Low-power contactless button system based on MEMS ScAlN pyroelectric detector

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ABSTRACT

We demonstrate a system-level low-power contactless button using MEMS ScAlN-based pyroelectric detector. As pyroelectric detectors can sense instantaneous temperature change, the human finger can act as a thermal source to activate the button. Using our in-house fabricated ScAlN-based pyroelectric detector which does not require any IR source, we package it into a contactless button system designed with electrical read-out circuits and signal processing. This contactless button system could detect the presence of a finger at a center distance measured up to ~4 cm away, ~2 cm radius circle area, suitable for application as contactless elevator button. Our contactless button system using ScAlN-based pyroelectric effect is characterized, tested and compared with a commercial contactless button. The power consumed is measured ~3.5× lower than that of commercial contactless button. The results obtained provide a potential solution towards energy efficient low-power contactless button system.

Keywords: scandium aluminum nitride, pyroelectric detector, contactless button system, MEMS, CMOS compatible, infrared

1. INTRODUCTION

One way coronavirus disease 2019 (COVID-19)[1] spread is through contact with surfaces contaminated with COVID-19.[2] The virus can easily be transmitted from person to person via this avenue in public places where surface touch is inevitable. One common surface where touches are exchanged frequently is the elevator button surface. To reduce such spreading, there has been increasing interest towards contactless sensing technology.[3] Contactless elevator buttons currently available in the market mainly use an infrared (IR) source that emits light continuously. When a finger is placed in front of the IR source, the IR light will be reflected by the finger and then detected by the photodetector placed next to the source. This technique could be energy consuming as it requires the IR light to be constantly switched on.

Pyroelectric detectors are thermal sensors that sense instantaneous temperature change. They are compact and can function at room temperature without the need for liquid nitrogen (N_2) cooling, unlike photon detectors which usually require cooling.[4] Their thermal sensing capability is widely used for a number of applications including gas sensing,[5-7] temperature sensing,[8-10] ultraviolet/ infrared (UV/ IR) light detection,[11-15] thermal imaging[16-17] etc. When considering using pyroelectric detectors in contactless button system, they could potentially replace the traditional way contactless button works. Instead of having an IR source and a photodetector to detect reflection from the finger, the finger could potentially act as a source for detection by the pyroelectric detector. In this way, 2 components (IR source and photodetector) could be reduced to one (pyroelectric detector) in the system. In addition, power consumed by the system could be greatly reduced as we remove the IR source that will usually continuously consume power with its continuous emission.

In this paper, we developed a pyroelectric-induced contactless button system using our in-house fabricated scandium aluminum nitride (ScAlN) -based pyroelectric detector. No IR source is used and the detector is packaged with read-out circuits and signal processing. The read-out circuit board is optimized to further reduce power consumption. The system is tested and finger presence is detected up to ~4 cm away, ~2 cm radius circle area. The power consumed from this ScAlN-based pyroelectric-induced contactless button system is measured and compared with a commercially available

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contactless button. Our contactless button system measures power consumption ~3.5× lower than commercially available contactless button. To the best of our knowledge, this is the first demonstration of a low power ScAlN-based pyroelectric-induced contactless button system. The results obtained provide a promising and potential solution towards low-power energy efficient contactless button system for reduction of COVID-19 transmission via touch buttons.

2. EXPERIMENTAL

2.1 Pyroelectric device structure

Figure 1 shows an exploded view of the layer stack in the membrane structure of 12% ScAlN-based pyroelectric device used in the contactless button system. The membrane structure consists of ~1 µm thick 12% doped ScAlN as the pyroelectric sensing material with area of ~0.54 mm × 0.54 mm. This sensing layer is sandwiched between a titanium nitride (TiN) top electrode and a molybdenum (Mo) bottom electrode. Silicon dioxide (SiO_2) is beneath the Mo bottom electrode to provide thermal isolation. There is an air cavity below SiO_2. Above the TiN top electrode is a dielectric stack of absorber with SiO_2 - silicon nitride (SiN) – SiO_2 layers. This dielectric stack of absorber will help to enhance light absorption onto the pyroelectric sensing layer. Further details on the pyroelectric device structure could be found in Ref. 14-15, 18.

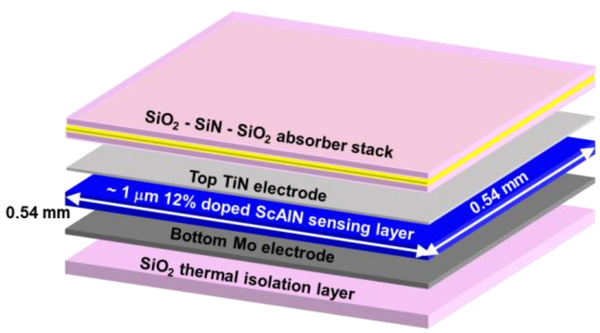

Figure 1. Exploded view of the layer stack in the membrane structure of 12% ScAlN-based pyroelectric detector.

2.2 Electronics and signal processing

With the fabricated ScAlN-based pyroelectric detector, a low-power contactless button system is designed as depicted in Figure 2. The system consists of the pyroelectric detector which generates sub-nA current (I_d) when it senses instantaneous change in temperature. I_d is then converted to voltage (V_i) using low-noise transimpedance amplifier. To better utilize the input range of the 12-bit analog-to-digital converter (ADC) embedded in the microcontroller unit (MCU), further amplification and signal filtering are designed for better detector signal extraction. The contactless button system is powered by a laptop computer with 5 V supply via universal serial bus (USB) cable. We do not require the use of IR source in our system, and low-power electrical components are used to further reduce the power consumption in this contactless button system.

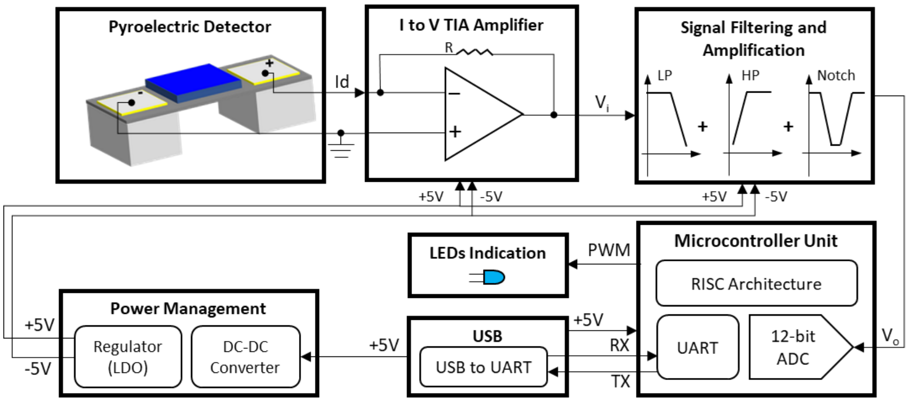

Figure 2. Electrical diagram of ScAlN-based pyroelectric detector for contactless button system.

3. RESULTS AND DISCUSSION

Figure 3 shows photo images of the ScAlN-based pyroelectric-induced contactless button system in operation. When the button is 'OFF', it is on stand-by mode with dimly lit light emitting diodes (LEDs) around it. When a finger is placed above it (at a distance of ~2 cm above the detector), the button is switched 'ON' as indicated by the brightening of the blue LEDs.

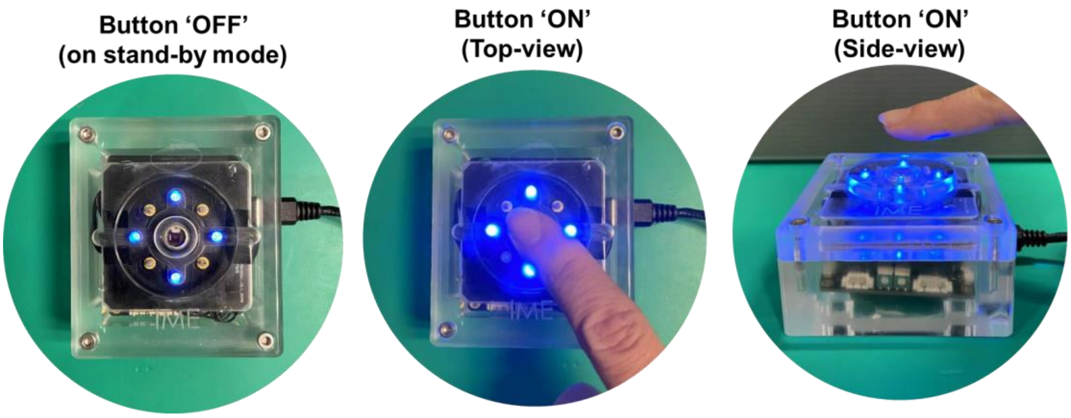

Figure 3. Photo images of the contactless button system using ScAlN-based pyroelectric detector illustrating the button 'OFF' when on stand-by mode, the button 'ON' when a finger hovers on top of the button.

Figure 4 shows the measurement data obtained when the finger is placed at different position with respect to the pyroelectric device. Fixing the origin as the position where the pyroelectric device is, the finger is positioned from 0 (above the device) to 4 cm radius away from the device as illustrated by Fig. 4a. The finger is also positioned at different distances above the device to measure the effect of z-axis distance on the device signal output (Fig. 4b). Figure 4c shows the peak-to-peak voltage measured from the pyroelectric device as the position of the finger with respect to location of the device changes. Inset denotes the r- and z- directions in which the finger position will move to. The peak-to-peak voltage reaches the highest when the finger is positioned 2 cm above the pyroelectric device. As this distance (z-axis) increases, the peak-to-peak voltage reduces. The output signal in general drops when the finger moves from 2 cm above the device to 6 cm above the device. If the finger is not above the device (r = 0 cm), but at r = 2 cm or r = 4 cm distance away from the device, the output signal detected by the device will get weaker. The green region (Fig. 4c) denotes the detectable region when the pyroelectric device detects signal with respect to the finger position. Although the output signal gets weaker when radius increases, we can still detect output signal from the detector with the finger up to ~2 cm radius from the device. The detectable region up to z ~ 4 cm and r ~ 2 cm could help to ensure ample space between the finger and the button and at the same time ensure that neighboring buttons are not activated unnecessarily.

Table 1 compares our power measurements of a commercial contactless button bought off-the-shelf and the pyroelectric-induced contactless button in this work. The working principle of the commercial contactless button is based on an IR source emitted from the button and gets reflected onto the button when a finger is placed in front of the button. On the other hand, the contactless button presented in this paper is based on pyroelectric effect triggered by the finger. The omission of an IR source greatly helps to reduce the power consumption. Our contactless button system based on 12% ScAlN-based pyroelectric detector consumes ~92 mW operating power, ~3.5× lower power than that consumed by commercial contactless button which measures an operating power of ~318 mW.

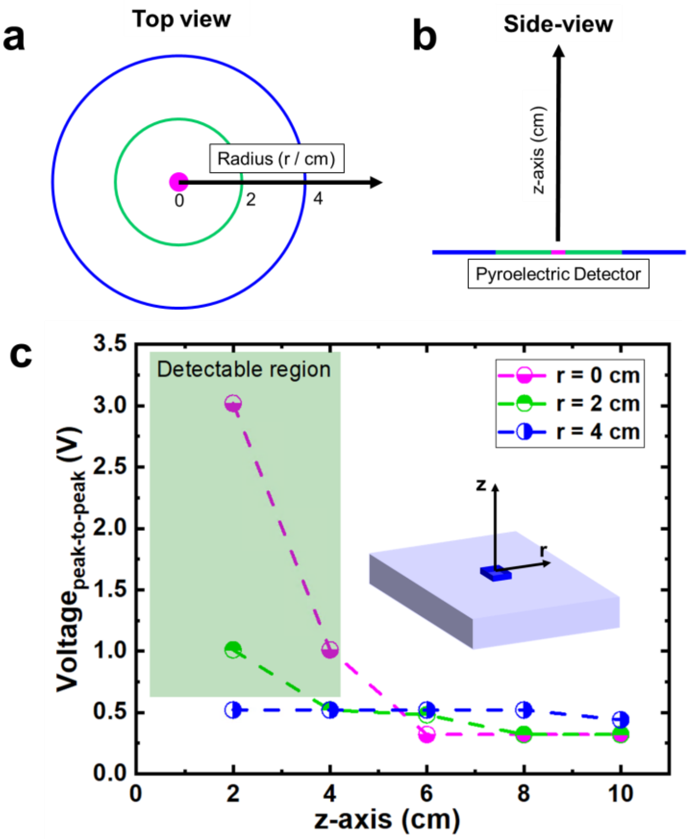

Figure 4. (a) Top view and (b) side-view showing finger movement distance and direction. (c) Output voltage signal detected by the pyroelectric device in the contactless button system with respect to distance of finger away from the button. Inset shows a schematic of the contactless button, indicating the r- and z- direction in which the finger will move along.

Table 1. Comparison table on the power from commercial contactless button bought off-the-shelf and 12% ScAlN-based pyroelectric-induced contactless button in this work.

Item	**Commercial Contactless Button**	**This Work (Contactless button based on 12% ScAlN-based pyroelectric detector)**
Photo Image		
Working Principle	IR reflected from the finger	Pyroelectric effect triggered by the finger
Operating Power (mW)	~318	~92

4. CONCLUSION

A contactless button system based on our in-house fabricated 12% ScAlN-based pyroelectric detector is demonstrated. No IR source is required and low-power electrical components are considered when building this system. The system is tested for output voltage signal as the finger moves apart 2 cm – 10 cm above the detector sensing surface, and at 0 cm, 2 cm and 4 cm radially from the center of the detector. The detector is able to sense the finger up to ~4 cm above the detector's surface and 2 cm radius from the detector's center. The operating power consumed by this system is measured and compared with a commercially available contactless button. The results show that our contactless button system consumes ~92 mW power when in operation. This is ~3.5× lower than the operating power measured from the commercially available contactless button which consumes ~318 mW. The results obtained indicate that contactless buttons could potentially further reduce their power consumption by using pyroelectric devices as the detector, thus contributing to energy efficient low-power contactless button system, as we learn to live with COVID-19 and move towards a sustainable touchless economy.

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