New infrared sensors are small, simple, and sensitive

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Infrared detectors have long provoked a strong interest in research and industry, and they are now used in many domains, including fire detection and defense systems. Small sensor size is an important factor, being linked to resolution of thermal imaging devices. These days detectors are commonly tens of microns in size. Much effort has gone into making devices smaller while improving their sensing ability, but often only by increasing cost or sacrificing ease of use.

Infrared sensors come in two main types: photon detectors, which rely on individual photon-electron interactions, and thermal detectors, which exploit temperature changes induced by infrared absorption. Photon detectors achieve high sensitivity, but have a number of drawbacks. They are usually cooled to 77K (liquid nitrogen temperature) or below, operate under vacuum, and can detect only certain ranges of infrared wavelengths. Thermal detectors, on the other hand, respond to broader wavelength bands. They can be used at room temperature and without any complex apparatus, but are slower than photon detectors and less sensitive to infrared. Better sensitivity currently requires photon detectors and thus cryogenic temperatures, complex devices structures, and complicated fabrication processes, leading to high costs. The perfect detector would have a simple design and would be small, sensitive, and easy to use. My coworkers and I are working toward this ideal with a type of thermal detector called a bolometer.

In a bolometer, the electrical resistance of the sensor changes when infrared absorption heats it. Bolometers can operate at room temperature and can be fabricated in a fairly simple fashion with standard cleanroom procedures. Two main parameters influence a bolometer’s performance: the sensitivity of its resistance to the temperature and the thermal insulation of the sensing layer from the rest of the device. Many ways of improving the sensitivity lead to complicated structures made of multiple layers of material. Here we present micron-size bolometer detectors that have a simple design, but also high sensitivity.

The core of our detector is a platinum thin-film strip whose resistance depends on the temperature. Electrons in the metallic film absorb incident infrared radiation, eventually raising the metal’s temperature and hence its resistance. An insulating layer of SiO₂ (silicon dioxide) between the platinum and the silicon substrate reduces the heat leakage to the substrate. The platinum film is patterned as a narrow rectangular ‘wire,’ which acts as the sensing part of the device, framed by four leads (see Figure 1). Two ‘source’ leads feed a bias current through the wire and two ‘sense’ leads allow measurement of the voltage drop across the wire (and thus its resistance). We experimented with a series of 300nm-wide wires that had lengths ranging from 300nm to 20μm as well as with broader wires ranging from 2×2μm to 8×16μm.

We studied the effect of wire geometry on the performance of our infrared sensors, as characterized by their responsivity.
and detectivity, two standard figures of merit for bolometers. Responsivity is the ratio of the output signal to the infrared power incident on the detector wire. Detectivity compares the response to the level of noise in the circuit. For these measurements, we set the bias currents so that they would dissipate the same amount of power in each detector wire, and we exposed the detectors to broadband near-infrared radiation from a blackbody source. We found that under these conditions the responsivity and detectivity increased with decreasing wire length. The device with a 300×300nm wire achieved the highest detectivity, \(2.7 \times 10^9\text{cmHz}^{1/2}\text{W}^{-1}\), which exceeds values reported for some other types of thermal detectors.\(^1\) The performance dropped sharply for broader wires: in work not yet published, the detectivity on average decreased by a factor of 50 when the width went from 300nm to 8µm. Interestingly, this study suggests that quantum mechanical effects are responsible for the high performance because the smallest detector wires are significantly narrower and shorter than the wavelength of the infrared radiation\(^2\) (our blackbody source spectrum peaks at 2.4µm).

We also worked on optimizing the performance by tuning the bias current and the thickness of the insulating SiO\(_2\) layer. Increasing the bias current improved performance, but the detectivity quickly reached a maximum limit value because of increased noise.\(^3\) In particular, so-called 1/f noise, which was not significant at lower bias currents, increased rapidly to become the dominant noise source, restricting the detectivity at higher bias currents. A maximum detectivity of \(2.3 \times 10^{10}\text{cmHz}^{1/2}\text{W}^{-1}\) was reached by the 300×600nm wire. The performance was enhanced with thicker SiO\(_2\) layers to confine the heat inside the platinum film: increasing the thickness from 50 to 350nm doubled the detectivity.\(^3\)

In summary, we have fabricated a simple infrared sensor based on a platinum thin-film wire whose performance is in the same range as today’s top bolometers. Detectivity can exceed \(10^{10}\text{cmHz}^{1/2}\text{W}^{-1}\) after tuning the operating parameters. Our sensors’ reduced dimensions (300×300nm in the smallest case) and ease of use and fabrication make it very promising for many infrared detection applications. In the near future, we plan to better understand the mechanism behind this detector’s high performance and how to optimize it further.

The author is grateful to the Icelandic Research Fund and the University of Iceland Research Fund for supporting this research.

### References

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