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Building ultra-thin flexible IR sensors from thermoelectric nanowires

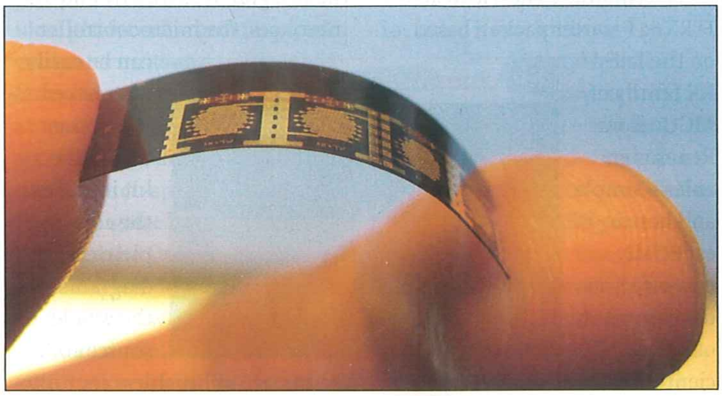
By Julien Happich

THERMOPILES ARE AT THE CORE of most infrared thermal detectors. Arrays of thermocouples are also used in thermoelectric generators and thermoelectric coolers based on the Seebeck and the Peltier effects respectively. Traditionally, thermopiles are designed on a silicon membrane with their hot and cold junctions placed beside each other in the same horizontal plane.

This makes them unsuitable for use as true heat flow sensors. What's more, the fragile silicon membrane requires a protective encapsulation with a glass window, which translates to rather bulky sensors.

Infrared thermal radiation detection devices find numerous applications, such as proximity sensors for entrance or presence detection systems, or in fire detection systems. Smaller and slimmer IR sensing devices could be used more extensively and not just as IR-thermometers. For example they could be used in wake-up circuits for computers and mobile phone applications, or even as input devices.

In 2008, Mikael Lindeberg, Chief of technical operations of JonDeTech AB, published a paper in the Journal of Micromechanics and Microengineering (JMM), describing a new manufacturing process for very thin thermopiles under the heading "A PCB-like process for vertically configured thermopiles". The thermopile structure described featured up to 224 vertically-arranged thermocouple legs deposited in a specially prepared polyimide flex material (figure 1). The whole structure was manufactured using mostly common printed circuit board processing steps such as photolithography, electrochemical deposition and etching. The clever bit was the thermoelectric legs (or junctions), each consisting of a bundle of a few hundred sub-micrometre-sized strands of metal (either antimony or nickel) vertically aligned through a 125µm thick dielectric layer. These metal wire bundles were achieved by selective electrochemical metal deposition though a set of grid patterns, in order to fill porous tracks in the polyimide foil (figure 2a).



A linear array of 0.2mm thick flexible thermopile IR sensors manufactured on a 125µm thin polyimide foil.

Once the thermoelectric materials where grown through the dielectric film, metal interconnections were plated to couple the thermoelectric legs into thermocouples (figure 2b), arranged side by side vertical to the foil plane. According to the paper, because the metal wire vias have a very small cross section, they only represent about 1% of the board in volume. This very low metal content means that despite the high heat-conductivity of the individual thermoelectric strands, the overall heat conduction and heat exchange between the two surfaces (effectively the hot and cold junctions) of the PCB is very small. This in turn makes

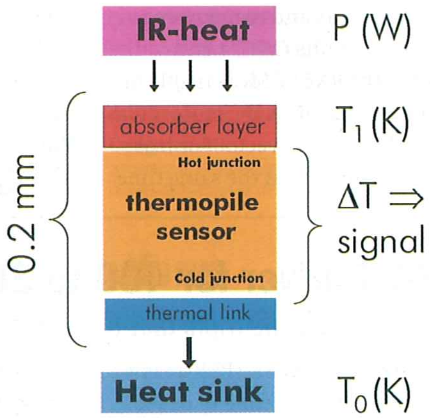


Figure 3: Model of the heat transport in JonDeTech's vertical thermopile sensor.

the thermopile structure very efficient at converting a temperature difference into an electrical voltage (figure 3). What's more, with the cold junction of the thermopile placed on the backside of the foil (opposite the hot junction), the entire substrate area can be used to build a thermopile, increasing the thermopile voltage together with the

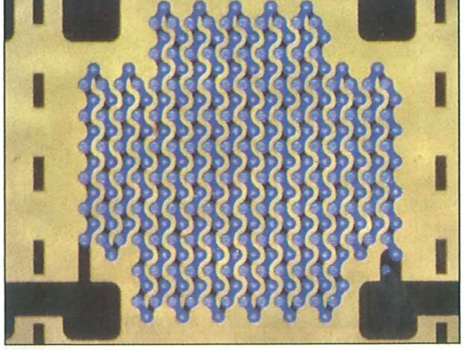


Figure 1: Top view of the 224 patterned leg connections (source JMM).

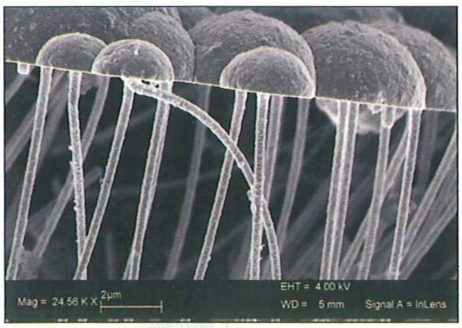


Figure 2a: Micrograph of nanometer strands forming one thermoelectric leg (source JMM).

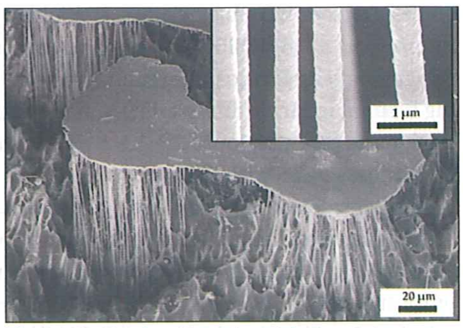


Figure 2b: Two bundles of metal wires interconnected to form a thermocouple (source JMM).

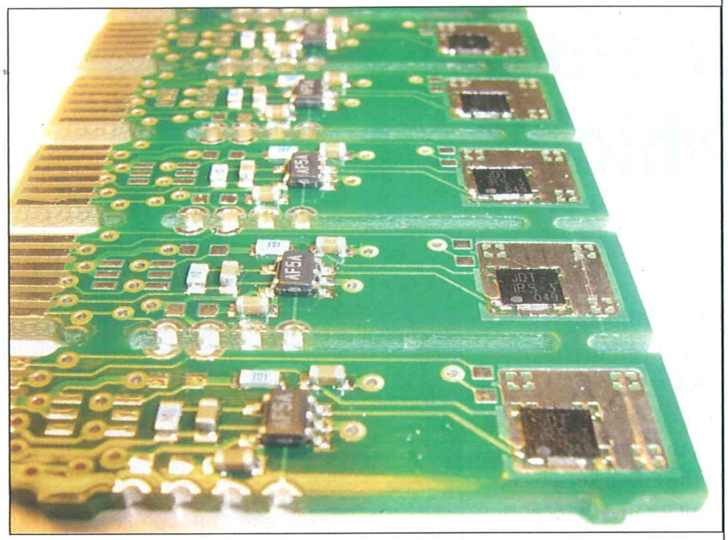


Figure 4: IR proximity sensor demo board showing a linear array with the associated signal conditioning circuitry.

thermocouple packing density. The manufacturing process also makes it fairly easy to accommodate custom geometry and sensor areas.

This research started in 2003, funded by Vinnova (research and innovation for sustainable growth) and SenseAir AB (Delsbo, Sweden). At the time Lindeberg was employed at SenseAir but research was done in collaboration with the Uppsala University. Late 2007, the SenseAir Board decided to register and transfer some of the intellectual property to a new company, JonDeTech AB was founded in January 2008 to develop and produce the heat sensors.

At electronica this year, JonDeTech AB was demonstrating a linear array of several ultra-slim IR sensors, less than 0.2mm thick. Produced in a plastic foil material, the sensors are surface mountable to most PCB carriers including flexible substrates that could fit on almost any curved surface. The demonstration board (figure 4) was very fast to pick up the proximity of one's hand via IR detection.

"We have found that without even using any optics or filters we can detect a human finger at 5 cm, a hand at 50 cm and a person at 1.5 meters", explains Lindeberg . "The measurement 'range' depends on the space angle of the object and the temperature of the object. The human skin is typically just 5 degrees above room temperature. Higher temperature differences can be seen at larger distances."

"The time constant of the sensor is between 50 and 70ms and the detection range can be further increased when using filters and focusing optics." Because the thermopile is vertically configured, it can measure a true heat flux and several sensors can be mounted side-by-side less than 0.3 mm apart. The electric voltage output can be readily amplified so that it can be read by an analog to digital converter. The sensors have one of the smallest impedances on the market, boasts the company, with 2 kOhm instead of around 100 kOhm, which is typical for many conventional thermopiles on silicon membranes. Hence the devices have low noise with respect to impedance/electrical resistance and are very easy to handle with respect to signal amplification.

The company is planning to license the technology in about three years from now, but first it aims to build a 'masterline' with a fairly high production capacity of a few million sensors per year. It will subcontract more and more process steps in the future, probably to PCB manufacturing companies, and today the company is looking for potential partners and electronic integrators in order to produce a more complete measurement system. ■