

Folded memory layers

The present invention concerns a ferroelectric or electret volumetric memory device, wherein a ferroelectric or electret memory material is provided in sandwich between first and second electrode layers respectively comprising
5 first and second parallel stripe-like electrodes forming word lines and bit lines of a matrix-addressable memory array, wherein word lines and bit lines of the array are oriented substantially at right angles to each other, wherein memory cells are defined in volumes of memory material sandwiched between respective crossings word lines and bit lines, and wherein a
10 plurality of memory arrays are provided in at least one stack such that the at least one stack of memory arrays realizes the memory device with a volumetric configuration.

In a wider sense the present invention also concerns data storage and/or processing devices based on ferroelectric thin films.

15 No prior art of direct relevance regarding braiding/folding as taught in the present invention has been identified. However, a brief general background shall be given to illustrate the present state of the art, put the present invention into context and highlight the objects of the invention:

Memory chips have the advantage over conventional magnetic, optical and
20 other mechanical storage devices of being capable of very fast read and write operations. Furthermore, they are solid state, have reasonably low power consumption and may offer high transfer speeds. The disadvantage is their limited capacity to store information, and a relatively high production cost relative to the storage capacity. Due to scaling problems and limited area,
25 typically restricted to less than 1 cm²/chip, this situation is not likely to be much altered in the foreseeable future.

A solid state memory concept which circumvents the limitations described above has been developed based on hybrid silicon/polymer chips. The approach includes stacking thin layers of polymeric memory films on silicon
30 substrates and accessing the passively addressed memory layers via the substrate circuitry. The problem with this solution, however, is that the number of memory layers in the stack typically is limited to 8 – 16 layers. Increasing this number is technically possible, but generally not practically viable for most mass market applications. Negative factors in this connection

include extra overhead and real estate costs for driver circuitry (decoders and sense amplifiers in particular); reduced yield due to increased number of processing steps; problems associated with planarization when the number of memory layers becomes larger than the range mentioned; and a larger number of processing steps increasing the risk that underlying polymer layers are negatively affected, with a reduced functionality as a result.

There is also an unbalance in the hybrid memory concept to the extent that producing the silicon part is complex and requires advanced (albeit standard) fabrication processing, while building the memory stack in itself is a very simple low cost procedure, which potentially could be done outside fabrication facility, with non-lithographic tools. However, when these stacks are built on silicon the factors listed above combine to make this more costly and capacity limiting than desirable, e.g. it does become more cost-effective to use two or several chips to achieve the same capacity.

Also, the procedure used to deposit memory films on silicon is in practice limited to simple spin coating. This deposition technique has several advantages, but may also introduce unwanted side effects, like creating a larger than desirable internal stress, problems in controlling the film morphology and uniformity, etc. One procedure used to improve morphology is stretching of films, which cannot be applied in the hybrid case, another is to anneal films under high pressure which is not very applicable either (when spin coating and rigid substrates like silicon is used).

Because of the area restrictions related to a silicon-based device, the only feasible patterning approach is standard photomicroolithography i.e. providing a high resolution line pitch. This excludes low cost, non-lithographic patterning tools like inkjet printing and micropatterning.

Another problem related to the hybrid concept is packaging, especially soldering, which requires temperatures much higher than the melting temperature of polymers (more than 60°C higher). The polymer does not necessarily destruct when exposed to higher temperatures than its melting temperature, but a rework (reanneal) is required to bring back the film properties. More problematic is what happens to the electrode/film interface, which easily is destroyed when the polymer enters the liquid phase. This represents a substantial problem when multilayer stacks are involved.

Film properties are also seriously affected by electrode application, e.g. the top electrode deposition may have negative effects on the bottom electrode interface, e.g. by kicking off undesired ion transport, which may initiate a fatigue process in the polymer films. Morphological chain defects may also be induced.

In regard of the above-mentioned disadvantages, it is thus a first object of the present invention to provide novel architectures for solid state thin-film-based devices whereby the effective area available for data storage and/or processing can be made large through stacking of individual layers in a dense volumetric structure.

It is a second object of the present invention to prescribe how such stacking can be achieved in a practical manner while at the same time providing individual addressability for locations inside the stack through a limited number of electrical connections that are accessible from the outside of the stack.

It is a third object of the present invention to provide stacks containing a multiplicity of matrices, where each matrix contains a large number of thin-film cells that can be individually connected via passive matrix addressing.

It is a fourth object of the present invention to provide individual stacks in the form of modular units suitable for integration into devices with specialized functions and/or into larger units that add the capacities of two or more separate stacked units.

It is a fifth object of the present invention to apply the stacking concept to the manufacturing of data storage and/or processing devices that contain sub-units demanding mutually incompatible process steps.

The above objects as well as further features and advantages are realized with a memory device which according to the invention is characterized in that a stack of memory arrays is formed with two or more ribbon-like structures being folded and/or braided into each other, each ribbon-like structure comprising a flexible substrate of non-conducting material, that first and second electrode layers respectively, are provided on each surface of the substrate, such that the electrode layers each comprises the parallel stripe-like electrodes provided extending along the ribbon-like structure and a layer of memory material covers one of the electrode layers thereof and

extends uninterrupted between the edges of the ribbon-like structure, that each memory array of the stack is formed by overlapping portions of a pair of adjacent ribbon-like structures folded and/or braided such that they cross in substantially orthogonal relationship, and that the word lines and the memory
5 layer of a memory array in a stack are contained in the first ribbon-like structure of a pair of adjacent structures of this kind and the bit lines contained in the second ribbon-like structure thereof thereof.

Further features and advantages of the present invention are disclosed by the dependent claims.

10 The invention shall now be explained in greater detail with reference to preferred embodiments and the appended drawing figures, of which

fig. 1a shows a longitudinal cross-section of ribbon-like structure as used in the present invention,

fig. 1b a transversal cross-section thereof,

15 fig. 1c two ribbon-like structures crossing and contacting each other, forming a memory array in the overlap area,

fig. 2a an example of a stack of ribbon-like structures according to the invention,

20 fig. 2b an example of an embodiment of the present invention with two stacks similar to the one in fig. 2a,

figs. 3a, 3b cross sections of respectively the first and second stacks in fig. 2b,

fig. 4a schematically a ribbon-like structure with connection areas or contact fields on the front and back, and

25 fig. 4b how the ribbon-like structures may be provided to form stacked memory arrays according to another embodiment of the present invention.

According to the invention, shown in figs. 1a and 1b, there is provided a ribbon with a carrier substrate 3 of a flexible material (e.g. polymer or metal) coated on one surface with a thin layer of memory film 1 on top of parallel
30 electrodes 2 (in the longitudinal direction), while the opposite surface of the ribbon either has a similar structure or a layer of parallel electrodes 4 only,

the whole embodiment thus constituting a ribbon-like structure R (henceforth termed only as "ribbon") as used in the present invention.

5 The memory film 1 has addressing, charge storing (bistability) and/or switchability capabilities allowing memory matrices to be passively addressed and memory cells to be constituted by the memory film 1 being sandwiched between crossing electrodes 2;4 by a suitable arrangement of two or more ribbons contacting each other and oriented mutually at an angle of about 90°.

10 According to a preferred embodiment of the invention two or more ribbons R are stacked together, such that at each interface portion a memory array M is created in the adjoining ribbons and represented by top and bottom electrodes 2;4 and the memory film 1 in between. This is illustrated in fig.1c, showing a crossing between two ribbons R_k and R_{k+1} which may constitute part of a larger stack. The ribbons R may have an arbitrary width and are mutually
15 oriented in 90° angles with respect to each other such that the resulting stack has a square/cubic (chip-like) shape. Fig. 2a shows how ribbon R2 is stacked against ribbon R1, ribbon R3 against ribbon R2, and so forth, up to ribbon R10 stacked against ribbon R9.

20 In fig. 2a the odd-numbered ribbons R1,...R9 form a first subset or assembly X_1 , the even-numbered ribbons R2,...R10 a second assembly X_2 oriented perpendicularly to the first. The resulting memory arrays form a stack S.

25 The ribbon overlaps are laminated together through an anneal process, e.g. under high vacuum/high pressure. By using a similar structure, i.e. memory film against memory film, compatibility problems related to the lamination process may be substantially reduced.

30 In an alternative embodiment the ribbons are folded according to a plurality of patterns, including concertina-wise, oval, circular/ring or twisted, as e.g. shown in fig. 2b. "Woven" threads may be made, which again can be used to make fabrics, etc. It will be possible to build large area structures in this way, thus enabling integration of memory into other devices, like into the casing of mobile phones, as a "top coating" on curved or other surfaces, etc.

The ribbons R1,...R9 arranged in a first subset or assembly X_1 and the ribbons R2,...R10 arranged in a second subset or assembly X_2 are applied in a memory device according to the invention. The embodiment of such a

memory device as shown in fig. 2b forms two distinct stacked structures S1, S2 as indicated by the boxes with stitched outlines. Each of the ribbons R1-R10 is bent such that pairs of odd and even numbered ribbons are permuted in the stack S2 with respect to the succession of ribbons in stack S1. This implies e.g. that the lowermost ribbon R9 in stack S1 is bent upwards to pair with the ribbon R10, while e.g. ribbon R1 which is paired with ribbon R10 in the stack S1 now is bent downwards to pair with ribbon R2 in stack S2.

If the embodiment shown in fig. 2b is regarded as a plan view of the arrangement of the ribbons in the device according to the invention, it will by persons skilled in the art readily be understood that the combination of displacements and staggering shall provide a significant contribution with regard to minimizing capacitive crosstalk or other undesired couplings between the separate memory arrays M forming each stack. Not only can each individual memory cell in a memory array in a stack be addressed, i.e. written or read, without unwanted disturbances which seriously reduce the signal/noise ratio of e.g. an output signal, but in addition a parallel addressing of all memory cells in an array and if desired all memory arrays in a stack will be possible while simultaneously still keeping any disturbing influences at a minimum.

The arrangement of the stacks S1, S2 in the memory device according to the invention is shown to better advantage in cross sections in respectively figs. 3a, and 3b. In stack S1 (fig. 3a) the first ribbon R9 is provided orthogonally to the second ribbon R2 and second electrodes 2 in ribbon R9 now can be considered as word lines in a memory array M1 with the bit lines provided by the electrodes 4 in ribbon R2 and so on. In other words a memory array M comprises and is formed by a portion of respectively adjacent pairs of ribbons R_k , R_{k+1} in a stack S. The stack S2 as shown in fig. 3b appears similar to the stack S1 in fig. 3a, but with the directions of adjacent pairs of ribbons R now rotated by 90° such that the orthogonal crossing between successive ribbons in the stack S2 is retained. It will be seen from fig. 2b that the first assembly X_1 of odd-numbered ribbons R1...R9 and the second assembly X_2 of even-numbered ribbons R2...R10 each could be followed by a similar adjacent assembly of ribbons provided in the lateral direction (i.e. in a side-by-side arrangement) with a corresponding orientation such that additional stacked structures S could be formed in the regions where the

assemblies X_1 , X_2 intersect. The additional assemblies of ribbons can also be provided in a staggered arrangement if so desired. Moreover it can also be seen from a contemplation of the arrangement in fig. 2b that the direction of staggering could be inverted between neighbour stacks of memory arrays, i.e.

5 for instance of ribbon R9 in stack S1 would still pair with ribbon R10 in stack S2, but now in the projected position of ribbon R1 in stack S2, while of course ribbon R1 then still would pair with ribbon R2 in stack S2, but now in the projected position as shown for ribbon 9 in fig. 2b, and so on. The implication of this is of course that similar considerations would also be
 10 applied to the stagger of the ribbons in the even-numbered assembly X_2 of ribbons R2,...R10. The distance as measured by the length of the electrodes 2,4 and ribbons R between the memory arrays M in one stack S1 and the memory arrays M in the other stack S2 would then be similar.

At the end of the ribbons R there can be provided connecting and contact
 15 means 5, as shown in figs. 4a and 4b. This would e.g. allow the electrodes 2,4 to be passively connected to pads on an underlying, not shown silicon chip, in which case sufficient redundancy is required to allow for a certain degree of misalignment. Alternatively or in addition there is provided for some (e.g. decoder/router) circuitry based on thin-film transistors (TFT) at
 20 the electrode ends, reducing the number of contacting points to facilitate a more robust connection. Such robustification may not only allow for a much denser electrode pattern, and thus increased storage density, but also allow folded (and packaged) memory stacks to be connected to the silicon chips (or pads connected to the silicon chip(s) by the end user, thus opening up for
 25 very low cost add-on memory modules.

A further enhancement of this concept would be to provide all driver circuitry, also including sensing circuitry, and required to operate the memory, at the ribbon ends. This would turn into the folded memory stack completely self-sustained unit.

30 Yet another enhancement would be to distribute the required circuitry evenly over the ribbons, directly in contact with (at the sides of) each individual memory matrix, as row and column drivers/decoders, and just contacting every one of these to a common bus/traffic coordinator on the ribbon(s) and then communicate with external hardware via hardwired or wireless
 35 contact(s).

When silicon or silicon/TFT circuitry on a supporting substrate is used, ribbon surfaces can be attached to silicon driver circuitry by bending one surface end over the other as shown in fig. 4b before attachment to contact pads on the underlying, not shown device substrate surface. If all driver
5 circuitry is built on the ribbon(s) such bending is not required.

The resulting memory stack S built in this manner represents novel approaches and solutions to the problems discussed in the introduction. What basically takes place from an architectural standpoint is that because each memory array M is built on an individual substrate, the challenges are mostly
10 reduced to those related to building single layer memories. This shall involve simple modular sub-units represented by the individual ribbons, which can be manufactured in specialized manufacturing equipment before being assembled in scalable fashion into stacks.

The concept allows the use of a very large number of stackable memory
15 ribbons, the only restriction being access to silicon real estate in the silicon or hybrid silicon/TFT circuitry case, a restriction which does not exist in the "all circuitry on the ribbon (all-TFT)" case. This translates directly into a very large storage capacity, or arbitrarily large storage capacity in the all-TFT cases.

20 Because the approach is close to processing a single layer memory, most, if not all, the process and temperature compatibility issues related to multi-layer processing vanish.

Similarly, by avoiding the deposition of top electrodes directly onto the memory films, possible negative effects of such procedure can also be
25 avoided. A further positive effect on film morphology is the possibility to utilize stretching of the films before baking, thus ensuring a more orderly crystalline structure. Alternative deposition techniques to spin coating, like dip-coating/doctor blading/meniscus coating, may also have positive influence on film morphology.

30 Because the available area is large, a much more relaxed patterning process can be implemented, allowing non-lithographic tools and true reel-to-reel processing to be realised. This in its turn appreciably shall reduce the production costs.

The large feature sizes that can be utilized will also improve the signal/noise ratios with respect to cell signals, simply because cell sizes are so much larger. This will allow more variation in film thickness etc., thus reducing potential problems related to processing memory structures on flexible
5 substrates.

High temperature packaging is facilitated in cases where devices are built on silicon chips, since the silicon part can be processed and soldered before the polymer is attached.

CLAIMS

1. A ferroelectric or electret volumetric memory device, wherein a ferroelectric or electret memory material (1) is provided in sandwich between first and second electrode layers (2;4) respectively comprising first and second parallel stripe-like electrodes forming word lines (2a) and bit lines (4a) of a matrix-addressable memory array (M), wherein word lines (2a) and bit lines (4a) of the array (M) are oriented substantially at right angles to each other, wherein memory cells are defined in volumes of memory material (1) sandwiched between respective crossing word lines (2) and bit lines (4), and wherein a plurality of memory arrays are provided in at least one stack (S) such that the at least one stack of memory arrays realizes the memory device with a volumetric configuration, characterized in that a stack (S) of memory arrays (M) is formed with two or more ribbon-like structures (R) being folded and/or braided into each other, each ribbon-like structure (R) comprising a flexible substrate (3) of non-conducting material, that at least one electrode layer (2;4) is provided on a respective surface of the substrate, such that the at least one electrode layer (2,4) comprises parallel stripe-like electrodes (2a,4a) provided extending along the ribbon-like structure (R) and a layer of memory material (1) covers the at least one electrode layer thereof and extends uninterrupted between the edges of the ribbon-like structure, that each memory array (M) of the stack (S) is formed by overlapping portions of a pair of adjacent ribbon-like structures (R) folded and/or braided such that they cross in substantially orthogonal relationship, and that the word lines (2a) and the memory layer (1) of a memory array (M) in a stack (S) are contained in the first ribbon-like structure (R) of a pair of adjacent structures of this kind and the bit lines (4a) contained in the second ribbon-like structure (R) thereof.
2. A ferroelectric or electret volumetric memory device according to claim 1, characterized in every second memory array (M) of a stack (S) being provided in a mutually staggered arrangement.
3. A ferroelectric or electret volumetric memory device according to claim 1 wherein more than one stack (S) is provided, characterized in that the ribbon-like structures (R) are folded and/or braided in manner so as to realize a pair-wise permutation of the succession of ribbon-like structures from stack to stack.

4. A ferroelectric or electret volumetric memory device according to claim 1, characterized in that the ribbon-like structures (R) are arranged in two or more subsets (X) thereof, with the ribbon-like structures (R) in each given subset being oriented parallel to each other as viewed from the top of the stacks, and non-parallel to ribbon-like structures (R) in other different subsets.
5. A ferroelectric or electret volumetric memory device according to claim 4, characterized in that at least one ribbon-like structure (R) from each of at least two subsets (X) is provided with longitudinal electrodes (2;4) on one side and a memory layer (1) on the other.
6. A ferroelectric or electret volumetric memory device according to claim 4, characterized in that the number of ribbon-like structures (R) and subsets (X) thereof are selected to minimize the length of the ribbon-like structures (R) compatible with a given functionality of the stack (S).
7. A ferroelectric or electret volumetric memory device according to claim 1, characterized in that each of the ribbon-like structures (R) has been pre-formed and prepared with insulating and/or conducting and/or semiconducting layers and structures in its cross section and/or on one or both of its surfaces.
8. A ferroelectric or electret volumetric memory device according to claim 1, characterized in that two or more ribbon-like structures (R) in the stack (S) each comprises a set of electrodes (2a;4a) respectively provided on opposite surfaces of the substrate (3) and extending along the length of the ribbon-like structure.
9. A ferroelectric or electret volumetric memory device according to claim 8, characterized in that each electrode set (2a;4a) is electrically accessed by being connected to a contacting field or area incorporating active and/or passive circuitry at or near one or both ends of the ribbon-like structures (R), said contacting fields in turn being connected electrically or optically to circuitry external to ribbon-like structures (R).
10. A ferroelectric or electret volumetric memory device according to claim 1, characterized in that the stack (S) contains at least two different types of ribbon-like structures (R).

11. A ferroelectric or electret volumetric memory device according to claim 1, characterized in that at least one ribbon-like structure (R) in the stack (S) has a global insulating layers on one or both of its surfaces.
- 5 12. A ferroelectric or electret volumetric memory device according to claim 1, characterized in that at least one ribbon-like structure (R) in the stack (S) has a length which is different from the other ribbon-like structure (R), in the stack (S).