# Choosing Detectors for Third Generation Infrared Systems

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## Abstract

A decision of choosing the right detector technology for third generation thermal imaging systems is directly derived from the expectations and the requirements of these systems.

It is now evident that third gen. thermal imager will still need the higher resolution capabilities as well as capabilities in multispectral detection and polarization sensitivity. Four technologies candidates are analyzed; the field-proved HgCdTe (MCT), uncooled microbolometer technology, Antimonide based materials and quantum well infrared photodetectors (QWIP). Taking into accounts the risks, maturity and technologies gap of each technology, we claim that for non-strategic applications (not low background conditions), QWIP technology is the most favorite. The ternary and super lattice Antimonide based material group seems to be theoretically the best alternative, but are not recommended due to it maturity and the high risk involved in this technology. We anticipate large penetration of the uncooled detectors to the low-end and medium-end market. The HgCdTe will still be in progress due to the inertion of the large funding and the strategic importance of this detectors technology.

Key words: Third generation infrared detectors, multispectral, QWIP, MCT, Uncooled, Antimonide.

## 1. Introduction

Infrared imaging systems are becoming a differentiating key factor of military superiority. In the modern battlefield, the infrared systems engaged with wide variety of applications, such as: ground based air based and space based surveillance and targeting systems. Such as weapon night sights, aircraft navigation and piloting, night fire control systems etc.

The heart of each infrared imaging system is the infrared detector which is usually based on a semiconductor material sensitive to the low energy infrared photons.



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Actually, the evolution and progress in the infrared imaging systems are very closely related to the progress of the infrared detector technology. Therefore, the generation definition of infrared systems is very much related to the generation definition of the infrared detectors and technology.

The main material used for infrared detectors throughout the last three decades is the ternary II-VI compound known as Mercury Cadmium Telluride (HgCdTe or MCT), a variable bandgap material, that varies as a function of it composition from semimetals of HgTe to a wide bandgap material (1.6eV) of CdTe. At a composition of 80% Mercury (%Hg of the HgCd), the band gap of the HgCdTe is 0.1eV, thus, adequate for detection of 10 micrometer infrared light.

During the nineties, 2D technology starts to be available in the medium wavelength infrared-MWIR (3-5 microns band) base on InSb compounds as well as in HgCdTe. In the long wavelength (8-12microns band) however, the HgCdTe material fail to give the requirements of large format 2D arrays due to metallurgical problems of the epitaxial layers such as uniformity and number of defected elements. The QWIP on the other hand start to play an important role as a good alternative for LWIR large format 2D arrays in the LWIR during that time. Several more technologies became available during these years; we analyze their development and the usage of these detector technologies for future applications.

## 2. Evolution of the Infrared system generations

The difficulties to produce high uniformity MCT especially of this high Mercury content material have caused lots of problems related to the uniformity between detector elements. These problems have driven the infrared system to use a single element infrared detector of which the scenery image is reconstruct using a serial scanning scheme, in which high speed horizontal mirror is built into a setup with a slow moving vertical scanning mirror that performs a video image in a full frame rate. Those images suffer from high noise due to pure performance of the detectors as well as very short integration time due to the short dwell time. Infrared system based on these type of system have not even considered as a first generation infrared.

As the MCT technology was further developed a linear arrays of 60, 120, 180 and 240 elements could be produced with a relative acceptable uniformity. This led to the development of  first generation (common module type) systems that are in use until today for most of the tactical applications. In order to reconstruct the video image out of these short detector linear arrays, a polygon or a rotating mirror were often used along the horizontal direction. In the vertical direction an interlaced mirror that doubled the video lines along with an electronic line filling scheme was used in order to obtain a full video standard imagery. The horizontal resolution of first generation was compatible with TV standard where the vertical resolution was low due to the few elements of the infrared focal plane array. In addition, due to the short dwell time during the scanning the integration time was short, giving rise to a low sensitivity and hence low contrast of the collected image.

Activities toward development of a second generation detectors focal plane arrays and thus higher performance infrared systems started in the late eighties in which MCT detectors as long as 480x4 elements were developed especially in the long wavelength –LWIR (8-12micron) [1] .

At the same time medium format 320x240 elements 2D arrays were developed for the medium wavelength -MWIR (3-5micron) made of either MCT or Indium Antimonide (InSb). Figure 1 shows two examples of representative of the first generation and second generation infrared systems made by Elop. The First gen. system example is the handheld "INTIM" which is based on a linear array of 240 elements made of MCT, and the second generation infrared system shown is the "CRYSTAL" based on a medium format (320x256) 2D focal plane array made of InSb.

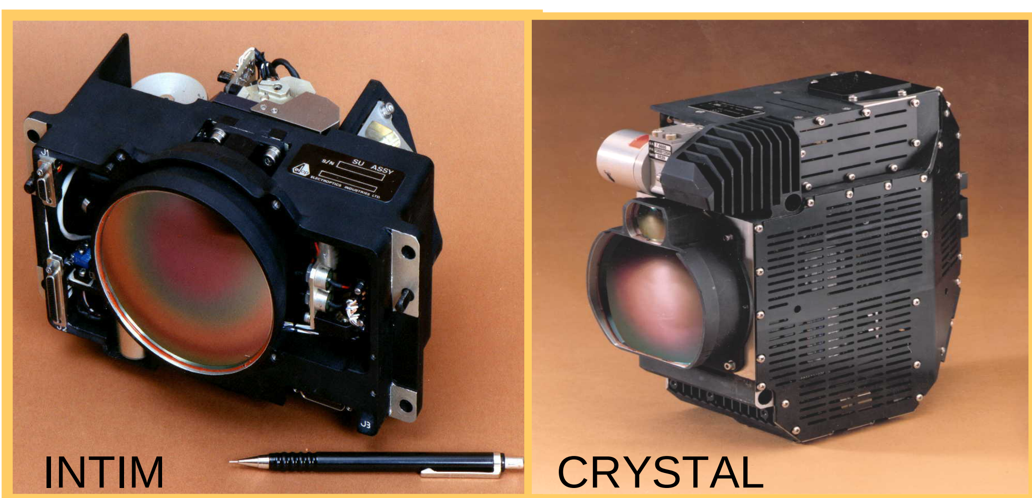


**Figure 1:** First gen. Elop's INTIM  IR system based on 240 element MCT and Second gen. Elop's CRYSTAL based on 2D 30x256 focal plane array of InSb

These second generation infrared systems are currently replacing most of the first generation thermal imagers, giving rise to a much higher performance of the infrared systems as well as high fidelity of the thermal imagery.

During the late eighties Honeywell and TI have introduced the uncooled microbolometers and uncooled pyroelectric technology, respectively, thus open up a new era in the infrared technology[(2)]. The importance of the uncooled technology was that for the first time there was a real potential to position the IR technology as an affordable technology for low-end application as well as for many application of the commercial market.

The second generation systems were started an industries standard during mid Nineties. It seems at that time that there was no reason for further development of a new generation of infrared systems and detectors.

## 3. Third generation infrared systems requirements

One of the Gulf-war lessons has been thought was that there is a good reason to further increase the detection, recognition and identification ranges of the infrared systems. The reason was that during the gulf war allies forces could open fire only after fully identify the target, where the Iraqi forces fired based on detection only. It should be noted that based on the Johnson criteria in order to detect a target only one line pair (resolution segment) should be on the target where for recognition and identification 3 and 6 line pairs have to be achieved on the target, respectively. Therefore, Identification ranges are between 2 and 3 times shorter than detection ranges. This firing policy of the Iraqi forces open a wide gap of firing ranges between the allies forces  and Iraqi forces that need to be bridged. The brut force way to increase ranges is by increasing resolution and sensitivity of the infrared systems (and hence the detectors), i.e., going to a large format 2D focal plane arrays. In addition, It was founded that identification ranges can be further increased by using the multispectral detection and correlating the images in different wavelength.

The multispectral detection requirements rose also from the need to overcome washout problem in where the thermal contrast of the infrared image is washed out to the point that the target and the background cannot be distinguished from each other. Figure 2 shows an example in which a target - background contrast changes from positive to negative over the MWIR (3-5micron) spectral range. In this case, a detector that covers the entire spectral range will get into washout because of the opposite sign of the integrated contrast cancellation.

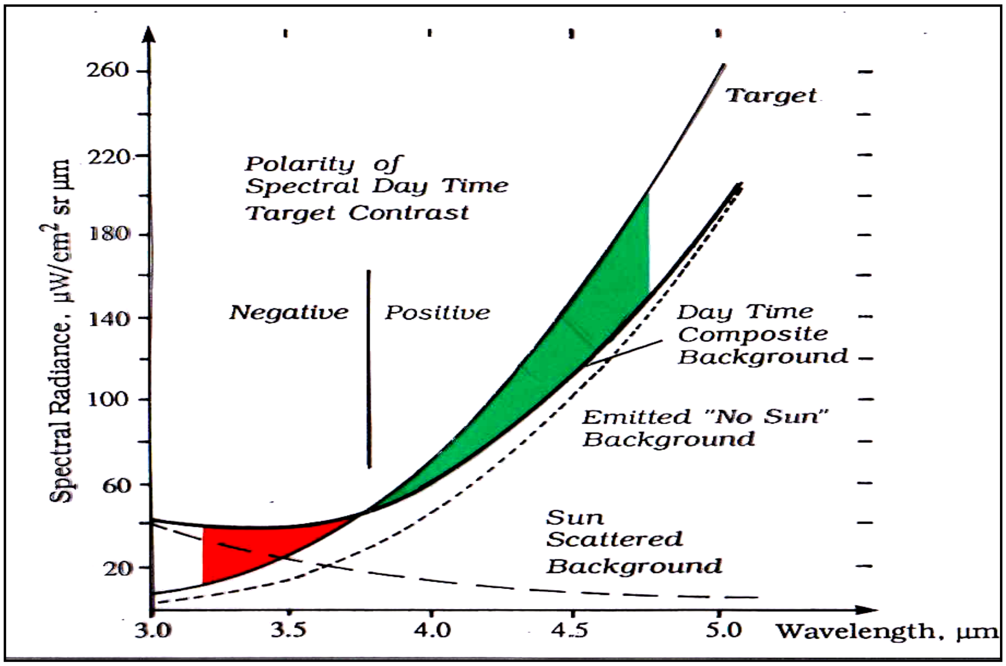


**Figure 2:** Target and background contrast reversal in the MWIR spectral range.

Alternatively, by dividing this spectral range into two bands up to 4.2 microns and from 4.2 micron and summing up the inverse of the second band and the output of the first band will yield a contrast enhancement unlike if an integrated response of the entire spectral band was used. It is clear now that for third generation, in addition to the increase of the system resolution and sensitivity, a dual or multispectral detection is an important requirement. The usage of multispectral infrared system that can cover several bands can be in the MWIR at the LWIR as well as in both infrared spectral windows.

Other feature that can be of importance is the ability of the infrared system to detect polarized light. It was found that man made objects as well as artificial surface reflect polarized light unlike the background which is usually unpolarized. Therefore, being able to detect polarized light a contrast of made man object can further increase. It should be noted the going to third generation does not mean necessarily increasing of the performance. One of the requirements for 3$^{rd}$ gen. infrared detectors is very low cost as well as disposable detectors. Therefore there is a trend in third gen. (as was in second gen.) of expanding the applications of infrared detectors to the low end as well as to the high end. Figure 3 shows this expending of the applications and performances.

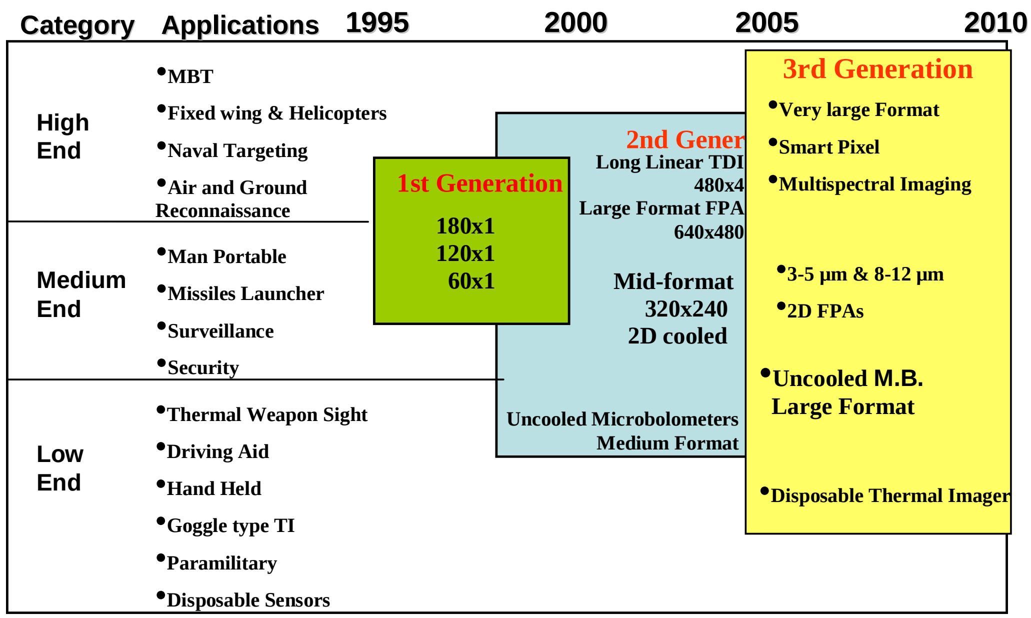


**Figure 3:** Applications of infrared system generation – evolution perspective.

## 4. Detector candidate for third generation infrared systems

There are four detectors technologies that may meet some of the specification of third generation infrared systems: MCT, Antimonide based compounds (ABC), quantum well infrared photodetector (QWIP) and uncooled microbolometer detectors.

The later uncooled technology will probably developed parallel to other cooled technologies. It seems that this technology is lack the capabilities of replacing the cooled detectors but defiantly will replace some of the low end and mid end applications. Although very good figures of noise equivalent temperature (NET) are sited by the manufacturing companies, one should remember that this numbers are usually at f/1 optic and deteriorated rapidly as we increase f/#. A better figure to evaluate the potential of the uncooled detectors to move to the high end applications is by evaluating its D*. It is shown in figure 4 that in terms of D*, There is a gap of two order of magnitude between peak D* of the cooled detector compare with that of the uncooled. In spite of the lower D* of the uncooled detectors, due to the increase in the size of the uncooled detector arrays towered 640x480, decreasing the pitch, and still maintaining the NET of each detector element, The uncooled technology is going to gain most of the low-end and mid-end applications of the third generation infrared systems.

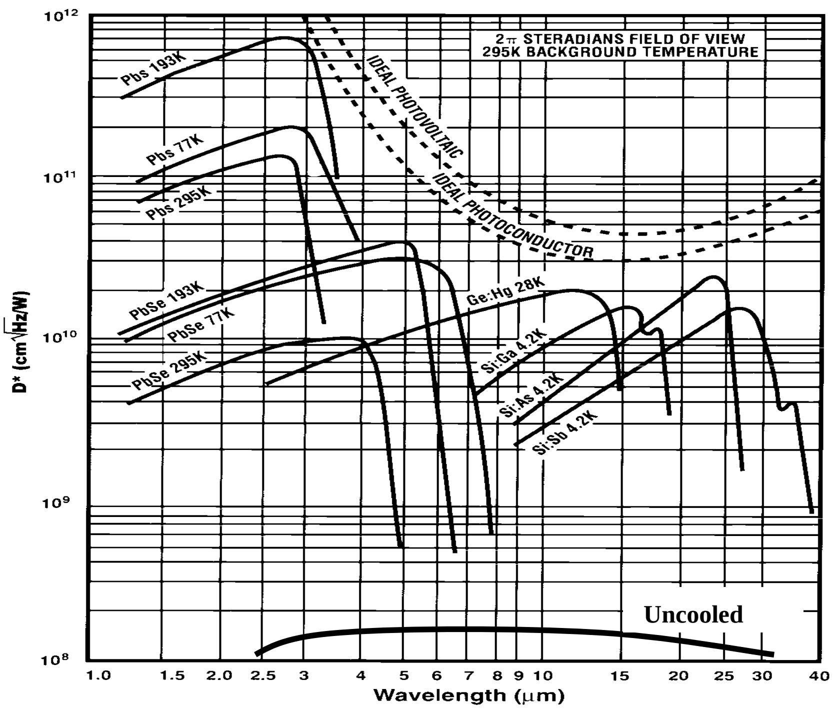


**Figure 4:** D* of different cooled poton's detectors compare to uncooled

MCT technology is lack the capability of making large format focal plane arrays at the LWIR band, since the uniformity and the operability of such arrays are very poor[3]. Therefore, it is accepted today that MCT is going to cover the MWIR where the Mercury content of the compound semiconductor is half of the LWIR. As shown by DRS and others, dual color detector can be made in quite large format in the MWIR. Thus, MWIR MCT can be a good candidate for third generation only in that spectral band. For applications that require operation in the LWIR band as well as applications that will mix the two bands (MWIR and LWIR) most probably MCT will not be the optimal solution.

The third candidate for third generation infrared detectors is the Antimonide Based Compounds (ABC). The theoretical potential of this group can be easily seen in the diagram presented in figure-5.

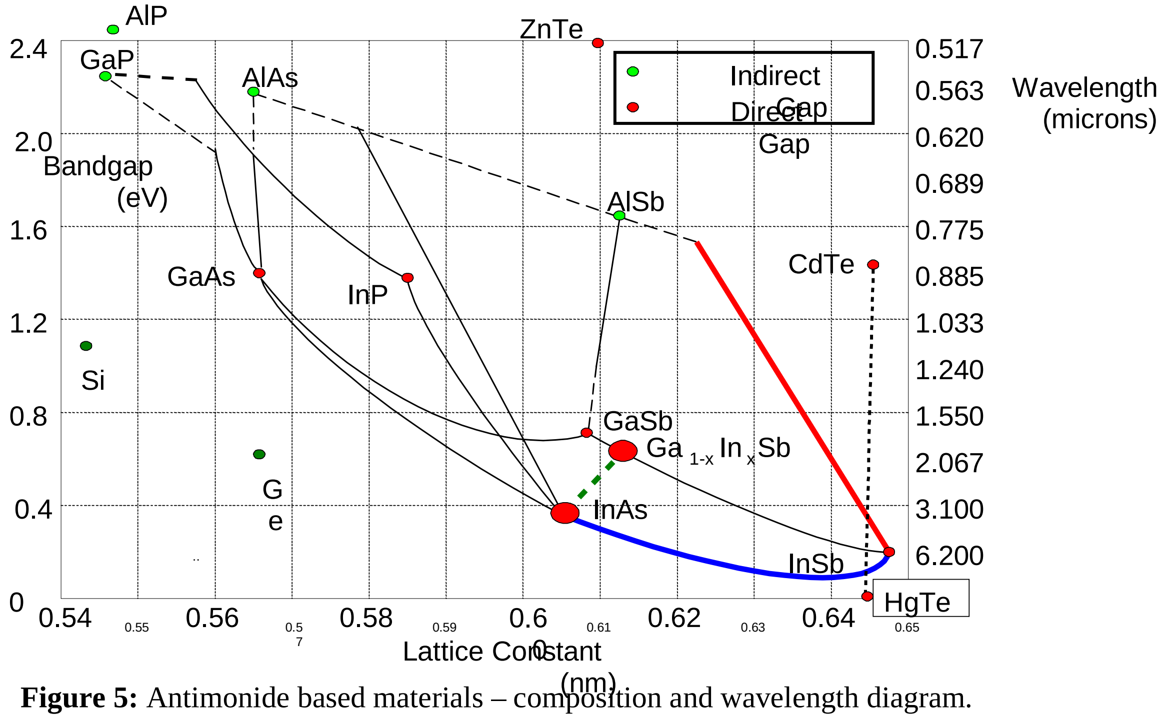


**Figure 5:** Antimonide based materials – composition and wavelength diagram.

The Antimonide family can be considered as an alternative to MCT and as a candidate for third gen. infrared detectors.

Among the alloys, epitaxial layers of $InAs_{1-y}Sb_y$ on GaSb with $0.07<y<0.11$ and $In_{1-z}Al_zSb$ on InSb with $0<z<0.03$ both span important windows in the MWIR band. The bandgap sensitivity of the $In_{1-z}Al_ZSb$ is similar to that of the MCT. In the case of $InAs_{1-y}Sb_y$ this band gap sensitivity is more than half of the MCT(4). Therefore, during the epitaxial growth of these layers the requirement for temperature stability is much less than for MCT. Consequently, the uniformity achieved in such layer is better than for MCT.

Antimonide based compounds can be also grown as a super lattices based on $InAs/Ga_{1-x}In_xSb$ grown on lattice matched GaSb substrate. This epitaxial superlattices layer seems to be an attractive alternative to MCT with good spatial uniformity and an ability to span cut-off wavelength from 3-20micrometer in a single material system having high quantum efficiency.

On the other hand it seems that yet material and surface problems are giving rise to a poor performance of the detectors. The technical challenges that researchers are facing today do remind the development efforts of the HgCdTe two decades ago and thus not recommended in the near future as a leading technology due to the risk involved in this development. Therefore, this technology, although high potential theoretically, is still immature and further development should be invested but not as a main stream.

The fourth option for third generation detector is the Quantum Well Infrared Photodetector (QWIP) technology. This technology is based on the mature GaAs process and can yield large format focal plane arrays. In addition, varying the width of the quantum wells and the Al concentration of the barriers, the cut off wavelength can be tuned from 5.5microns up to 18microns, thus, spanning the entire LWIR and VLWIR bands. In addition, as was demonstrated by several groups(5), adding Indium to the quantum wells will deepen the wells and response at the 3-5microns spectral band can be achieved. In addition, multispectral detection can be easily obtained by QWIP technology by growing quantum wells stacks of different parameters tailoring the wavelength response to the desires wavelength. Enlarging QWIP response from the LWIR band toward 1micron (SWIR) can be done using a monolithic structure that incooperate interband absorption and intersubband absorption. Using this sachem QWIP detectors were response to 8-12 band as well as to 1micron of the laser beam, simultaneously(6). Using the fact that QWIP absorb light after diffracting from its grating, polarization sensitive QWIP can be made using grating orientation.

Two main deficiencies of the QWIP technology need to be discussed. The requirement of cooling the QWIP to 65K-70K in order to achieve equivalent performance to the MCT that operating at 77K.

The second deficiency is the internal quantum efficiency (QE) which is around 20% compare to the MCT which can be reached to 60%-70%. The operating temperature and the quantum efficiency are two parameters that are linked to each other. A trivial possibility to increase the QE can be done by increasing the doping concentration of the Silicon in the wells; in this case we can increase the QE to be as high as in MCT. Doing so will exponentially increase the dark current and hence the shot noise associate with it, for a given operating temperature. The reason for the high dark current of the QWIP is that QWIP is a majority carrier device; thus, increasing the carrier concentration has a direct effect on the dark current and the noise. When needed and possible, cooling the QWIP to lower temperature (lower than 50K) will enable increase of the doping concentration without increasing the dark current dramatically, and thus increasing the QE. For most of the tactical applications, quantum efficiency of 20% is sufficient, since even for high QE detector like MCT, most of the available integration time is not used due to the size limitation of the integration capacitor of the detector readout circuit. Therefore, for most of the tactical applications low QE (as low as 10-20%) does not really effect the performance.

Only for strategic applications, where we deal with a low background the lower QE of the QWIP become a deficiency.

## 5. Summary and Conclusions

For the third generation infrared system, it seems that most of the low and medium end application will be govern by the uncooled technology.

For the high end application there will be a differentiation of technologies. For tactical application, there is a good chance to move to the QWIP technology since it is the only affordable technology that can provide today with the LWIR/MWIR capabilities as well as large format focal plane arrays.

For strategic application where high quantum efficiency is important due to the low background, there is a justification to go to the high-high end technology (high price) of either MCT or in the future the Antimonide based materials.

## References


1. Gabby Sarusi, Natan Ziv, O. Zioni, J. Gaber,M. Schechterman, I. Wiess, I. Friedland, M. Lerner and A. Friedenberg, SPIE Vol. 3436,194(1998)
2. Kevin C. Liddiard SPIE Vol. 4130, 119 (2000)
3. A.C. Goldberg, T. Fischer and Z. Derzko, SPIE (See this proceeding)
4. Philip Klipstein, Eli Jacobson, Olga Klin Yassen, Zipora Calahorra, Eliezer Weiss, Shlomo Risemberg and David rozenfeld, SPIE (See this proceeding)
5. E. Costard, P. Bois, X. Marcadet, E. Herniou, P. Tribolet, M. Vuillermet, SPIE Vol. 4130, 463(2000)
6. N. Cohen, A. Zussman and G. Sarusi, Infrared Physics and technology 42,391(2001)