for the continuous heat treatment of specific products comprising:

an elongate tubular muffle having product input and exit ends, a section of said muffle adjacent said input end being formed as a venturi, said venturi having a throat at its juncture with the remainder of said muffle and being flared outwardly toward said input end;

a conveyor extending axially through said muffle for transporting said products therethrough;

means adjacent said exit end for introducing gas into said muffle at relatively low pressure with flow directed toward said input end; and

means arranged in the throat of said venturi for introducing gas at relatively high pressure with flow directed toward said input end thereby to draw gas introduced in the region of said exit end axially through said muffle substantially without turbulence.

7. A furnace in accordance with claim **6** and including gas barriers within said input and output ends of said muffle to limit the flow of gas through said ends substantially without interference with said conveyor.

8. A furnace as in claim **6** and including:

a heat barrier adapted to define distinct temperature zones in said venturi section and the remainder of said muffle;

said means for introducing gas into said throat of said venturi being formed with a gas conveying tube extending into said muffle through said heat barrier.

9. A furnace in accordance with claim **6** and including:

a gas exhaust system operatively coupled into said venturi section of said muffle and arranged to exhaust said gas introduced into said venturi section and said gas introduced at said exit end of said muffle.

10. A furnace in accordance with claim **9** wherein:

said gas exhaust system includes a second venturi section extending outwardly from said venturi section of said muffle;

and means for introducing gas into said second venturi section in the direction in which gas is exhausted from said furnace.

11. A furnace in accordance with claim **10** wherein said gas introduced in said second venturi is directed substantially at right angles to the direction of gas introduced into said venturi section of said muffle.

References Cited

UNITED STATES PATENTS

1,881,536	10/1932	Harmon.	
3,086,764	4/1963	Beck	263—8

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263—15, 37, 50