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by

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A 30-PAIR THIN FILM THERMOELECTRIC PILE

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Key words: thin-film thermoelectric pile, vacuum film coating, sensitivity, response rate, time constant, signal measurements and testing.

A thin-film thermoelectric pile is an infrared probe element without selectivity with respect to the optical spectrum. The performance indicators of a thermoelectric pile are stable; its structure is firm, sensitivity is high, and response time is short, and the response range of the optical spectrum is wide. A thin-film thermoelectric pile can operate at normal temperatures for measuring direct current. The instruments and meters involved do not require additional bias and do not require an adjustment system. Since the pile has its unique advantages, its applications are wide, used as reception elements for noncontact temperature measuring instrumentation, infrared interference alarm instruments, and hot-metal position detectors.

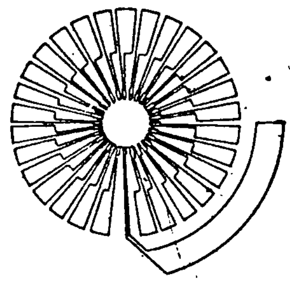

Fig. 1. Diagram showing mask board of 30-pair thin-film thermoelectric pile

II. Structure and Fabrication

A thin-film thermoelectric pile is fabricated by series connection of multiple pairs of thermocouples arranged on a certain rule. Every pair of thermocouples is fabricated by depositing a film coating with two high-purity metal materials (antimony and bismuth) on a mode-covering plate in high vacuum. For thermoelectric pile depositing on a polyester thin film adhering to the substrate of the thermoelectric pile, its structural shape is determined by the mask board. First, vacuum antimony depositing onto the mask board is conducted before bismuth butt-deposition. After bismuth is deposited, the forming of the thermoelectric pile is accomplished. Fig. 2 shows the forming layout of the 30-pair thin-film thermoelectric pile. After forming, the pile is coated in a black color. The function of the black coating is to increase the output response value of the thermoelectric pile. Later, the pile should be temperature-aged and electrically-aged in order to stabilize the pile. Fig. 3 shows the structure of the 30-pair thin-film thermoelectric pile developed by the authors.

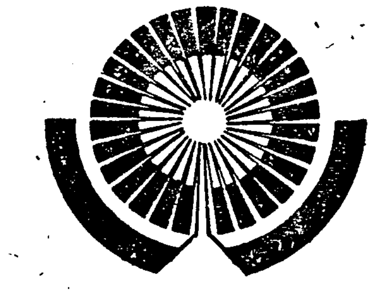

Fig. 2. Diagram showing shape of 30-pair thin-film thermoelectric pile

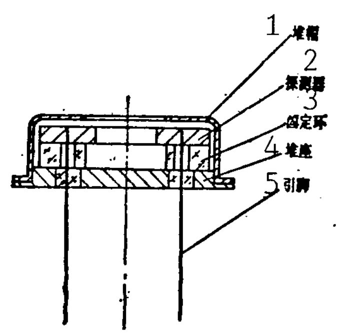

Fig. 3. Schematic diagram showing structure of 30-pair thin-film thermoelectric pile
KEY; 1 - pile cap 2 - probe 3 - fixed ring
4 - pile seat 5 - support footing

II. Base Material and Substrate Material

The thin-film thermoelectric pile is fabricated by depositing two different metal thin films onto a thermoelectric-pile by applying the high vacuum film deposition technique. the base material of the pile should adhere satisfactorily to the depositing layer of the pile, with good insulation. Moreover, the base material should have the temperature-aging property in fabricating such pile. The authors used the base materials with a high-pressure, low-density polyethylene thin film, a bidirectionally stretched polypropylene thin film, and a polyester thin film. The transmissibility of high-pressure, low-density polyethylene is good, but its thermal endurance is lower than 100°C, thus making it unsuitable as base material of the thermoelectric pile. The thermal endurance of bidirectionally stretched polypropylene is 125°C; its adherability is also good; however, its adherability to the high-purity metal layer of the pile is unsatisfactory. As proven experimentally, such polypropylene thin film is also unsatisfactory as the base material of the pile. The transmissibility of the polyester thin film is lower than that of polyethylene and polypropylene, but its thermal endurance and adherability to metal thin films are good. Therefore, the authors applied the polyester thin film as the base material of the thermoelectric thin-film pile.

Ceramic and aluminum alloys were used as the pile substrate. Talc porcelain powder was used as the starting material in making the ceramic substrate; in designing the molding die, the talc porcelain powder was cast with compression by heating prior to baking. After processing, the aluminum substrate should be anodized in order to upgrade its insulating properties. Both porcelain and aluminum alloy substrates are suitable as the pile substrate. In the pile developed by the authors, aluminum alloy substrate was the kind predominantly used.

III. Pile Seat and Pile Cap

The pile seat and cap can be machined according to the design requirements. Considering the machinability and exterior appearance, as the pile seat and cap the authors selected a transistor pipe seat and pipe cap. For a small thermoelectric pile, B-4 QD pipe seat was selected matching with a 6mm high pipe seat. For large thermoelectric piles, the pipe seat of an LM surface acoustic wave filter was chosen. In the factory-made pipe seats, the lead-out wire is relatively short, therefore the lead-out wires of two kinds of pipe seats were redesigned based on actual requirements.

IV. Main Technical Performance Indicators

Resistance, response rate, and time constant are three major technical properties of the thermoelectric pile. For the 30-pair thin-film thermoelectric pile, the resistance range is between 2 and 3kilo-ohms. Measuring and testing of the response rate involved the laser tube method. From the output of the laser tube, a light beam with a certain power illuminates the response surface of the pile, which outputs the corresponding thermoelectric voltage. When a 1mW laser beam illuminates the response surface of the pile, the output thermoelectric voltage is between 5.5 and 7.0mW. The time constant of the pile was tested with an Se 16 light ray recording oscillograph. The time required for the thermoelectric voltage to rise from 0 to 98% of the final value was less than 2s for large piles, and lower than

1s for small piles. Table 1 lists the test data.

TABLE 1. Measurement Data of Response Rate for 30-pair Thin-film Thermoelectric Pile

编 号 1	测试功率(mW) 2	响应率R(mV/mW) 3
T155	1.016	5.81
	86.8	5.70
T173	1.016	6.13
	86.8	6.22
T701	1.016	5.57
	86.8	5.51
T118	1.016	5.76
	86.8	6.66

Remark: Measurements were made at the China Academy of Metrology.
KEY: 1 - number 2 - testing power 3-response rate

The time constant curves of the thermoelectric pile are shown in Figs. 4 and 5.

V. Performance Experiments with Thermoelectric Pile

For quality inspection of the fabrication technique of the thin-film thermoelectric pile, the authors conducted environmental experiments of vibration, humid heating, high temperature, and low temperature (among other subjects). As shown by the experimental results, the thin-film pile can attain the requirements for environmental conditions.

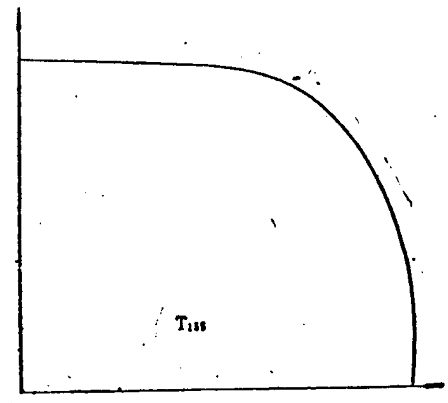

Fig. 4. Time constant curve of T_{155} thermoelectric pile

1. Oscillation experiments

The oscillation experiments involved the transportation, storage, and experimental method ZBY-002-81 for instruments and meters. In other words, under the conditions of 10g acceleration, the oscillation frequency was between 60 and 120times per minute, and impact oscillation was 1000times. Table 2 shows the situation for the thermoelectric pile specimens before and after the experiments.

2. Humid heating experiments

According to the transportation, storage, and experimental methods for instruments and meters, the experimental conditions are as follows: temperature, 40 plus or minus 2^{0}C; relative humidity, between 95 and 98%; and storage time, 48h. Table 3 shows the experimental situations.

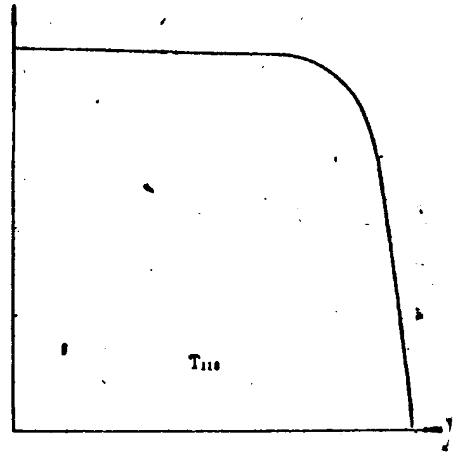

Fig. 5. Time constant curve of T_{118} thermoelectric pile

TABLE 2. Signal Variations Before and After Vibration of Thermoelectric Pile

a 热电堆振动前信号				b 热电堆振动后信号				
室温 (°C) c	中温炉温度 (°C) d	水冷套温度 (°C) e	信号 (μV) f	室温 (°C) c	中温炉温度 (°C) d	水冷套温度 (°C) e	信号 (μV) f	变化率 (%) g
32	600	40	470.50	33.5	600	40	470.75	+0.053
			405.00				409.00	+0.987
			454.00				453.25	−0.165
			433.60				436.00	+0.553

KEY: a - signal before vibration of thermoelectric pile b - signal after vibration of thermoelectric pile c - room temperature d - temperature of intermediate-temperature oven e - water-cooling jacket temperature f - signal g - variation rate

3. Low-temperature experiments

According to the transportation, storage and experimental methods for instruments and meters, the experimental conditions were as follows: temperature, -40 plus or minus $3^{\circ}C$; and storage time, 2h. Table 4 shows the situations after the experiments.

TABLE 3. Signal Variations After Vibration and Humid Heat Experiment of Thermoelectric Pile

室温 a (°C)	中温炉温度 (°C) b	水冷套温度 (°C) c	信号 d (μV)	变化率 e (%)
29.5	600	40	468.00	−0.584
			409.00	0
			458.00	+1.048
			430.60	−1.238

KEY: a - room temperature b - temperature of intermediate-temperature oven c - water cooling jacket temperature d - signal e - variation rate

4. High-temperature experiments

According to the transportation, storage, and experimental method for instruments and meters, the experimental conditions are as follows: temperature, 55 plus or minus 2°C; and storage time, 5h. Table 5 shows the situation after the experiment.

5. Stability experiments for thermoelectric pile

The authors conducted 200h of long-term stability experiments on the pile. Table 6 shows the experimental results.

6. Variation of resistance of pile before and after 100°C

The pile we placed in an oven to raise the temperature from room temperature to 100°c for 4h at the latter temperature. Then the temperature was again lowered to room temperature. The variation in resistance was measured before and after the temperature rise, as shown in Fig. 7.

TABLE 4. Signal Variations After Vibration and Humid-Heat Low-Temperature Tests of Thermoelectric Pile

室 温 a (°C)	中温炉温度 b (°C)	水冷套温度 c (°C)	信 号 d(μV)	变化率 e (%)
29	600	400	469.00	+0.213
			407.00	−0.489
			457.00	−0.218
			431.00	−0.093

KEY: a - room temperature b - temperature of intermediate-temperature oven c - water cooling jacket temperature d - signal e - variation rate

7. Signal testing at different positions

The same thermoelectric pile was placed at different positions; Table 8 shows the measurement results.

From Table 8, the output signals will be different when there is a stable oven temperature during testing, with a change in the positions in which the pile was installed.

VI. Signal Testing of Same Type of Thermoelectric Pile

Generally, the structural shape of the thin-film thermoelectric pile is in two types: strip-shaped, and radial-shaped. Developed by the authors' institute, the thin-film thermoelectric pile is radial-shaped; in this shape, there are models of this pile in China and abroad. Measurements and tests were made by the authors.

TABLE 5. Signals After Vibration as Well as Testing with Humid Heat, Low Temperature, and High Temperature of the Thermoelectric Pile

室 温 a (0°)	中温炉温度 b (°C)	水冷套温度 c (°C)	信 号 d (μV)	变化率 e (%)
28	600	400	470.00	+0.213
			405.00	−0.491
			453.00	−0.875
			431.00	0

KEY: a - room temperature b - temperature of intermediate-temperature oven c - water cooling jacket temperature d - signal e - variation rate

1. Measurement and test conditions

The optical system is a dual-reflection lens system. The diameter of the optical examination aperture is 1m. The color filter wafer is between 8 and 14micrometers; the test distance is 1m; and the furnace temperature is controlled at 300^{0}C. Table 9 shows the test results.

2. Table 10 shows the results of measuring and testing under the same conditions.

VII. Applications

Developed by the authors, the thin-film thermoelectric pile has a range of temperature measurement between 100 and 500^{0}C, with a response time less than or equal to 1s (for 98% of the final value) in the model WFHZ-81 microcomputer infrared radiation thermometer. All the technical indicators of the sample device satisfied the design requirements. On-site experiments of the sample infrared radiation thermometer were conducted at a steel plant, with good results.

TABLE 6. Stability Experiments of Thermoelectric Pile

时间 (h) a	24	48	72	96	120	144	168	192	200	差值 c	变化率 (%) d
b 信	458	457	459	459	459	459	458	458	458	±1	±0.22
号	448	449	449	447	449	449	448	448	448	±1	±0.22
(μV)	432	432	433	434	433	433	433	433	433	+2	+0.46

Remarks: 1 - 600°C intermediate-temperature oven 2 - 40°C reference terminal of thermoelectric pile 3 - 1905 Q for test instrument 4 - variation rates of stability experiments of thermoelectric pile include fluctuation in oven temperature, temperature error of isothermal water bath, variation of ambient temperature, and test instrument errors

KEY: a - time b - signal c - difference in value d - variation rate

VIII. Conclusions

(1) The thin-film thermoelectric pile described above is an infrared probe device with vacuum film deposition by using the mask method. Its stability is good, the noise is low, and its linearity is also good.

(2) The above-mentioned pile employed a pipe seat and cap of a semiconductor device so that the pile has unique features of small size, attractive appearance, and firm structure. Its cost

is low, and it is easy to produce in lots.

TABLE 7. Variation of Resistance Before and After 100°C for Thermoelectric Pile

热电堆加热前 a		热电堆加热后 b		变化率 c
室温(°C) d	阻值(kΩ) e	室温(°C) d	阻值(kΩ) e	(%)
18	3.741	19.5	3.743	+0.05
	2.931		2.939	+0.27
	2.861		2.863	+0.07

KEY: a - before heating the thermoelectric pile b - after heating the thermoelectric pile c - variation rate d - room temperature e - resistance value

(3) The thin-film thermoelectric pile is the core component in an infrared temperature measuring instrument. Its successful development will have the corresponding function of developing novel types of infrared instruments and meters.

[Photograph of Shao Quilin, one of the authors, appears at beginning of article]

TABLE 8. Signal Measurements and Tests for the Same Thermoelectric PIle at Different Positions

角　度 a	信号(μV) b	变化率(%) c
0°	460	0
60°	472	+2.61
120°	470	+2.17
180°	484	+5.22
240°	472	+2.61
300°	450	−2.17

KEY: a - angle b - signal c - variation rate

Remarks: 1 - Temperature of intermediate-temperature oven was 600°C during tests 2 - 40°C was temperature of the water-cooling jacket temperature of the thermoelectric pile

TABLE 9.

编 a 号	T119	T121	T135	T144	1 M
信号(μV) b	153	156	165	164	151

Remarks: 1 - 1M is an imported model 2 - T_{119} and T_{121} are small thermoelectric piles at the authors' institute 3 - T_{135} and T_{134} are large thermoelectric piles at the authors' institute
KEY: a - number b - signal

TABLE 10

编　号 a	T155	T173	T202	T203	68	1 M
信号 (μV) b	1336	1434	1153	1168	1044	1142

Remarks: 1 - T_{155} and T_{163} are large thermoelectric piles at the authors' institute 2 - T_{202} and T_{203} are small thermoelectric piles at the authors' institute 3 - No. 68 is a model at other work unit in China 4 - No. 1M is an imported model
KEY: a - number b - signal

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