$$\overline{R}_1(u^1,u)),\ \ldots,\ R_n(\max_{u^{n1}\in U^{n1}} \overline{R}_{n1}(u^{n1},u^n,u),\ \ldots$$

$$\ldots,\ \max_{u^{nn_n}\in U^{nn_n}} \overline{R}_{nn_n}(u^{nn_n},u^n,u),\overline{R}_n(u^n,u)),\overline{R}(u));$$

2) при каждом $u\in U$ и $u^{ij}\in U^{ij}$ $(i=1,\ \ldots,\ n;\ j=1,\ \ldots,\ n_i)$

$$\max_{u^i\in U^i} R = R(\max_{u^1\in U^1} R_1(\overline{R}_{11}(u^{11},u^1,u),\ \ldots,\ \overline{R}_{1n_1}(u^{1n_1},u^1,u),$$

$$\overline{R}_1(u^1,u)),\ \ldots,\ \max_{u^n\in U^n} R_n(\overline{R}_{n1}(u^{n1},u^n,u),\ \ldots,$$

$$\overline{R}_{nn_n}(u^{nn_n},u^n,u),\overline{R}_n(u^n,u)),\overline{R}(u)).$$

Нетрудно видеть, что метод покомпонентного подъема порождает в данном случае трехуровневую итерационную схему (ср. [1]). Нетрудно также обобщить данную методику для многоуровневых систем.

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J. PIHLAU

PLATED WIRE ASSOCIATIVE MEMORY ELEMENTS

J. PIHLAU. ASSOTSIATIIVMÄLU ELEMENDID SILINDRILISTEL MAGNETKILEDEL
Я. ПИХЛАУ. ЭЛЕМЕНТЫ АССОЦИАТИВНОЙ ПАМЯТИ НА ЦИЛИНДРИЧЕСКИХ МАГНИТНЫХ ПЛЕНКАХ

Among a large number of magnetic elements proposed in recent years for the realizing associative memory (AM), plated wire elements deserve, in our opinion, most serious attention, due to their low cost, high speed and excellent NDRO properties. Nonvolatility is a further essential advantage of plated wire as compared with its strongest competitors — semiconductor integrated circuits.

Plated wires can be used as AM elements in two basic modes. The first type elements are characterized by operating plated wires as word lines of memory [1], the second type elements — by operating plated wires as digit lines of memory. A number of the main first type AM elements is presented in Tab. 1. The output signal of those elements is produced at the ends of one plated wire (schemes A — E) or as the difference of signals in two plated wires (scheme F). A bit is stored at 1—4 crosspoints of word and digit lines as clockwise («+» in Tab. 1) or anticlockwise («—» in Tab. 1) magnetization in the circumferential easy direction. Interrogate drivers for searching of 1 or 0 are turned on or off as indicated in Tab. 1. Schemes A and B are suited only for serial-by-bit interrogation, because their match and mismatch signals differ by polarity. In the remaining schemes C—F match and mismatch signals also differ by amplitude. In the case of ternary output mismatch output signal can be positive or negative, dependent upon whether a 1 or 0 is searched for.

Table 1

Scheme	Cross-points	1 stored	0 stored	1 searched	0 searched	Output
A	1	—	+	OFF	ON	Signal — signal Binary
B	1	—	+	ON		Signal — signal Binary
	2	+	—		ON	
C_1	1	—	—	ON	ON	Signal — no signal Binary
	2	—	+	OFF	ON	
C_2	1	—	—	ON	OFF	Signal — no signal Ternary
	2	—	+	OFF	OFF	
D_1	1	—	+		ON	Signal — no signal Binary
	2	—	—	ON	ON	
	3	+	—	ON		
D_2	1	—	+	ON		Signal — no signal Binary
	2	—	—	OFF	OFF	
	3	+	—		ON	
D_3	1	—	+	ON	ON	Signal — no signal Ternary
	2	—	—	OFF	ON	
	3	+	—			
E_1	1	—	+	OFF	ON	Signal — no signal Binary
	2	—	—		ON	
	3	+	+	OFF		
E_2	1	—	+	ON	ON	Signal — no signal Ternary
	2	—	—		ON	
	3	+	+	ON		
F_1	1	—(I wire) —(II wire)	—(I wire) +(II wire)	ON		Signal — no signal Binary
	2	—(I wire) +(II wire)	—(I wire) —(II wire)		ON	
F_2	1	—(I wire) —(II wire)	—(I wire) +(II wire)	ON		Signal — no signal Ternary
	2	—(I wire) +(II wire)	—(I wire) —(II wire)		OFF	

The ternary output allows to classify all words at one time as less than, greater than, or equal to the search word. In described AM elements near-zero match signal (noise) is produced by incomplete cancellation of NDRO signals in two adjacent crosspoints of plated wires. The degree of cancellation and therefore the mismatch signal to noise ratio is dependent on the identity of writing, disturbing and interrogating currents and on the uniformity of magnetic films and memory planes. An improvement in mismatch signal to noise ratio can be achieved at the expense of increasing the number of code bits required or by using addition control bits (for example, a parity bit). In Tab. 2 a scheme is given, where 5 crosspoints of word and digit lines are used for storing 2 binary digits. Masked bits are designated with M, while the other symbols are the same as in Tab. 1.

Table 2

Crosspoints		1	2	3	4	5
Code	00	+	—	+	+	+
	01	+	+	—	+	+
	10	+	+	+	—	+
	11	+	+	+	+	—
Interrogation	00	ON	ON			
	OM		ON	ON		
	MO		ON		ON	
	01	ON		ON		
	1M				ON	ON
	M1			ON		ON
	10	ON			ON	
	11	ON				ON

It appears that a second type element can be set in correspondence to every first type AM element described above when guided by a simple rule: the functions of word and digit lines in plated wire memory plane must be interchanged, and turn-on or turn-off of interrogate drivers must be substituted by positive or negative interrogate pulse, respectively. More detailed information about the operation of plated wire in longitudinal NDRO interrogation mode, on which all second type AM elements are based, is published elsewhere [2, 3]. There it is also shown that by using the effect of hysteresial rotation of net magnetization in magnetic film the elements can likewise operate successively without transverse bias field. The main disadvantages of the second type AM elements are the sensitiveness to transverse disturbing fields and the smallness of sense signals in the case of a word strap consisting only of 1—2 turns. The essential advantage of the second type elements is that there only one writing tact is required, during which the magnitude of the transverse field is not limited. On the contrary, the first type elements require 2 writing tacts for both directions of easy axis magnetization, and the magnitude of the transverse writing field is limited from above to the NDRO value. The first and second type AM elements can also be combined so that it is possible to interrogate memory from the direction of both coordinates.

The simplest way of AM realization consists in connecting every word line with a match /mismatch detector. But a large amount of peripheral circuits due to such solution has prevented the realization of economical AMs. There are several approaches to the reduction in the peripheral circuits. One is to use a current generated by mismatch signal voltage, in plated wire, which at the ends is shortened to a ground plane, to write information into a receiving bit [4]. Another is to arrange word lines into a matrix, to each row and each column of which corresponds a match/mismatch detector [5]. In this case the number of match/mismatch detectors is decreased to $2\sqrt{n}$ (n — number of words in AM). By using partial interrogation of AM, the number of detectors can be decreased to $\sqrt{n}$. The increasing of interrogation time is accompanied by a considerable simplification of memory and by decreasing consumed power and general noise level.

Choice of a proper scheme described above for a practical AM may be accomplished considering the relative importance of conditions such as search speed, permissible number of crosspoints along word and digit lines or number of current drivers, interrogation power, drive current margins, etc. For example, among the variants described with output "signal — no signal" the minimum number of crosspoints (2 per bit) is required by scheme C, whereas the widest margins on drive currents enable scheme F. In experimental memory planes measured by the author mismatch signal to noise ratio over 50 selected crosspoints was typically 10—15. Although so far we have no experimental data on testing large plated wire AM stacks, it may be concluded that the interrogation of more than 4—5 bits in parallel in a large-capacity plated wire AM is non-practical. Moreover, when this is permissible by the conditions of associative search speed, the best economical solution is the execution of serial-by-bit interrogation. This conclusion is also confirmed by a recent communication concerning the realization of a plated wire associative processor to be used as part of an air traffic control system [6].

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