Application technology of hot film flow sensor in intelligent electronic cigarette

Bin Zhang¹,a, Pengfei Ma¹,b, Xiaoyin Zheng¹,c, Guocai Qiu¹,d, xinzhu Chen¹,e*
¹Guangzhou Aosong Electronics Co., Ltd
aemail: bin.zhang@aosong.com, bemail: pengfei.ma@aosong.com
cemail: xiaoyin.zheng@aosong.com, demail: guocai.qiu@aosong.com
e*Corresponding author’s email: xinzhu.chen@aosong.com

Abstract: the application technology of hot film flow sensor in intelligent electronic cigarette is discussed, and the hardware scheme and software implementation of the technology are discussed and studied. This paper forecasts the development trend of intelligent electronic smoke for smoke inhalation monitoring.

1. Introduction
The bans imposed by each country on cigarettes and consumers’ growing health awareness lead to the continuous shrinkage of the traditional cigarette market and the increasing decrease in people’s demand for cigarette. Meanwhile, tobacco companies across the world start to accelerate their development of new tobacco products, among which electronic cigarettes are seeing their market segment expanding rapidly in this background. The usage of electronic cigarettes is undergoing changes thanks to the new function of flow monitoring, which allows consumers to monitor the smoke they inhale every day so as to reduce damage to their health. This paper presents an in-depth discussion about the application of hot film flow sensors to, and a forecast on the trend of, intelligent e-cigarettes.

2. Working Principle Overview
Electronic cigarettes, also known as vapes, is a kind of atomizer used for e-liquid. American E-Liquid Manufacturing Standards Association (AEMSA) defines them as “electronic atomizing inhalation devices that imitate regular cigarettes and transform the e-liquid mainly composed of propylene glycol and/or glycerin into an aerosol” [1], and describes them from the four aspects of smoke inhalation, smoke production, nicotine delivery and power supply.

The generally battery-powered e-cigarettes will turn on their atomization devices once detecting inhalations caused by negative pressure on the mouthpieces so that users are allowed to inhale atomized e-liquid. In the entire process, feeling of inhalation is still available but a variety of carcinogenic byproducts otherwise generated by burning traditional cigarettes are eliminated.

3. The Development of Electronic Cigarette Products
E-cigarettes have undergone three generations of technological innovation. The first generation, sets of devices that deliver nicotine via atomization, remains identical to real cigarettes in their appearance with white body and yellow mouthpiece, which makes customers readily accept. Nevertheless, the increasing expansion of their market share has their weakness exposed completely that the failure to produce smoke
arising from atomizer burnout during long-term use imposes a significant negative influence on consumption experience. To resolve that issue, the second generation is presented to the public.

This generation of e-cigarettes get refined atomizers by combining them with mouthpieces and meanwhile adding protective covers externally, which dramatically improves the reliability of the overall devices.

The third generation, which adopts disposable atomizing mouthpieces and has a higher level of integration as a whole, has gained the widest popularity in recent years. These products are composed of power supplies and atomizers which remain magnetically connected to each other so that users are allowed to switch to any other atomizers at will.

So far new orientation has been identified in the market of e-cigarettes. Their e-liquid diversifies, ranging over the flavor of chocolate, mint, fruit and red wine, which are particular favorites with customers; their appearance diverges from that of traditional e-cigarettes and looks more fashionable in their novel design which deeply impresses customers with the striking resemblance to pens and USB flash drives; their isolated e-liquid has been a trend compared with open e-liquid. Additionally, e-cigarettes also have their manufacturing techniques, e-liquid materials and atomization systems enhanced in line with market demand, which contributes to their rapid growth in recent years.

4. The Principal Components of Electronic Cigarettes

E-cigarettes are principally composed of atomization systems (including the two parts responsible for storing and atomizing e-liquid) and control systems (batteries and circuits). They can be divided into four kinds, including those that can be used singly, replace cartridges, inject e-liquid beforehand and refill later by their structures of atomization systems. The former two kinds adopt high hydroscopicity cellucotton in their atomization systems to store e-liquid, which are safe and portable but cannot detect how much e-liquid has been used. The latter two, whose atomization systems are made of the materials of plastic or glass, store e-liquid directly in their transparent containers, which clearly show the consumption of e-liquid.

The liquid atomized in e-cigarettes is the so-called e-liquid, generally containing propylene glycol, glycerin and the natural edible spice of soval. Currently most e-cigarettes sold in market cover all kinds of nicotine concentrations in their e-liquid in order to improve customer experience. Propylene glycol and glycerin, two major solvents, are usually blended previously. The damage caused by e-cigarettes to people’s health depends on how noxious their e-liquid proves. The e-liquid in a concentration range of high, medium and low to none is of benefit for users to gradually reduce and eventually quit smoking. Per-puff content of nicotine at high concentration is one third of that from real cigarettes, which plays a vital role in minimizing the health damage inflicted by traditional cigarettes.

5. The Principle of Hot Film Flow Sensors

Hot film flow sensors, major means of measuring and controlling fluids, are a kind of essential detection technology in current flow science that can convert physical flow information to transferable digital information. Flow sensors are widely applied to the process control of chemical production and biomedicine, and meanwhile serve as critical parameters and indicators for scientific experiments and energy measurement [2].

Hot film flow sensors have been one of contemporary research hotspots thanks to their excellent performance, basing their theory on Thomas’s proposition that “the heat absorbed or released by a gas is in direct proportional to its mass flow” [a]. When heated as a whole by their own heating units, hot film flow sensors will create a temperature difference ΔT in their exterior thermistors used for measuring temperature due to the loss of heat caused by fluid flow. The mass flow of a gas can be reflected through the temperature difference ΔT occurring in two thermistors. The coating on sensors’ chips equip these products with high precision, reproducibility, stability and corrosion resistance, while the processing technology of MEMS reduces their size and cost, enabling flow sensors to move in the mainstream direction of miniaturization, intelligence and high-accuracy measurement.
6. The Application of Hot Film Flow Sensors to Intelligent E-cigarettes

6.1 Technological solution architecture

The intelligent e-cigarettes that have the function of flow monitoring are composed of two parts: one is the atomization and control systems created in the third generation, while another turns out to be hot film sensor chips and flow ducts. The overall solution architecture is shown as follows:

![Figure 1: Schematic diagram of solution architecture](image1)

6.2 Working principle of hot film flow sensor

The trend in sensors towards miniaturization, digitalization and integration helps hot film flow ones get qualified as the mainstream among airflow sensors. To minimize the heat conduction and loss, and reduce heating power in the sensing parts of chips, designers apply cantilever structures to sensors, so that the coefficient of heat dissipation will not increase due to excessive loss of the heat produced by heating resistors when hot film flow sensors operate. The resulting drastic decrease in heating power is effective to reduce sensors’ demand.

Sensors are manufactured by putting temperature sensitive resistors and heating resistors on a cantilever under which the silicon is etched with a cup. The characteristics possessed by cantilever structures will eventually reduce sensors’ operating power [4].

Among the four resistors on a cantilever is a heating resistor in the center, on both sides of which are two parallel temperature detection resistors that can identify the change in flow in accordance with the temperature change ΔT they have detected. The last one is ambient temperature detection resistors located in air intake which are capable of compensating their own measured temperature in line with ambient temperature the sensors have detected. Sensors themselves can also utilize two controlling resistors to detect ambient temperature so as to reduce its influence on the output of air flow sensors.

In the flow detection circuit created based on the bridge made up of the heating resistor and two temperature detection resistors, the former maintains its heating temperature at 160°C higher constantly than the ambient temperature, meaning that one’s change will cause another’s correspondingly. As a result, the minimized effect exerted by external ambient temperature on sensor output guarantees the sensitivity of flow sensors.

![Figure 2: Schematic diagram of flow sensor structure](image2)
6.3 Working principle of hot film flow sensors

Figure. 3 Schematic diagram of the working principle of hot film flow sensors

S1 and S2 are flow detection thermistors in hot film flow sensors, while R1 and R2 prove two matched resistors constituting the Wheatstone bridge which are responsible for processing the bridge’s differential signals by calculating pressure signals based on voltage ones.

S3 is a resistor capable of detecting gas temperature, while R3, a matched voltage divider resistor, is used to facilitate the detection of signals input through chips’ AIN2 pins.

The heating resistor provides S1 and S2 with an operating environment of high temperature in which a temperature difference will occur when flow passes. R4 is a current limiting resistor that prevents the heating resistor from burning out.

U4 works as a voltage regulator which makes the supply voltage of 5 V stabilized at 3.3 V required for power supply; U3 and P5 are two circuits responsible for level translation.

6.4 The application of hot film flow sensors to intelligent e-cigarettes

The flow detection sensor chips in e-cigarettes can monitor the smoke inhaled by users in real time, providing users with the following intelligent experience:

① detecting whether users need e-liquid atomization so as to control the signaling switches of atomization systems

② adjusting heating power to meet users’ intake demand in accordance with air flow inhaled, which reduces power dissipation and prolongs operating time in the premise of satisfying users’ demand

③ monitoring users’ intake by allowing users to monitor their own health index through the intelligent systems of mobile applications, official accounts and applets and to set up their daily intake so as to ensure health

7. The Trend of Intelligent Electronic Cigarettes

The critical trend towards intelligent e-cigarettes means that traditional cigarettes will gradually be replaced. Scientific and technological advancements make tobacco industry around the world pay ever-increasing attention to e-cigarettes, a new type of consumer goods that boast a huge market waiting to be developed. The trend in the fourth generation of e-cigarettes will be those intelligent ones capable of monitoring air flow. Hot film flow sensors are bound to be essential products in e-cigarette industry due to their contributions to the highlights of real-time monitoring and long endurance which can meet users’ requirements of health, experience and long-term use.
References
[1] Li, B.J. (2014) Main disputes and government regulation of global e-cigarette market development [J]. Acta tobacco Sinica, 4: 72-78
[2] Wei, N.H., Hua, S. Xiu, J. (1998) Research and development of thermal and multi flow flow sensors [J]. Sensor world, 6: 19-23
[3] Yue, D., Wang, D.S., Zhou, Z.Y. (1995) Semiconductor thermal current / flow sensor [J]. China Railway Science, 1(16): 50-55
[4] Cheng, Y. Wang, J., Yin, Y.Z. (2009) Development of hot film flow chip [J]. Measurement and measurement technology, 11: 27-28.