Development History and Current Situation of Resistor Array Technology at Home and Abroad

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ABSTRACT
The development experience and current situation of resistance array technology at home and abroad are briefly reviewed. Foreign resistance array technology started early and completed the development from small-scale to large-scale, from scanning to snapshot. At present, it is developing towards specialization such as ultra-high temperature resistance array. Domestic resistance array technology has experienced three generations of technology. The first generation is manufactured by PMOS process, with poor performance; The second generation is manufactured by CMOS process, which solves most of the performance problems, but the duty cycle and scale are restricted by processing technology, so it is difficult to improve; The third generation uses membrane transfer technology to solve the conflict of two-dimensional machining technology between the duty cycle and circuit complexity, but the technology and process maturity still need to be improved.

Keywords: *Resistor Array, Infrared Scene Projector, Hardware in the Loop Simulation*

1. INTRODUCTION

Infrared imaging technology undoubtedly plays an important role in the research and development of modern guided weapon system. With the development of technology, the performance index of infrared imaging guidance weapon system is rising, and the function is becoming more and more complex. In the field of electro-optical countermeasures technology, the confrontation between spear and shield is becoming increasingly fierce. A key research topic is how to evaluate the performance of infrared system in the design process of high-precision infrared detection system. The traditional infrared system performance evaluation process is to carry out software simulation in the early stage, and field test and real system test after the system construction in the later stage. Firstly, it is difficult to simulate a comprehensive and real infrared scene at the pure software level. Secondly, in the field test and real system test, the long cycle and high cost have always been a difficult problem to solve. If only the field test is used to verify and test the infrared guided weapon system, it is bound to prolong the development cycle of the weapon system, The development cost has increased greatly. In order to solve the above problems, infrared imaging hardware in the loop simulation technology came into being. Infrared imaging hardware in the loop simulation technology has extremely important application value in constructing high-precision infrared scene in the laboratory, verifying the tracking algorithm in real time, and reducing the time and cost of infrared system design. Some studies show that when using the hardware in the loop infrared scene simulation system based on MOS resistor array to test an infrared system, the longer the time of using the hardware in the loop infrared scene simulation system, the lower the test cost[1].

As early as 1969, the US Army night vision and electro-optical laboratory used a method of covering the target mask on the blackbody to simulate the infrared image. When using this method, the temperature difference between the target and the background is not higher than 4k [2]. Then a variety of hardware in the loop infrared scene simulation systems have sprung up. Now, the hardware in the loop infrared scene simulation system has become the primary means to evaluate and test various military infrared imaging systems. Infrared target projector is the core component of hardware in the loop infrared scene simulation system. Its function is to convert the simulated infrared image data generated by computer into real dynamic infrared image, so as to simulate the infrared scene similar to the real scene. The dynamic infrared image will be received by the imaging device of the infrared system, and a series of performance indexes of the infrared system, such as the accuracy of tracking algorithm, will be simulated and tested. In terms of hardware in the loop simulation technology in the world, the United States is the most advanced country and has applied a series of infrared target projectors based on resistance array devices, digital micromirror (DMD) devices and laser diode array devices to the hardware in the loop infrared scene simulation system[3-6]. Among these infrared target projectors, the infrared target projector based on resistance array ranks first in the procurement share of U.S. military infrared simulation devices because of its excellent performance of high frame rate, high maximum temperature difference and high gray level, and fully covers the infrared target simulation applications of the U.S. Army, navy and air force.

2. WORKING PRINCIPLE OF RESISTANCE ARRAY

MOS resistor array is the core component of the hardware in the loop infrared scene simulation system based on resistor array. Its structure is shown in Figure 1. Each cell of MOS resistor array is called pixel, which is composed of MOS resistor and unit driving circuit. The unit driving circuit is actually a voltage controlled current source, which controls the current flowing through the MOS resistor by controlling the voltage of the driving circuit, so as to control the infrared radiation intensity of the MOS resistor. The loading position of the control voltage will be controlled by the location circuit of the MOS resistance array. When the location circuit is scanned and gated, the control voltage will change with the simulated infrared image data generated by the computer, generate the corresponding infrared radiation intensity on the MOS resistance of each pixel, and then project the corresponding infrared image.

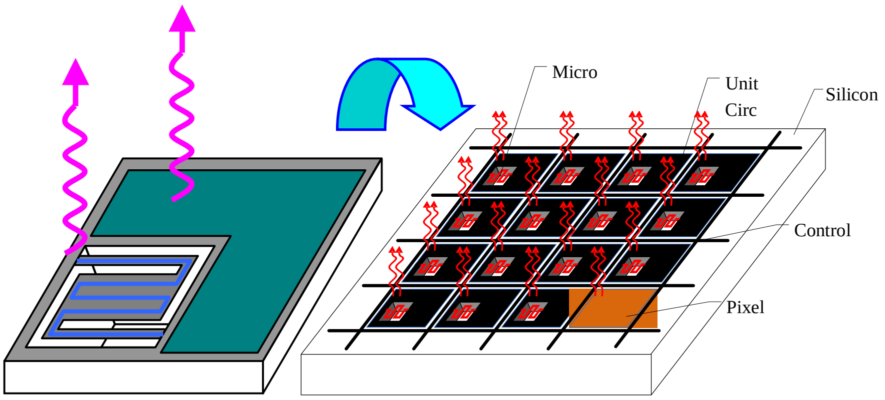

Figure 1. Schematic diagram of resistor array structure

3. DEVELOPMENT HISTORY AND CURRENT SITUATION ABROAD

In terms of the research and development of foreign resistor arrays, more representative ones are British Aerospace Corporation (BAE), Honeywell of the United States and Santa Barbara infrared (SBIR) of Canada [7-9]. As early as 1991, BAE developed TPS-4 resistor array with a pixel scale of 256 × 256 and a frame rate of 250Hz. Honeywell subsequently developed nodds type I resistor array in 1992, with a pixel scale of 128 × 128 and a frame rate of 100Hz. Later, BAe company launched TPS-5 resistor array, a successor product of TPS-4 resistor array, in 1998, upgrading the pixel scale to 512 × 512, and can reach a frame rate of 120Hz. In the same year, Honeywell launched DIRSP resistor array with pixel scale of 672 × 544, the frame rate can reach 180hz at most. The previous resistor array mostly adopts scanning driving mode. The location circuit will gate each column of the resistor array in turn and input the voltage signal in order to scan and light the pixels column by column. This driving mode will make the lighting time of each pixel in the resistor array different in the same frame. In addition, the resistor itself has a certain temperature rise time, so the infrared image projected by the resistor array will have a certain time delay and tear, which will have a certain impact on the simulation accuracy. Therefore, SBIR company added a control voltage sampling capacitor, a reset MOS transistor transmission gate and a snapshot MOS transistor transmission gate in the traditional unit driving circuit, changed the traditional scanning unit driving circuit into snapshot unit driving circuit, and developed MIRAGE-1 resistor array in 1999. MIRAGE-1 resistor array uses snapshot driving mode to realize synchronous lighting of all pixels, with a pixel scale of 512 × 511 and a frame rate of 200Hz. After that, BAe and Honeywell also successively invested in the development of resistor array based on snapshot driving mode. In 2000, Honeywell developed BRITE II resistor array with a pixel scale of 512 × 512 and a frame rate of 200Hz. In 2005, Bae developed TPS III resistor array with pixel scale up to 1024 × 1024, and can reach a frame rate of 200Hz. As for SBIR, it acquired Honeywell's resistor array technology in 2001, which made SBIR become a leader in the field of resistor array. After that, SBIR company continued the technical route of Honeywell company, and successively developed mirage series resistor array products with different technical index requirements, such as MIRAGE-1.5, MIRAGE-H, MIRAGE-XL, MIRAGE-CR1, MIRAGE-WF1, MIRAGE-XL-CR1, etc. These products have a radiation temperature of up to 675K, and their frame rate can reach 200Hz and up to 400Hz. Among them, the pixel scale of MIRAGE-XL series resistor array is 1024 × 1024, the pixel scale of MIRAGE-WF series resistor array is 1536 × 768[10]. MIRAGE-CR series resistor array is mainly aimed at simulating deep space infrared background. It can work in ultra-low temperature environment, and the minimum radiation temperature can reach 50K.

At present, the development of foreign resistor array technology has been very mature and can meet the needs of most hardware in the loop infrared real-time simulation. However, the development of infrared imaging guidance weapon system has driven greater demand for pixel scale, maximum frame rate and maximum radiation temperature, which has also prompted many researchers and institutions to carry out continuous work in this field [11]. In terms of improving the pixel scale, like most integrated circuits, subject to the production technology of large-scale integrated circuits, the fabrication yields of read-in integrated circuits (RIIC) driving resistor arrays will decrease significantly with the increase of size, which means that it is impractical to drive the resistor array which scale is larger than 1024 × 1024 with a single RIIC. It also challenges the material, pixel structure and RIIC design of resistor array in improving the maximum frame rate and maximum radiation temperature. In recent years, SBIR has carried out an ultra-high temperature resistance array (UHT) project. The UHT program is funded by the Test Resource Management Center (TRMC) Test and Evaluation/Science & Technology (T&E/S&T) Program through the U.S. Army Program Executive Office for Simulation, Training and Instrumentations (PEO STRI). The goal is to design, assemble and test a new infrared hardware in the loop simulation system, the system will have more excellent performance in terms of pixel scale, maximum frame rate and maximum temperature [12]. The project designed a new RIIC. Through the through-silicon vias (TSVs) and quilt packaging (QP) technologies, the RIIC can support the seamless splicing of multiple RIICs of the same standard to manufacture super large resistor arrays. At the same time, UHT project also explored a pixel structure called "fast turn", which is formed by directly depositing the film on the silicon substrate instead of the polyimide spacer of the previous standard pixel, and then etching the silicon substrate to form a suspended micro suspended bridge structure. Although the maximum radiation temperature of the pixel of this structure is lower than that of the standard pixel, it can make the pixel manufacture faster and lower cost, which is convenient for the data collection and advance verification of various technical indexes and performance of the resistor array before formal finalization and manufacture. Simulation on a 512 × 768 size RIIC has confirmed that the design can achieve a maximum frame rate of 500Hz and provide an ultra-high radiation temperature of more than 1500k [13]. The project is still in progress now, and the next goal is 2000K. Bae also published a research project on ultra-high temperature resistor array, with the ultimate goal of reaching the maximum radiation temperature of 2500K, or even 3000K.

Due to the technical maturity of resistor array and its advantages in frame rate and radiation temperature difference, most of the hardware in the loop simulation experiments of infrared imaging guidance system abroad choose the infrared scene projection device with resistance array as the core device. The U.S. Navy used BAe's TPS-4 resistor array as the core to build its "standard-3" missile kinetic kill warhead test and evaluation system [14], and the U.S. Air Force also used its infrared hardware in the loop simulation system with Honeywell's Brite II resistor array as the core to conduct a series of tests on the infrared seeker of its high-altitude kinetic kill weapon [15].

4. DEVELOPMENT HISTORY AND CURRENT SITUATION AT HOME

The resistor array started late in China. At first, it was imitated according to the open literature of foreign countries. Later, with the progress of technology and the development of domestic semiconductor industry, it gradually formed its own technical roadmap. Shanghai Institute of Technical Physics, Chinese Academy of Sciences successfully developed the first domestic principle 8 × 8 resistor array device in 1993, and based on this, developed the first generation of domestic 64 × 64 resistor array. The circuit of the domestic first generation 64 × 64 resistor array is manufactured by PMOS process, and the monocrystalline silicon micro bridge array is manufactured by silicon anisotropic etching technology based on EDP (catechol + ethylenediamine + water). Due to many problems such as small scale, high power consumption, low radiation capacity and poor resistor uniformity, the practicability of the first generation of domestic resistor array is obviously insufficient, which can only be used as a device for technical accumulation and principle verification.

Based on the domestic first generation resistor array technology, Shanghai Institute of Technical Physics has developed the domestic second generation resistor array technology. The circuit of domestic second generation resistor array is manufactured by CMOS process, abandoning the EDP etching technology with obvious short board and selecting TMAH (tetramethylammonium hydroxide) etching technology compatible with CMOS process, so that the composite membrane microbridge structure can be designed and manufactured [16]. Compared with the monocrystalline silicon membrane of the first generation resistor array, the composite membrane of the second generation resistor array uses a separate heater to separate the heating function from the support and radiation functions, which solves the problems of too small micro bridge resistance, poor uniformity and small duty cycle. During the Tenth Five Year Plan period, Shanghai Institute of Technical Physics completed the development of 128 × 128 resistance array based on domestic second-generation resistor array technology. Compared with the first generation resistor array, its micro bridge resistor has doubled, the duty cycle has increased nearly three times, the resistance uniformity has been significantly improved, and the problem of heating fracture of monocrystalline silicon micro bridge in vacuum environment has been solved, The resistance array can run in the vacuum environment, which avoids the reduction of radiation intensity caused by the contact between the micro bridge resistor and the filling gas, and reduces the power consumption of the resistance array. During the Eleventh Five Year Plan period, Shanghai Institute of Technical Physics further developed the domestic second generation 256 × 256 resistor array based on the second generation domestic 128 × 128 resistor array. Compared with 128 × 128 resistor array, it adopts more advanced CMOS process, expands the pixel scale, increases the duty cycle of micro bridge and reduces the power consumption of resistor array, It can reach a maximum medium wave radiation temperature of 600k and a frame rate of 200Hz.

Both the domestic first and second generation resistor arrays use the two-dimensional processing technology that the circuit and micro bridge are on the same plane and share the whole pixel area, resulting in the problem of binary choice with conflicting duty cycle and circuit complexity, and restricting the performance of the resistor array in both aspects. Two-dimensional processing technology can also be used to develop 512 × 512 scale resistor array, but for larger scale resistor array, two-dimensional processing technology is no longer applicable. As early as the mid-1990s, the United States transplanted the technology used in the development of uncooled infrared focal plane detector to the manufacturing of resistor array, fine micromachined the silicon wafer on the circuit with silicon wafer, and completed the development of suspended membrane array. In this resistor array structure, the thin film structure is suspended above the circuit and only uses the slender legs as the contact point to contact the lower circuit. This structure solves the problem that the micro bridge and the circuit occupy a limited pixel area. However, there is no process and conditions to realize this processing technology in China. In order to solve this problem, Shanghai Institute of Technical Physics has developed a hybrid technology that processes integrated circuits and micro bridge arrays separately and combines them through special processes. Through this technology, domestic 128 × 128 suspended membrane resistor arrays have been successfully manufactured during the Eleventh Five Year Plan period. Compared with the previous generation products, the duty cycle of 128 × 128 suspended membrane resistor array has been greatly improved, the maximum radiation temperature of medium wave has reached 580k, and the power consumption has been greatly reduced. Although the domestic third generation resistor array technology is not mature enough, and there is still space for improvement in many aspects of process level and performance index, with the continuous breakthrough of key technologies, domestic resistor array technology and domestic infrared hardware in the loop simulation system will step to a new level.

5. CONCLUSIONS

Foreign resistor array technology began in the late 1980s. After decades of development and application, it has reached a very high level in most process and performance indexes, and is developing to larger scale, higher temperature and higher frame rate now. From the initial imitation to the precipitation of three generations of technology, domestic resistor array technology has broken through the micromachining process of resistor array and laid the technical foundation of domestic large scale resistor array. However, compared with foreign countries, China's domestic resistor array is still far inferior to the most advanced foreign similar products in various technical indexes, and there is still a gap of at least 20 years in resistor array technology. We still have a long way to go in realizing the localization of high-end large-scale resistor arrays and building China's domestic infrared hardware in the loop simulation system.

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