Notice

DESCRIPTION CN119362000A

An integrated apparatus and method for preparing ferrite-microwave dielectric ceramic composite substrates using flash Joule heating.

一种利用闪蒸焦耳热法制备铁氧体-微波介质陶瓷复合基板的一体化设备及方法

[0001]

Technical Field

技术领域

[n0001]

This invention belongs to the field of composite material preparation, and specifically relates to an integrated device and method for preparing ferrite-microwave dielectric ceramic composite substrates using flash Joule heating.

本发明属于复合材料制备领域，特别涉及一种利用闪蒸焦耳热法制备铁氧体-微波介质陶瓷复合基板的一体化设备及方法。

[0003]

Background Technology

背景技术

[n0002]

In modern radar systems, microwave ferrite circulators are a key magnetic device. Their function is to use ferrite gyromagnetic materials and magnetic resonance to achieve signal isolation and transmission, thereby controlling the signal connection and disconnection between the antenna and the transceiver branch.

在现代雷达系统中，微波铁氧体环行器是一种关键磁性器件，其作用是利用铁氧体旋磁材料和贴磁共振来实现信号的隔离和传输，以控制天线与收发支路的信号通断。

With the rapid development of radar technology, microwave devices and components are developing towards miniaturization, integration, high power density, and broadband.

随着雷达技术的迅猛发展，微波器件和组件向着小型化、集成化、高功率密度化、宽带化的方向发展。

Microstrip loop devices designed based on traditional single ferrite substrates are limited by the low dielectric constant, high magnetic loss, and low thermal conductivity of ferrite materials, as well as technical problems such as second harmonic interference. The miniaturization, broadband, and high power performance of these devices have reached their limits and cannot meet the needs of the development of high-power, ultra-wideband (S-Ku) radar.

而基于传统单一铁氧体基片设计的微带环行器件受制于铁氧体材料的介电常数低、磁损耗大、导热系数低，且存在二次谐波干扰等技术问题，器件小型化、宽带化、高功率作用已趋于极限，不能满足新型雷达高功率、超宽带(S-Ku)发展的需要。

Microwave dielectric ceramics have become a research focus in the field of materials science due to their excellent properties, such as low dielectric loss, high dielectric constant, and relatively stable temperature coefficient of dielectric constant. Therefore, developing heterogeneous integrated circulators can inherit the technical characteristics of dielectric ceramics, such as high dielectric constant, low loss, and tunable performance, to achieve miniaturization and ultra-wideband performance breakthroughs, and solve the problem that single ferrite devices cannot meet the requirements of ultra-wideband, high power, and low impedance matching. Existing heterogeneous integration processes include co-firing, glass slurry brazing, and bonding. However, these connection methods have significant drawbacks. For example, co-firing requires different materials to have similar coefficients of thermal expansion; otherwise, stress mismatch between materials may occur during sintering, leading to cracks or failure. While glass slurry brazing can provide better sealing performance, its mechanical strength is usually lower than that of traditional metal brazing or welding techniques. Glass itself is brittle and is prone to cracking or breaking when subjected to impact, vibration or mechanical load. Furthermore, all of the above-mentioned connection methods require a relatively long molding time. Therefore, a new and efficient connection method is needed to prepare high-quality ferrite composite substrates. Flash Joule heating (FJH) is a method based on the instantaneous high temperature generated by capacitor discharge. Its principle is to use the Joule heat generated when current passes through a conductor to rapidly heat the conductor material. Unlike traditional heating methods, FJH can reach extremely high temperatures (>2500K) instantaneously. The huge temperature

gradient reduces the side effects of long-term high-temperature heating and has been widely used in the efficient preparation of materials such as graphene, high-entropy alloys, and electrode materials.

微波介质陶瓷由于具有优异的性能，已成为现今材料科学领域的研究重点，它具有介电损耗低、介电常数高，介电常数温度系数相对稳定等优点。 因此，开发异质集成环行器可以继承介质陶瓷的高介电常数、低损耗以及性能可调控等技术特点，实现器件的小型化和超宽带性能突破，解决单铁氧体器件无法满足超宽带、高功率和低阻抗匹配难题。 现有的异质集成工艺包括共烧、玻璃浆料钎焊连接、胶结等。 然而这些连接手段都有较大的弊端，例如共烧工艺要求不同材料具有相似的热膨胀系数，否则在烧结过程中可能会导致材料之间的应力不匹配，从而引发裂纹或失效；而玻璃浆料钎焊虽然可以提供较好的密封性能，但其机械强度通常低于传统的金属钎焊或焊接技术。 玻璃本身较脆，在受到冲击、振动或机械负荷时容易发生破裂或断裂。 并且上述连接手段都需要经历较长的成型时。 因此需要开发一种全新高效的连接手段以制备高质量的铁氧体复合基片。 闪蒸焦耳加热(FJH)是一种基于电容器放电产生瞬时高温的方法，其原理是利用电流通过导体时产生的焦耳热，使导体材料迅速加热。 与传统加热方法不同，FJH可以在瞬时达到极高的温度(>2500K)，巨大的温度梯度减轻了长期高温加热的副作用，已被广泛的运用于石墨烯、高熵合金、电极材料等材料的高效制备。

[0005]

Summary of the Invention

发明内容

[n0003]

To address the problems existing in the prior art, this invention provides an integrated device and method for preparing ferrite-microwave dielectric ceramic composite substrates using flash Joule heating. This method can achieve high-quality bonding between ferrite wafers and microwave dielectric ceramics in a very short time. The resulting composite substrate has a narrow transition region of heterogeneous materials, which greatly avoids the deterioration of electromagnetic properties caused by the irregular element distribution in the transition region. Furthermore, this invention can control the heating time to adapt to the preparation requirements of different materials.

针对现有技术存在的问题，本发明提供一种利用闪蒸焦耳热法制备铁氧体-微波介质陶瓷复合基板的一体化设备及方法，可以在极短的时间完成铁氧体圆片和微波介质陶瓷的高质量连接，所制备出的复合基片异质材料过渡区窄，极大程度上避免了过渡区内无规则元素分布引起的电磁性能恶化，且本发明可以控制通电加热的时间，以适应不同材料的制备需求。

It saves production time, shortens the production cycle, and improves economic efficiency.

节约了生产时间、缩短了生产周期、提高了经济效益。

[n0004]

This invention is achieved through the following technical solution:

本发明通过下述技术方案实现：

[n0005]

An integrated device and method for preparing ferrite-microwave dielectric ceramic composite substrates using flash Joule heating is characterized by comprising a central control system, a recognition camera, a path planning system, a Joule heating system, a base, a preheating system, a reaction chamber, and conductive fixtures.

一种利用闪蒸焦耳热法制备铁氧体-微波介质陶瓷复合基板的一体化设备及方法，其特征在于：包括中央控制系统、识别摄像头、路径规划系统、焦耳加热系统、基台、预加热系统、反应腔室、导电夹具。

[n0006]

The central control system plays a role in command transmission and data processing in the entire integrated equipment, and connects the path planning system, recognition camera, Joule heating system, base temperature control system, and telescopic system of upper and lower cover plates of reaction chamber.

中央控制系统在整个一体化设备中起到命令传递、数据处理的作用，连接路径规划系统、识别摄像头、焦耳加热系统、基台温度调控系统、反应腔室上下盖板的伸缩系统。

[n0007]

The path planning system connects to a visual scanning camera and is integrated with the central control system. The visual scanning camera identifies the color changes of ferrite and microwave dielectric ceramic on the composite substrate and the diameter of the materials to determine the relative positions of dissimilar materials. The data is transmitted to the central control system. The central control system receives the transmitted signal, plans the travel route, adjusts the position of the cover plate telescopic rod, and transmits the planar path signal to the path planning system. After receiving the signal, the path planning system completes the travel command and transmits the completion command to the central control system. The central control system then transmits the discharge signal to the flash heating system according to the manually input parameter signal to complete the discharge.

路径规划系统连接视觉扫描摄像头并与中央控制系统集成，视觉扫描摄像头识别复合基板上铁氧体与微波介质陶瓷的颜色变化以及材料的直径大小以确定异种材料的相对位置，将数据传输到中央控制系统，中央控制系统接收传输信号规划行进路线规划，调整盖板伸缩杆位置，并将平面规划路径信号传输到路径规划系统，路径规划系统接收信号后完成行进指令并向中央控制系统传输完成指令，中央控制系统根据手动输入的参数信号随即对闪蒸加热系统传递释电信号，完成放电。

[n0008]

The Joule heating system is used for the storage and release of electrical energy. It is equipped with 20 capacitors, which are charged by connecting the power supply before the experiment.

焦耳加热系统用于电能的存储及释放，内配备20个电容器，在实验进行前接通电源对电容器充电。

After preparation is complete, a standby signal is released. The central control system recognizes the signal and adjusts the extension distance of the upper and lower cover plates so that the upper cover plate electrode contacts the upper surface of the ferrite and the lower surface contacts the conductive copper sheet. During the experiment, the Joule heating device automatically measures the resistance value at the connection point. Based on the discharge signal transmitted by the central control system, the signal parameters are

analyzed to determine the required voltage value, and a portion of the capacitors are selected to discharge the material. The resistance value, discharge time, voltage, current and other parameters are recorded and transmitted back to the central control system.

准备完毕后释放待机信号，中央控制系统识别信号并调整上下盖板伸缩距离使上盖板电极与铁氧体上表面接触，下表面与导电铜片接触，实验时焦耳加热设备自动测量接通处电阻值，根据中央控制系统传输的释电信号，分析信号参数判断所需要的电压值并选取部分电容器对材料放电，并记录电阻值、放电时间、电压电流等参数传回中央控制系统。

[n0009]

The base is connected to the lower cover plate, and heating resistance wires surround the base. The temperature control system is integrated with the central control system, which can preheat the base and improve the material activity.

基台与下盖板相连，基台四周环绕加热电阻丝，温控系统与中央控制系统集成，可实现对基台的预加热，提高材料活性。

The cover plate has an array of through holes arranged in the same way as the microwave dielectric ceramic substrate. The diameter of the cover plate holes is slightly larger than the diameter of the ferrite disc. Conductive copper wires are arranged inside the through holes. Copper sheets are welded to the upper part of the copper wires and embedded in the cover

plate at a distance of about 0.5mm from the upper surface to fix the position of the ferrite disc and make full contact with the copper sheet.

盖板上排布阵列贯穿孔径，排列方式与微波介质陶瓷基片一致，盖板孔径直径略大于铁氧体圆片的直径，贯穿孔径内部排布导电铜线，铜线上部焊接铜片嵌入盖板与上表面约0.5mm距离以便于固定铁氧体圆片的位置并与铜片完全接触。

[n0010]

The reaction chamber consists of four parts: the uprights, the upper cover plate and the upper cover plate telescopic rod, the lower cover plate and the lower cover plate telescopic rod, and the quartz glass outer wall.

反应腔室由立杆、上盖板及上盖板伸缩杆、下盖板与下盖板伸缩杆、石英玻璃外壁四部分组成。

The upper part of the pole has a hole to facilitate the neat connection of all wires.

立杆上部开孔便于所有线路规整接出。

The upper part of the cover plate is connected to the telescopic rod, and the lower part is connected to the path planning system.

上盖板上部与伸缩杆相连下接路径规划系统。

The upper part of the lower cover plate is connected to the base, and the lower cover plate and the base have the same through-array aperture, which facilitates the connection of array copper wires.

下盖板上部与基台相接，下盖板与基台分布相同的贯穿阵列孔径，便于阵列铜导线接出。

The lower cover plate is connected to the lower telescopic rod, and works simultaneously with the upper cover plate to achieve the Z-axis movement of the composite substrate.

下盖板下部与下伸缩杆相连，与上盖板同时作用以实现复合基片的Z向运动。

[n0011]

The recognition camera is a high-precision visual recognition camera that can scan and identify the specific location and size of materials of different colors.

识别摄像头为高精度视觉识别摄像头，可扫别出不同颜色材料的具体位置以及大小。

The visual recognition camera is connected to the central control system, which can transmit scanning signals in real time to analyze the position and size of foreign materials. Based on this signal, the central control system works in conjunction with the path planning system to complete high-precision route travel.

视觉识别摄像头连接中央控制系统，可将扫描信号实时传入，以分析异种材料的位置及大小，根据此信号，中央控制系统与路径规划系统联动以完成高精度的路线行进。

In addition, after the electrolytic process is over, the diffusion trend and range of the elements can be judged based on the color change, which can be used to roughly assess the quality of the experiment.

此外释电过程结束后还可以根据颜色变化判断元素扩散趋势以及扩散范围，可对实验质量进行粗略评估。

[n0012]

The conductive clamp is designed for non-conductive ferrite materials. In specific experiments, it can clamp the composite substrate and perform thermal processing on the composite substrate through its own Joule heating effect. The array aperture on the upper surface is consistent with the aperture distribution on the ceramic substrate, and the diameter is smaller than the diameter of the ferrite disc to facilitate clamping the ferrite. At

the same time, sufficient scanning points are left for the scanning head and infrared camera. The lower part has a groove and protrudes downward to facilitate the accommodation of the ferrite disc and cooperate with the groove on the substrate so that the entire conductive clamp is in a conductive path when the voltage is released.

导电夹具针对不导电的铁氧体材料，在具体实验过程中可将复合基片夹住，通过其自身的焦耳热效应对复合基片进行热加工，上表面阵列孔径与陶瓷基板上孔径分布一致，直径小于铁氧体圆片直径以便于将铁氧体夹住，同时留出扫描识别头和红外摄像头足够的扫描位点，下部有凹槽并向下凸起，便于容纳铁氧体圆片并与基板上的凹槽配合使整个导电夹具在释放电压时处于通路。

[n0013]

The path planning system includes an infrared temperature recognition head, which can perform infrared scanning on microwave dielectric ceramic substrates and ferrite wafers during the preheating stage. The scanned temperature signals are transmitted to the central control system to further adjust the temperature range. During the Joule heating stage, the heating curve can be recorded to select the most suitable process parameters.

路径规划系统包含一个红外温度识别头，在预热阶段可对微波介质陶瓷基板以及铁氧体圆片进行红外扫描，扫描出的温度信号传递给中央控制系统以进一步调节温度范围，焦耳加热阶段可记录升温曲线从而筛选出最合适的工艺参数。

In addition, the X slider in the path planning system contains a graphite electrode (in this case, the negative electrode) to adapt to the working environment under ultra-high temperature conditions.

此外，路径规划系统中X滑块上包含一个石墨电极(此处为负极)，以适应超高温下的工作环境。

The graphite electrode, scanning head, and infrared thermometer are all located on the X slider.

其中，石墨电极、扫描识别头、红外测温仪同时分布于X滑块。

[n0014]

The Joule heating system can charge 20 capacitors at once, and can be partially discharged as needed, allowing for multiple discharges. In addition, it is equipped with real-time voltage monitoring and safety valves to ensure that the voltage is below safe levels when the device is fully discharged.

焦耳加热系统可一次性完成对20组电容器的充电而使用时可根据需求选择部分放电从而可多次放电，此外配有实时电压监测和安全阀门以保证整个设备放电结束时人体可接触的在安全电压以下。

[n0015]

A circuit box is fixed at the bottom of the base. External copper wires are integrated here and connected to the electrode (the positive electrode in this case) and the Joule heating device.

基台下部固定一个电路箱，外接的铜导线在此处集成并共同与电极(此处为正极)相连并外接焦耳加热设备。

[n0016]

The bottom of the reaction chamber is connected to the side of the upright rod with a fixed base platform. A raised ring around the outer wall of the base platform is used to fix the quartz glass tube and prevent it from sliding.

反应腔室底部与立杆侧接有固定底座台，底座台外壁一圈凸起以固定石英玻璃管防止产生滑动位移。

Both the upper and lower cover plates are covered with silicone spiral pads on their outer rings to enhance friction with the tube wall.

上下盖板外环皆覆有硅胶螺旋垫以加强与壁管的摩擦。

[n0017]

An integrated apparatus and method for preparing ferrite-microwave dielectric ceramic composite substrates using flash Joule heating, characterized by the following steps:

一种利用闪蒸焦耳热法制备铁氧体-微波介质陶瓷复合基板的一体化设备及方法，其特征在于采用以下步骤：

[n0018]

Step 1: Preparation before composite substrate fabrication mainly includes the preparation of ferrite and microwave dielectric ceramic materials. Ferrite is processed into small discs, and microwave dielectric ceramic is processed into substrates and holes are drilled according to regulations. The diameters of the discs and holes are designed based on the difference in thermal expansion between dissimilar materials, so that the circular holes on the substrate are slightly larger than the discs.

步骤一：复合基片制备前的准备，主要包括铁氧体与微波介质陶瓷材料的制备，将铁氧体加工成小圆片，将微波介质陶瓷加工成基片并按规定打孔，其中根据异种材料热膨胀的差距设计圆片与孔的直径，使基片上的圆孔略大于圆片。

[n0019]

Step 2: Place the microwave dielectric ceramic substrate on the substrate and manually insert the disc into the circular hole using tweezers.

步骤二：将微波介质陶瓷基片放在基板上，手工用镊子将圆片嵌入圆孔。

When embedding, care should be taken to ensure that the ferrite disc falls into the array of circular holes on the substrate and makes good contact with the copper sheet on the substrate (this step is for ferrite materials with a certain degree of conductivity; if the ferrite material is not conductive, place the dielectric ceramic substrate and the ferrite disc in a conductive fixture and fix them).

嵌入时应注意铁氧体圆片落入基板的阵列圆孔中并于基板处的铜片良好接触(此步针对具有一定导电性的铁氧体材料，若铁氧体材料不导电，则将介质陶瓷基板和铁氧体圆片置于导电夹具并固定)。

[n0020]

Step 3: Cover the quartz glass reaction tube, and the central control system releases motion signals to the telescopic rods at the upper and lower cover plates, so that the composite substrate is in the appropriate reaction position.

步骤三：盖上石英玻璃反应管，中央控制系统向上下盖板处的伸缩杆释放运动信号，使复合基片处于合适的反应位置。

[n0021]

Step 4: Visual recognition camera scans and identifies the ferrite discs as brownish-brown discs and the microwave dielectric ceramic as a light yellow square substrate (the conductive clamp is a dark yellow copper sheet). The scanning head moves around to identify the relative positions of all ferrite discs and microwave dielectric ceramics and transmits this signal to the central control system.

步骤四：视觉识别摄像头识别扫描，铁氧体应为棕褐色圆片，微波介质陶瓷为淡黄色方形基片(导电夹具为深黄色铜片)，扫描头空走识别所有铁氧体圆片与微波介质陶瓷的相对位置，并将此信号传输到中央控制系统。

[n0022]

Step 5: The central control system receives the position signal and plans the route, then transmits the route to the path planning system to begin connecting the starting points.

步骤五：中央控制系统接收到位置信号并规划行进路线，将行进路线传递到路径规划系统，开始起始点的连接。

The central control system transmits the working signal to the temperature control system and the flash Joule equipment (this step is for ferrite materials with a certain degree of conductivity; if the material is not conductive, no route planning is required, and the negative electrode is simply placed close to the conductive clamp).

中央控制系统将工作信号传递给温控系统以及闪蒸焦耳设备(此步针对具有一定导电性的铁氧体材料，若材料不导电，则无需进行路线规划，只需将负极紧贴导电夹具)。

[n0023]

Step Six: The temperature control system reaches the preheating temperature to improve the reactivity of the heterogeneous material; the flash evaporation Joule device controls the capacitor charging and discharges the positive and negative electrodes according to the received parameter signals. Due to the current flowing through the ferrite wafer, heat is generated instantaneously and the temperature rises. When the temperature reaches a certain level, the ferrite wafer expands due to heat and the elements inside the wafer begin to diffuse towards the dielectric ceramic side. Meanwhile, the microwave dielectric ceramic also begins to expand due to thermal radiation and expands towards the ferrite side.

步骤六：温控系统工作达到预热温度，提高异质材料反应活性；闪蒸焦耳设备控制电容充电，根据接收到的参数信号对正负极进行放电，铁氧体原片内由于电流流过，瞬间产生热量，温度升高，当温度

达到一定程度时，铁氧体圆片受热膨胀片内元素开始向介质陶瓷一侧扩散，而微波介质陶瓷由于热辐射也开始膨胀并向铁氧体一侧膨胀。

This allows dissimilar materials to diffuse and connect with each other. Due to the extremely rapid cooling time and the absence of a heat preservation time, the joint transition zone is very narrow, thus avoiding the local performance deterioration caused by an excessively wide transition zone, which would affect the overall performance of the composite substrate. (This step is for ferrite materials with a certain degree of conductivity. If the material is not conductive, the composite substrate is connected and formed by thermal radiation through a conductive clamp.)

使得异种材料相互扩散连接，由于降温时间极快且无保温时间，接头过渡区很窄，从而避免过渡区过宽引起的局部性能恶化而影响复合基板整体性能(此步针对具有一定导电性的铁氧体材料，若材料不导电，则通过导电夹具热辐射使复合基片连接成型)。

[n0024]

Step 7: The temperature recognition head scans the temperature of the wafer and substrate, collects the heating signal, and transmits it to the central control system. The central control system compares the temperature with the temperature at which the phase begins to diffuse. At the same time, the visual scanning camera transmits the scanned image to the central control system for observation. If the temperature difference is within a reasonable range, the

next point is scanned and electrolysis is performed. (This step is for conductive ferrite materials. If the ferrite material is not conductive, single-point scanning is not required. Simply heat the composite substrate and repeat step 6.) If the condition does not meet the requirements, the voltage parameters are adjusted. If no obvious bonding is observed during scanning, step 6 is repeated.

步骤七：温度识别头扫描圆片及基片温度，收集升温信号，传递给中央控制系统，中央控制系统将温度与物相开始扩散温度对比，同时视觉扫描摄像头传输扫描影像至中央控制系统以供观察，若在温差合理范围内，则进行下一点的扫描及释电，(此步针对导电铁氧体材料，若铁氧体材料不导电，则无需单点扫描，只需加热复合基板重复步骤六)若不符合则调整电压参数且扫描影响未观察到明显结合则重复步骤六。

[n0025]

Step 8: Complete the discharge at all path points and evaluate the performance of the composite substrate.

步骤八：完成所有路径点的释电，评估复合基片性能。

Compared with the prior art, the present invention has at least the following advantages and effects:

本发明对于现有技术，至少具备如下优点及效果：

[n0026]

Compared with traditional connection methods, this invention can complete high-quality connection in a very short time, solving the problems of slow heating speed and low efficiency of traditional heating methods. Moreover, this invention does not require a long heating and holding process during the heating process, and the connection transition zone is narrow, avoiding the intermediate layer performance deterioration zone formed by excessive element diffusion. Furthermore, the entire process does not require the introduction of a third phase material, thus ensuring the purity of the heterogeneous integrated substrate.

本发明与传统连接方式相比，可以在极短的时间内完成高质量的连接，解决了传统加热方式升温速度慢效率低的问题，且本发明在加热过程中无需长时间的升温保温过程，连接过渡区窄，避免了元素过度扩散而形成的中间层性能恶化区，且整个过程无需引入第三相物质从而保证了异质集成基片的纯度。

[n0027]

This invention can release voltage as required according to different materials and different element diffusion methods to obtain different reaction transition zone ranges, with strong controllability, and can meet the connection of various materials.

本发明可以根据不同材料以及不同元素扩散方式按要求释放电压，以获得不同的反应过渡区范围，可控性强，满足多种材料的连接。

It also has a wide temperature range, capable of operating at temperatures up to 3000K.

同时温度范围广，可实现最高3000K的温度环境。

[n0028]

This invention occupies a small area, has a small actual reaction chamber, and a wide range of applications. It can be used with both conductive and non-conductive ferrites. Compared with traditional heating furnaces, it is easier to install, has low external heat radiation, resulting in high energy utilization, and has a small area of human exposure, making it safer and more reliable.

本发明占地面积小，实际反应腔室小，使用范围广，可同时运用于导电铁氧体和非导电铁氧体，并且相对于传统的加热炉更加便于安置，且对外热辐射低故而能源利用率高，对人体暴露面积小更加安全可靠。

[n0029]

The invention has a relatively simple structure and the technical means are simple and easy to implement, and it has outstanding substantial progress compared with the prior art.

本发明构造相对简单，技术手段简便易行，相对于现有技术具有突出的实质性进步。

[0033]

Attached Figure Description

附图说明

[n0030]

Figure 1 is a schematic diagram of the overall structure of an integrated equipment for preparing ferrite-microwave dielectric ceramic composite substrates using the flash Joule heating method.

图1是一种利用闪蒸焦耳热法制备铁氧体-微波介质陶瓷复合基板的一体化设备整体结构示意图；

[n0031]

In Figure 1, the numbers represent: 1-Reaction chamber; 2-Path planning system; 3-Lower cover plate; 4-External power supply wiring integration system; 5-Graphite negative electrode; 6-Positive electrode connection port; 7-Visual scanning recognition head; 8-Central control system; 9-Joule heating system; 10-Internal circuit diagram of Joule heating system; 1-1-Upright pole; 1-2-Quartz glass outer wall; 1-3-Base; 4-1-Upper cover plate telescopic rod wiring; 4-2-Power cord integration interface; 4-3 Scanning recognition head and temperature sensor wiring; 4-4-Lower cover plate telescopic rod wiring.

图1中编号表示：1-反应腔室；2-路径规划系统；3-下盖板；4-外电源接线整合系统；5-石墨负极；6-正极接线口；7-视觉扫描识别头；8-中央控制系统；9-焦耳加热系统；10-焦耳加热系统内部电路图；1-1-立杆；1-2-石英玻璃外壁；1-3-底座；4-1-上盖板伸缩杆接线；4-2-电源线整合接口；4-3扫描识别头及温度传感器接线；4-4-下盖板伸缩杆接线。

[n0032]

Figure 2 is a process flow diagram of an integrated equipment and method for preparing ferrite-microwave dielectric ceramic composite substrates using flash Joule heating.

图2是一种利用闪蒸焦耳热法制备铁氧体-微波介质陶瓷复合基板的一体化设备及方法工艺流程图。

[n0033]

Figure 3 is a partial enlarged view of the reaction chamber, where ABC are schematic diagrams of the reaction chamber under different conditions.

图3是反应腔室局部放大图，其中ABC为不同状态下的反应腔室示意图

[n0034]

In Figure 3, the numbers indicate: 4-external power supply wiring integration system; 1-1-upright pole; 1-2-quartz glass outer wall; 1-3-base; 1-4-base cable hole; 1-5-upper telescopic pole.

图3中编号表示：4-外电源接线整合系统；1-1-立杆；1-2-石英玻璃外壁；1-3-底座；1-4-底座通线孔；1-5-上伸缩杆。

[n0035]

Figure 4 is a partial enlarged view of the top cover plate, which includes a schematic diagram of the path planning system structure. ABCD are enlarged views of different areas.

图4是上盖板局部放大图，其中包括路径规划系统结构示意图，ABCD为不同区域放大图。

[n0036]

The numbers in Figure 4 represent: 2-1-X-axis slide rail; 2-2-Y-axis slide rail; 2-3-Y-axis slider connection port; 2-4-Enlarged view of Y-axis slider; 2-5-X-axis slider; 2-6-X-axis slider connection port; 2-7-Infrared temperature tester; 2-8-Graphite negative electrode welding connection port; 2-9-Visual scanning recognition head.

图4中编号表示：2-1-X轴滑轨；2-2-Y轴滑轨；2-3-Y轴滑块接线口；2-4-Y轴滑块放大图；2-5-X轴滑块；2-6-X轴滑块接线口；2-7-红外温度测试仪；2-8-石墨负极焊接接线口；2-9-视觉扫描识别头。

[n0037]

Figure 5 is a partial enlarged view of the lower cover plate, including a schematic diagram of the base and preheating system structure.

图5是下盖板局部放大图，其中包括基台和预加热系统结构示意图

[n0038]

In Figure 5, the numbers represent: 6-positive terminal; 3-1-microwave dielectric ceramic substrate; 3-2-top view of ferrite disc; 3-3-pre-drilled laser hole in microwave dielectric

ceramic; 3-4-copper wire integrated circuit box; 3-5-substrate; 3-6-side view of ferrite disc; 3-7-copper sheet embedded in substrate; 3-8-arrayed copper wire posts; 3-9-junction box support post; 3-10-preheating resistance wire; 3-11-preheating system wiring point; 3-12-resistance wire limiter; 3-13-silicone spiral pad on lower cover; 3-14-motor of lower cover telescopic rod.

图5中编号表示：6-正极接线口；3-1-微波介质陶瓷基板；；3-2-铁氧体圆片俯视图；3-3-微波介质陶瓷预打激光孔；3-4-铜线集成电路箱；3-5-基板；3-6-铁氧体圆片侧视图；3-7-基板内嵌铜片；3-8-阵列排布铜线柱；3-9-接线箱支撑柱；3-10-预加热电阻丝；3-11-预加热系统接线处；3-12-电阻丝限位器；3-13-下盖板硅胶螺旋垫；3-14-下盖板伸缩杆电机处。

[n0039]

Figure 6 is a schematic diagram of a conductive clamp.

图6是导电夹具示意图。

[0044]

Detailed Implementation

具体实施方式

[n0040]

The technical solutions of the embodiments of the present invention will be further described in detail below with reference to the accompanying drawings.

下面将结合附图对本发明实施例的技术方案做进一步的详细描述。

[n0041]

Example

实施例

[n0042]

As shown in Figure 1, this invention discloses an integrated device and method for preparing ferrite-microwave dielectric ceramic composite substrates using flash Joule heating, characterized in that it includes a central control system 8, a recognition camera 7, a path planning system 2, a Joule heating system 9, a base and preheating system 3, and a reaction chamber 1.

如图1所示，本发明公开了一种利用闪蒸焦耳热法制备铁氧体-微波介质陶瓷复合基板的一体化设备及方法，其特征在于：包括中央控制系统8、识别摄像头7、路径规划系统2、焦耳加热系统9、基台与预加热系统3、反应腔室1。

[n0043]

The central control system 8 plays the role of command transmission and data processing in the whole integrated equipment, and connects the path planning system 2, the recognition camera 7, the Joule heating system 9, the base temperature control system 3, and the telescopic system of the upper and lower cover plates of the reaction chamber 1.

中央控制系统8在整个一体化设备中起到命令传递、数据处理的作用，连接路径规划系统2、识别摄像头7、焦耳加热系统9、基台温度调控系统3、反应腔室1上下盖板的伸缩系统。

[n0044]

The path planning system 2 is connected to the visual scanning camera 7 and integrated with the central control system 8. The visual scanning camera 7 identifies the color changes and diameter of the ferrite 3-2 and microwave dielectric ceramic 3-1 on the composite substrate to determine the relative positions of the dissimilar materials and transmits the data to the central control system 8. The central control system 8 receives the transmission signal, plans the travel route planning 2, adjusts the position of the cover plate telescopic rod, and

transmits the planar planning path signal to the path planning system 2. After receiving the signal, the path planning system 2 completes the travel command and transmits the completion command to the central control system 8. The central control system 8 then transmits the discharge signal to the flash heating system 9 according to the manually input parameter signal to complete the discharge.

路径规划系统2连接视觉扫描摄像头7并与中央控制系统8集成，视觉扫描摄像头7识别复合基板上铁氧体3-2与微波介质陶瓷3-1的颜色变化以及材料的直径大小以确定异种材料的相对位置，将数据传输到中央控制系统8，中央控制系统8接收传输信号规划行进路线规划2，调整盖板伸缩杆位置，并将平面规划路径信号传输到路径规划系统2，路径规划系统2接收信号后完成行进指令并向中央控制系统8传输完成指令，中央控制系统8根据手动输入的参数信号随即对闪蒸加热系统9传递释电信号，完成放电。

[n0045]

The Joule heating system 9 is used for the storage and release of electrical energy. It is equipped with 20 capacitors, which are charged by connecting the power supply before the experiment.

焦耳加热系统9用于电能的存储及释放，内配备20个电容器，在实验进行前接通电源对电容器充电。

After preparation is complete, a standby signal is released. The central control system 8 recognizes the signal and adjusts the extension distance of the upper and lower cover plates so that the electrode of the upper cover plate contacts the upper surface of the ferrite 3-1 and the lower surface contacts the conductive copper sheet 3-7. During the experiment, the Joule heating system 9 automatically measures the resistance value at the connection point. Based on the discharge signal transmitted by the central control system 8, the system analyzes the signal parameters to determine the required voltage value and selects a portion of the capacitors to discharge the material. The system records the resistance value, discharge time, voltage, current and other parameters and transmits them back to the central control system 8.

准备完毕后释放待机信号，中央控制系统8识别信号并调整上下盖板伸缩距离使上盖板电极与铁氧体3-1上表面接触，下表面与导电铜片3-7接触，实验时焦耳加热系统9自动测量接通处电阻值，根据中央控制系统8传输的释电信号，分析信号参数判断所需要的电压值并选取部分电容器对材料放电，并记录电阻值、放电时间、电压电流等参数传回中央控制系统8。

[n0046]

The base is connected to the lower cover plate 3, and heating resistance wires 3-10 surround the base. The temperature control system is integrated with the central control system 8, which can preheat the base and improve the material activity.

基台与下盖板3相连，基台四周环绕加热电阻丝3-10，温控系统与中央控制系统8集成，可实现对基台的预加热，提高材料活性。

The cover plate has an array of through holes arranged in the same way as the microwave dielectric ceramic substrate 3-1. The diameter of the cover hole is slightly larger than the diameter of the ferrite disc. Conductive copper wires 3-8 are arranged inside the through holes. Copper sheets 3-7 are welded to the upper part of the copper wires and embedded in the cover plate at a distance of about 0.5mm from the upper surface to fix the position of the ferrite disc and make full contact with the copper sheet 3-7.

盖板上排布阵列贯穿孔径，排列方式与微波介质陶瓷基片3-1一致，盖板孔径直径略大于铁氧体圆片的直径，贯穿孔径内部排布导电铜线3-8，铜线上部焊接铜片3-7嵌入盖板与上表面约0.5mm距离以便于固定铁氧体圆片的位置并与铜片3-7完全接触。

[n0047]

The reaction chamber consists of four parts: upright rod 1-1, upper cover plate and upper cover plate telescopic rod 1-5, lower cover plate and lower cover plate telescopic rod 3-14, and quartz glass 1-2 outer wall.

反应腔室由立杆1-1、上盖板及上盖板伸缩杆1-5、下盖板与下盖板伸缩杆3-14、石英玻璃1-2外壁四部分组成。

The upper part of pole 1-1 has a hole to facilitate the neat connection of all lines 4.

立杆1-1上部开孔便于所有线路4规整接出。

The upper part of the cover plate is connected to the telescopic rod 1-5, and the lower part is connected to the path planning system 2.

上盖板上部与伸缩杆1-5相连下接路径规划系统2。

The upper part of the lower cover plate is connected to the base. The lower cover plate and the base plate have the same through array aperture, which facilitates the connection of array copper wires 3-8.

下盖板上部与基台相接，下盖板与基台分布相同的贯穿阵列孔径，便于阵列铜导线3-8接出。

The lower part of the lower cover plate is connected to the lower telescopic rod 3-14, and works simultaneously with the upper cover plate to achieve the Z-axis movement of the composite substrate.

下盖板下部与下伸缩杆3-14相连，与上盖板同时作用以实现复合基片的Z向运动。

[n0048]

The recognition camera 7 is a high-precision visual recognition camera that can scan and identify the specific location and size of materials of different colors.

识别摄像头7为高精度视觉识别摄像头，可扫别出不同颜色材料的具体位置以及大小。

The visual recognition camera is connected to the central control system 8, which can transmit scanning signals in real time to analyze the position and size of foreign materials. Based on this signal, the central control system 8 works in conjunction with the path planning system 2 to complete high-precision route travel.

视觉识别摄像头连接中央控制系统8，可将扫描信号实时传入，以分析异种材料的位置及大小，根据此信号，中央控制系统8与路径规划系统2联动以完成高精度的路线行进。

In addition, after the electrolytic process is over, the diffusion trend and range of the elements can be judged based on the color change, which can be used to roughly assess the quality of the experiment.

此外释电过程结束后还可以根据颜色变化判断元素扩散趋势以及扩散范围，可对实验质量进行粗略评估。

[n0049]

The path planning system 2 includes an infrared temperature recognition head 2-7, which can perform infrared scanning on the microwave dielectric ceramic substrate 3-1 and ferrite wafer 3-2 during the preheating stage. The scanned temperature signal is transmitted to the central control system 8 to further adjust the temperature range. During the Joule heating stage, the heating curve can be recorded to select the most suitable process parameters.

路径规划系统2包含一个红外温度识别头2-7，在预热阶段可对微波介质陶瓷基板3-1以及铁氧体圆片3-2进行红外扫描，扫描出的温度信号传递给中央控制系统8以进一步调节温度范围，焦耳加热阶段可记录升温曲线从而筛选出最合适的工艺参数。

In addition, the X slider 2-5 in the path planning system 2 contains a graphite electrode (the negative electrode in this case) to adapt to the working environment under ultra-high temperature conditions.

此外，路径规划系统2中X滑块2-5上包含一个石墨电极(此处为负极)，以适应超高温下的工作环境。

Among them, the graphite electrode, the scanning recognition head 2-9, and the infrared thermometer 2-7 are simultaneously distributed on the X slider 2-5.

其中，石墨电极、扫描识别头2-9、红外测温仪2-7同时分布于X滑块2-5。

[n0050]

The Joule heating system 9 can charge 20 sets of capacitors at once, and can be partially discharged as needed, allowing for multiple discharges. In addition, it is equipped with real-time voltage monitoring and safety valves to ensure that the voltage is below safe levels when the entire device is discharged.

焦耳加热系统9可一次性完成对20组电容器的充电而使用时可根据需求选择部分放电从而可多次放电，此外配有实时电压监测和安全阀门以保证整个设备放电结束时人体可接触的在安全电压以下。

[n0051]

A circuit box 3-4 is fixed at the lower part of the base. External copper wires 3-8 are integrated here and connected to the electrode (the positive electrode) and the Joule heating system 9.

基台下部固定一个电路箱3-4，外接的铜导线3-8在此处集成并共同与电极(此处为正极)相连并外接焦耳加热系统9。

[n0052]

The bottom of the reaction chamber is connected to the side of the upright rod with a fixed base platform 1-3. A raised ring around the outer wall of the base platform is used to fix the quartz glass tube and prevent it from sliding.

反应腔室底部与立杆侧接有固定底座台1-3，底座台外壁一圈凸起以固定石英玻璃管防止产生滑动位移。

Both the upper and lower cover plates are covered with silicone spiral pads 3-13 on their outer rings to enhance friction with the tube wall.

上下盖板外环皆覆有硅胶螺旋垫3-13以加强与壁管的摩擦。

[n0053]

An integrated apparatus and method for preparing ferrite-microwave dielectric ceramic composite substrates using flash Joule heating, comprising the following steps:

一种利用闪蒸焦耳热法制备铁氧体-微波介质陶瓷复合基板的一体化设备及方法，包括以下步骤：

[n0054]

Step 1: Preparation before composite substrate fabrication mainly includes the preparation of ferrite and microwave dielectric ceramic materials (taking K15 magnesium carbonate ceramic and zinc manganese spinel ferrite as examples (which have certain conductivity)). The ferrite is processed into small discs, and the microwave dielectric ceramic is processed into a substrate (50mm×50mm×2mm) and holes are drilled according to regulations. The diameter of the disc and the gap is designed according to the difference in thermal expansion of dissimilar materials, so that the circular holes on the substrate are slightly larger than the discs (preset hole diameter 5.1mm, disc diameter 5mm).

步骤一：复合基片制备前的准备，主要包括铁氧体与微波介质陶瓷材料的制备(以K15碳酸镁陶瓷、猛锌尖晶石铁氧体为例(具有一定导电性))，将铁氧体加工成小圆片，将微波介质陶瓷加工成基片(规格为50mm×50mm×2mm)并按规定打孔，其中根据异种材料热膨胀的差距设计圆片与空隙的直径，使基片上的圆孔略大于圆片(预设孔径5.1mm，圆片直径5mm)。

[n0055]

Step 2: Place the microwave dielectric ceramic substrate on the substrate and manually insert the disc into the circular hole using tweezers.

步骤二：将微波介质陶瓷基片放在基板上，手工用镊子将圆片嵌入圆孔。

When embedding, care should be taken to ensure that the ferrite disc falls into the array of circular holes on the substrate (the hole diameter on the substrate is 5.15 mm) and makes good contact with the copper sheet on the substrate.

嵌入时应注意铁氧体圆片落入基板的阵列圆孔(基板上孔径为5.15mm)中并于基板处的铜片良好接触。

[n0056]

Step 3: Cover the quartz glass reaction tube (quartz glass tube outer diameter 100mm, thickness 5mm), and the central control system releases motion signals to the telescopic rods at the upper and lower cover plates to place the substrate in the appropriate reaction position (generally the center of the quartz glass tube).

步骤三：盖上石英玻璃反应管(石英玻璃管外径100mm，厚度为5mm)，中央控制系统向上下盖板处的伸缩杆释放运动信号，使基片处于合适的反应位置(一般为石英玻璃管正中间)。

[n0057]

Step 4: Visual recognition camera scans and identifies the ferrite discs as brownish-red discs and the microwave dielectric ceramic as a light yellow square substrate. The scanning head moves around to identify the relative positions of all ferrite discs and microwave dielectric ceramics and transmits this signal to the central control system.

步骤四：视觉识别摄像头识别扫描，铁氧体应为棕褐色圆片，微波介质陶瓷为淡黄色方形基片，扫描头空走识别所有铁氧体圆片与微波介质陶瓷的相对位置，并将此信号传输到中央控制系统。

[n0058]

Step 5: The central control system receives the position signal and plans the route, then transmits the route to the path planning system to begin connecting the starting points.

步骤五：中央控制系统接收到位置信号并规划行进路线，将行进路线传递到路径规划系统，开始起始点的连接。

The central control system transmits operating signals to the temperature control system and the flash joule equipment.

中央控制系统将工作信号传递给温控系统以及闪蒸焦耳设备。

[n0059]

Step Six: The temperature control system reaches the preheating temperature to improve the reactivity of the heterogeneous material; the flash evaporation Joule device controls the capacitor charging and discharges the positive and negative electrodes according to the received parameter signals. Due to the current flowing through the ferrite wafer, heat is generated instantaneously and the temperature rises. When the temperature reaches a certain level, the ferrite wafer expands due to heat and the elements inside the wafer begin to diffuse towards the dielectric ceramic side. Meanwhile, the microwave dielectric ceramic also begins to expand due to thermal radiation and expands towards the ferrite side.

步骤六：温控系统工作达到预热温度，提高异质材料反应活性；闪蒸焦耳设备控制电容充电，根据接收到的参数信号对正负极进行放电，铁氧体原片内由于电流流过，瞬间产生热量，温度升高，当温度达到一定程度时，铁氧体圆片受热膨胀片内元素开始向介质陶瓷一侧扩散，而微波介质陶瓷由于热辐射也开始膨胀并向铁氧体一侧膨胀。

This allows dissimilar materials to diffuse and connect with each other. Due to the extremely rapid cooling time and the absence of heat preservation time, the joint transition zone is very narrow, thus avoiding the local performance deterioration caused by an excessively wide transition zone, which would affect the overall performance of the composite substrate.

使得异种材料相互扩散连接，由于降温时间极快且无保温时间，接头过渡区很窄，从而避免过渡区过宽引起的局部性能恶化而影响复合基板整体性能。

[n0060]

Step 7: The temperature recognition head scans the temperature of the wafer and substrate, collects the heating signal, and transmits it to the central control system. The central control system compares the temperature with the temperature at which the phase begins to diffuse. At the same time, the visual scanning camera transmits the scanned image to the central control system for observation. If the temperature difference is within a reasonable range, the next point is scanned and electrolysis is performed. If it does not meet the requirements, the voltage parameters are adjusted. If no obvious binding is observed during the scan, Step 6 is repeated.

步骤七：温度识别头扫描圆片及基片温度，收集升温信号，传递给中央控制系统，中央控制系统将温度与物相开始扩散温度对比，同时视觉扫描摄像头传输扫描影像至中央控制系统以供观察，若在温差合理范围内，则进行下一点的扫描及释电，若不符合则调整电压参数且扫描影响未观察到明显结合则重复步骤六。

[n0061]

Step 8: Complete the discharge at all path points and evaluate the performance of the composite substrate.

步骤八：完成所有路径点的释电，评估复合基片性能。

[n0062]

The above description is only a preferred embodiment of the present invention. It should be noted that those skilled in the art can make several improvements without departing from the principle of the present invention, and these improvements should also be considered within the scope of protection of the present invention.

以上所述仅是本发明的优选实施方式，应当指出，对于本技术领域的普通技术人员来说，在不脱离本发明原理的前提下还可以作出若干改进，这些改进也应视为本发明的保护范围。