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# A new type of fast dew point sensor using quartz crystal without frequency measurement

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ABSTRACT

Aiming at solving the problem of atmospheric humidity measurement, a new dew point sensor using quartz crystal without frequency measurement has been developed. The sensor is composed of the Peltier module and the quartz crystal. When active condensation begins to occur in the quartz crystal surface, the electrical characteristics of the quartz crystal will change. Consequently, the oscillation characteristics of the resonant circuit containing the quartz crystal will also change. Hence, the oscillation characteristics change can be used to identify the time of condensation. The cessation of oscillation was measured, due primarily to signal attenuation caused by dew formation. This method uses the sensitive properties of quartz crystal but with no frequency measurement and also exploit the stability of the circuit. The sensor we have developed has fast response time and recovery time, especially with excellent dehumidifying performance. The accuracy of the dew point sensor when compared with the MICHELL S4000 dew point meter is found to be ±0.3 °C DP in the range of −20 °C to 20 °C DP. The low-cost sensor is easy to carry and has certain corrosion resistance.



## 1. Introduction

Sensor technology has been improved significantly in recent years. Compared to existing sensor products and technologies, the main development focuses on improving sensitivity, reliability and repeatability [1]. Humidity sensors play an important role in process industries and environment control. In industry, humidity sensors are used for chemical gas purification, health monitoring of transformer oil, wafer processing in semiconductors, and paper and textile production. Humidity sensors are also used for greenhouse air conditioning, plantation protection (dew prevention), soil moisture monitoring, and cereal storage in agriculture. In medical field, respiratory equipment, sterilizers, incubators, pharmaceutical processing, and biological products employ humidity sensors. Humidity sensors are also used in automobile industries in rear-window defoggers, automobile fuel cells, and motor assembly lines [2–4]. Hence, there are endless applications where humidity measurement is needed. The type of humidity sensor required depends on the measurement range and application. The quality of a humidity sensor is assessed normally by high sensitivity, low response and recovery time, good reproducibility, and negligible drift due to aging and temperature. Practically, it is very difficult to fabricate a sensor having all desirable characteristics with measurement range from dew point to %RH. In recent years, many efforts have been taken in the investigation of humidity sensors with high sensitivity, rapid response, fast recovery and small hysteresis [5–9].

The dew point measurement is widely known as the most accurate method for measuring humidity. The core parts of dew point measurement are dew point detection and recognition. The present main dew point identification technologies include surface acoustic wave, photo electricity [10] , and image recognition [11], quartz crystal microbalance (QCM) [12] and so on. The Photoelectric method costs too much and the instrument is not easy to carry since it is only suitable for laboratory use. Both the surface acoustic wave and image recognition have complicated systems. Moreover, these two methods are not suitable for corrosive environment. Compared with previous methods, the QCM has advantages of stability and high sensitivity to mass change on the nanogram scale (1 ng/cm$^2$) [13]. As a sensor, the QCM has been widely used in monitoring change in mass loading by measuring the shift of its resonant frequency [14,15]. The quartz crystal microbalance with dissipation (QCM-D) is a special type of QCM based on the ring-down technique [16]. Dissipation is the time when the circuit is broken and

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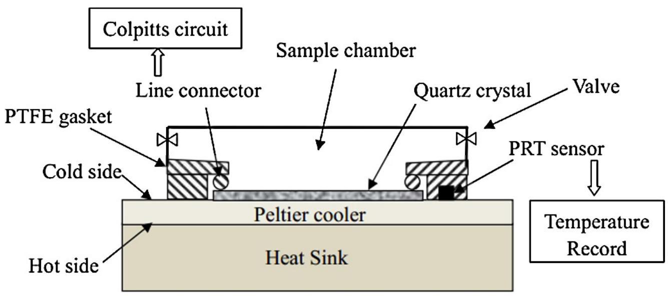


**Fig. 1.** The Schematic diagram of the sensing device.

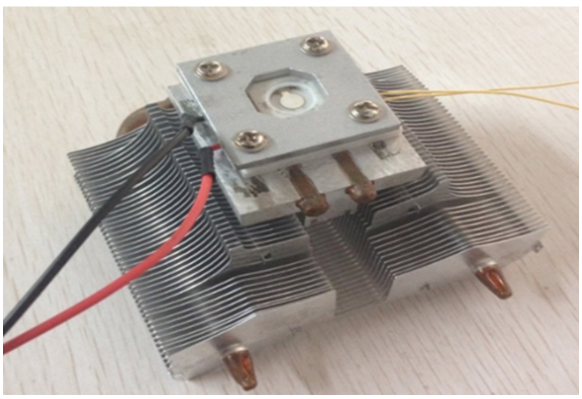

**Fig. 2.** Photograph of the sensor.

the crystal frequency is reduced to zero. Its most common application is the determination of a film thickness in a liquid environment. However, performance of the QCM-based sensor depends greatly on the chemical and physical properties of coating materials. Hence, this kind of sensor has a disadvantage of serious hysteresis.

In this paper, we design a new sensor for dew point measurement. The sensor is composed of the Peltier module and the quartz crystal. When active condensation begins to occur in the quartz crystal surface, the electrical characteristics of the quartz crystal will change. Consequently, the oscillation characteristics of the resonant circuit containing the quartz crystal will also change. Hence, the oscillation characteristics change can be used to identify the time of condensation. The traditional QCM sensor is measured in frequency. However, to obtain the high accuracy of the frequency value means that the measurement means to put forward high requirements. Our sensor is quite different from this traditional one. We also use the crystal quartz but with no frequency measurement.

This paper presents practical experiments that demonstrate feasibility of the sensor in detecting dew points. The experiments use the admittance analysis and micro methods to show that this new sensor has great reliability and accuracy in dew point recognition. Finally, the experiments show that the sensor has fast response and recovery time, and also excellent dehumidifying performance. Moreover, it can work in the corrosive gas environment because the sensing layer has corrosion resistance.

## 2. Qualitative description of the sensor

### 2.1. Structure of the dew point sensor

Fig. 1 is the Schematic diagram of the sensing device consisting of an AT-cut quartz crystal resonator with a resonant frequency of 4 MHz, a heat sink and a Peltier module (TEC). The Photograph of the sensor is shown Fig. 2.

A single-stage thermoelectric cooler (TEC1-3104) was stuck on a heat pipe radiator. Its heat surface was attached to the radiator in order to make a better cooling. Before attachment, the cold side of the cooler and the quartz crystal was cleaned with alcohol. Then, one side of the quartz crystal was tied to the cold surface of the TEC and the TEC was fastened with the quartz crystal by a Polytetrafluoroethylene (PTFE) gasket groove. By doing this, the two contact surfaces were better attached so as to make a good heat transfer. The following step was to get two wires out of the two electrodes placed on the quartz crystal surface and be connected to the Colpitts circuit. Beyond that, two platinum thermal resistances were used as the temperature sensor. One was affixed to the cold surface of the TEC to test the quartz crystal surface temperature while the other was exposed in experimental environment in order to provide the ambient temperature. It was also necessary to scrub the surface of the crystal with alcohol swab cottons, particularly when measuring the contamination gases. By the way, the quartz crystal should be placed in a cool, dry and sealed environment to prevent oxidation of the electrodes.

### 2.2. Sensitive mechanism of the dew point sensor

Fig. 3 shows the schematic diagram of dew point recognition principle. In the Colpitts circuit, there is a quartz crystal resonator (QCR) stuck on the semiconductor refrigeration device in order to produce condensation on its surface. The principle is described as: If there is no condensation, sinusoidal oscillation signals is output. And the bigger the refrigerating capacity is, more condensation will occur and then the bigger equivalent resistance of QCR gets. As a result, a DC bias signal is output. It's the signal mutation that can be used for dew point recognition. Beyond that, dew point temperature could be observed by measuring the surface temperature of QCR with PT100.

Since the Colpitts circuit has a great advantage of high frequency stability, it is commonly used as the drive circuit for the quartz crystal microbalance [17]. However, the Colpitts circuit fails to oscillate in the liquid because the characteristics of the quartz crystal change in the liquid and it causes no oscillation to occur in the circuit. Moreover, it is quite sensitive for the circuit to stop oscillating. Based on this sensitivity, this paper is aimed to use it to recognize the dew point.

## 3. Theory of operation and hardware implementation of the circuit electronics

### 3.1. Colpitts oscillation circuit analysis

The Colpitts oscillation circuit has a positive feedback based on the transistor. Hence, the circuit should hold both amplitude and phase conditions to keep self-sustained oscillating. It is formalized as follows:

(1) The Amplitude Condition: the total loop gain $A_V \times A_f = 1$;
(2) The Phase Condition: the total phase is $n \times 360$(n=0,1,2).

$A_V$ is defined as the amplification factor of the basic amplifier circuit and $A_f$ as the amplification factor of the feedback loop. It is clearly shown from Fig. 4(a) that the selected circuit and its components parameters need to be fixed by the resonance frequency of the quartz crystal.

Fig. 4(b) is equivalent circuit to Colpitts circuit. $U_{be} = U_i$, $g_m = \frac{\beta}{R_i}$, $\beta = \frac{\beta_0}{1+j\frac{f}{f_\beta}}$, $R_i$ is amplifier input resistance, $\beta_0$ is amplification of low frequency common emitter current, $f_\beta$ is the frequency of common emitter transistor cutoff, $X_1$ is the impedance crystal oscillator and