Challenges in packaging of IR detectors – technology of elastic electrical connections

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Abstract. This paper describes the study on flexible connections application in IR detector package. Such a connection is used between two modules in single package. One module is IR detector operating at -73 °C, other is electronic controlling circuit operating at room temperature. Flexible electrical connection must provide good electrical parameters in both DC and RF regime as well as poor thermal conductivity. 35 µm epoxy-phenolic foil with 5 µm Ni film and special RF compatible Ground-Signal-Ground geometry was successfully applied as connection. Low eutectic temperature InSn solder was used for soldering flexible connection to both IR detector and electronic circuit. Two types of soldering processes were investigated: bump and lap type. Flexible connection was tested for DC operation with long term stability test and RF parameters were determined. Authors found that both joining techniques are suitable for application in IR photodetector devices. However lap type joint is easier to apply in technological process, therefore it will be applied in final assembly.

1. Introduction
Middle and long wave IR photodetectors (MWIR, LWIR), such as those developed and produced by Polish company VIGO, have found important applications in IR spectrometry, quantum cascade laser based gas analyzers, laser radiation alerts and many other IR systems [1]. In such a device the control circuit operates at room temperature, while the IR detector has to operate at a temperature as low as -73 °C. The electrical connections between IR detector and control circuit are currently realized using 25 µm Au wires. The usage of Au wires causes excessive heat transfer to the IR detector and increases its operating temperature.

Figure 1. Concept of IR detector package with Ni microstrip line connection.
We propose a new solution of the electrical connection, which consists of: a Ni coplanar waveguide (5 μm thick) line on epoxy-phenolic substrate (Figure 1) and two solder joints: one between IR detector and coplanar waveguide and second between coplanar waveguide and electronic circuit. Ni line has worse thermal conductivity than Au (which reduce the heat transfer) and sufficiently good electrical properties. We designed the line in Ground-Signal-Ground (G-S-G) geometry and we calculated its dimensions for microwave operation. The construction of IR detector determine the maximum soldering temperature to 120 °C. The second reason for limiting soldering temperature is epoxy-phenolic foil on which Ni path are attached. Vitrification temperature of this foil is 130 °C, that limits soldering temperature.

To prove above concept Ni coplanar line in G-S-G geometry (250 μm – 100 μm – 250 μm) were prepared. In addition we made special test sample holders for Ni foil coplanar line from FR-4 laminate with Ni/Au paths and corresponding geometry. We made solder joints in two different ways. One way was called lap type. In this connection surface of FR-4 laminate and Ni coplanar line was firstly covered by flux and then wetted by InSn solder. The other was called bump type. In that connection after covering both surfaces with flux, 100 μm bumps made form InSn solder were applied between Ni coplanar line and the FR-4 test holder. After soldering process (all contacts are soldered in single step), we performed electrical measurements of DC and RF up to 3 GHz. The aim of this measurements was to evaluate which joining technique is more suitable for connection of IR detector and electronic circuit.

2. Experimental details

In Figure 2a we show geometry of design of coplanar line designed to operate at GHz frequencies regime. For single step soldering of all Ni coplanar line connections we designed and manufactured special termode (Figure 2b). This tool is equipped with heater and thermocouple. To achieve optimal soldering conditions we performed calibration of termode. We determined that for eutectic temperature of InSn solder (118 °C) heater should be set to 140 °C. For reducing soldering time, temperature at heater should be slightly increased.

![Figure 2](image)

**Figure 2.** (a) Ni coplanar line design pattern, (b) thermode for multiple contact formation.

We prepared two types of solder joints: lap type and bump type. We processed contacts for lap type solder joint in following steps:

1. application of acetic acid based flux on Ni coplanar line contacts,
2. wetting, with miniature soldering iron with precise temperature control, Ni contacts of coplanar lines. Temperature of soldering tip was 170 °C,
3. identical steps for FR-4 laminate contact pads,
4. clean of both surfaces from flux residue.

Than no-clean low solid flux was put between soldered contacts. Soldering process parameters were as follows: temperature of FR-4 test substrate: 50 °C, temperature of termode: 145 °C, applied pressure 1.2 N, soldering time 15 seconds.

Preparation steps For bump type solder joint:

1. application of colophony based flux on Ni coplanar line,
2. placement of 100 μm InSn bumps on Ni coplanar line contact pads,
3. preheating at 150 °C for bump joint formation.
Again no-clean low solid flux was applied between bumps and FR-4 contact pads. Soldering process parameters were as follows: substrate temperature 100 °C, termode temperature 140 °C, applied pressure 0.5 N and soldering time 15 seconds.

3. DC measurements
We measured the DC electrical parameters of both joints types in temperature range from room temperature down to -35 °C. Additionally we tested stability of those parameters after storage at low temperature (-35 °C). Results of resistance dependence on temperature are presented in Figure 3. Changes of resistance versus temperature for both connection types are the same. Resistance of lap type joint is slightly higher. This might be result of differences in contact area of both types of solder joints. In bump joint area of connection is connected with volume 100 µm InSn solder bump. In lap type joint area of connection is result of contact pads wetting distance. This distance was limited to Ni coplanar line pads. Therefore area of contact should be smaller in lap type joint.

![Figure 3](image)

**Figure 3.** Results of DC characterization. Changes in resistance in function of temperature.

4. RF measurements
In order to characterize the interconnects in an environment similar to the one in which they will operate in the IR detector, we mounted them onto 1.5 mm thick FR-4 frames with the same CPW pattern as in the detector. We further cut a rectangular hole in the FR-4 frame underneath the interconnects in order to separate the CPW strips from the ground plane. The FR-4 frame was also put on a an additional 5 mm thick plexiglass frame, also with a rectangular hole, in order to better emulate the operation of the interconnects in the free space.

We characterized RF properties of the above structures in the frequency range 0.01-3 GHz with a vector network analyzer (VNA). The VNA was calibrated with the multiline through-reflect-line TRL calibration [2] which employed a custom designed (see [3]) set of six transmission lines, an additional thru connection, and an offset short as a reflect standards. The calibration standards were manufactured on a 1.5 mm thick FR-4 substrate placed on a 5 mm thick plexiglass spacer with the same CPW pattern as in the IR detector.
Measurement results are shown in Figure 4, where we plot the magnitude of $S_{11}$ and $S_{21}$. We see that for both types of assembly technologies (lap type and bump type), the interconnects are well matched up to 1 GHz (return loss larger than 20 dB), and have insertion loss smaller than 0.1 dB. At frequencies larger than 3 GHz, the interconnect assembled with the bump technology presents slightly better matching and also smaller insertion loss. This can be explained with the fact that the current flow in the bump interconnect takes place on the surface of a metallic ball, which has larger conductivity than the lap type joint.

5. Conclusions
Both joining technologies fulfill demands of operation at DC and RF regime. Differences in RF and DC operation are really small and can be neglected. From technological point of view it is important to have assembly technology as simple as possible to reduce cost of single device. In our case more simple but only slightly worse technology is lap type solder joint. Taking all pros and cons we decide to apply lap in final device of IR photodetector.

6. References
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Acknowledgement
The work was supported by The National Centre for Research and Development, NCBR, Poland, project PBS2/B3/20/2013, INTIR.