

# Single-Photon Energy Resolving(QVD) Detectors Based on Thermoelectric Sensors and Digital Superconducting Readout for Hyperspectral Imaging

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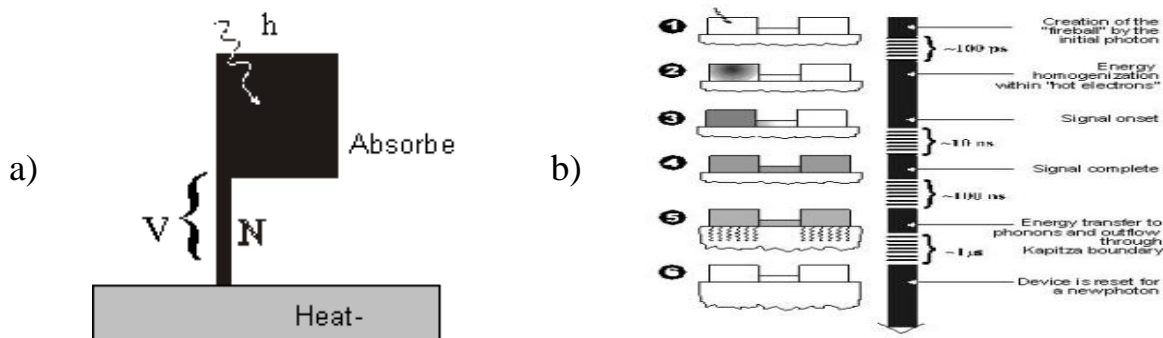
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## Abstract

1. Basic operational principles of QVD detectors.
2. Goals: high energy resolution, megapixel arrays, fast operation, high QE.
3. Experimental achievements.
4. Research areas under development.
5. Conclusions: no showstopper.

## 1. Basic operational principles of QVD detectors

The objective of this development was to find an appropriate effect in solid state physics capable of transforming directly the energy deposited in a detector by a photon, into a voltage pulse (the QV stage). Suppose this transformation is done, then superconducting electronics should be applied to digitize, store and read out the pulse signals (the VD stage) without reducing the energy resolution. Thermoelectric heat to voltage conversion was chosen for the QV stage ([Fig.1, a](#)). This led to a sensor design with no bias required, featuring a single lead per pixel, with fast read-out ([Fig.1, b](#)).



[Fig. 1.](#)

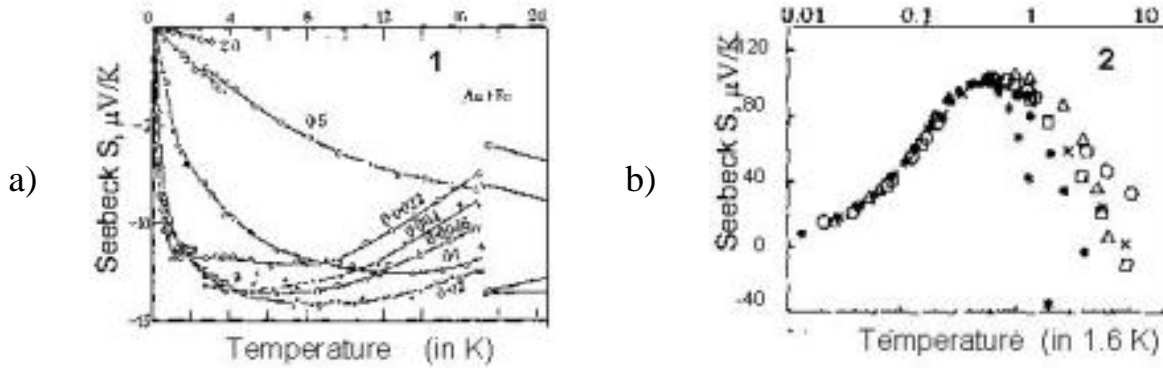
## 2. Goals: high energy resolution,

## megapixel arrays, fast operation, high QE

High energy resolution in this scheme is enabled by the fact that ordinary thermoelectric potentials are enhanced by the Kondo-effect at low temperatures in certain materials [\[1\]](#). According to theoretical considerations ( $L_0 = 25 \text{ n W} \cdot \text{W/K}^2$  is the so called Lorenz number,  $C_{\text{abs}}$  is the absorber heat capacity, and  $S$  is Seebeck's coefficient) [1]:

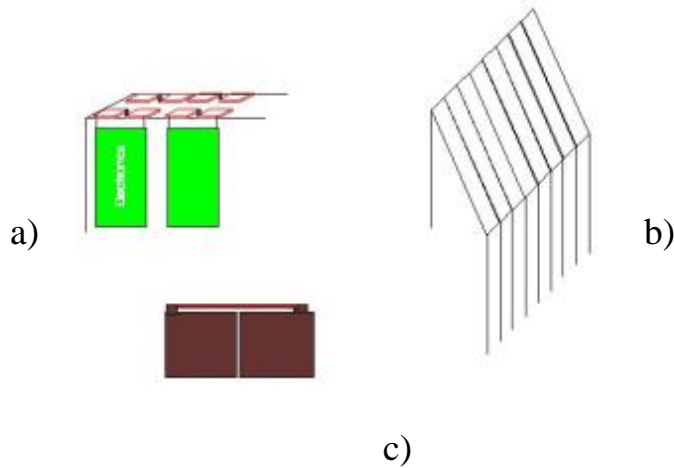
$$DE_{FWHM} = 2.35 \{2k_B T^2 C_{abs} [1 + L_0/S^2]\}^{1/2} \quad (1)$$

and  $DE_{FWHM}$  could achieve 1 eV or less with the appropriate choice of sensor material with  $S \sim 100$  mV/K and other device components [1]. Such materials have been identified (see [Fig.2](#)).



[Fig. 2.](#)

The high operational speed of these thermoelectric sensors is clear from [Fig. 1, b](#)). To make the megapixel arrays and high quantum efficiency feasible, we intend to use maximally all three spatial dimensions ([Fig.3](#)).



[Fig. 3.](#)

### 3. Experimental achievements

Currently for measurements we use samples shown in [Fig.4\(a-d\)](#). The measurement scheme is shown in [Fig.4,e](#). For the sensor material Au +100 ppm Fe (see [Fig.2, a](#)) was used, which is not as good as the hexaborates (cf. [Fig.2, a and b](#)), though it could produce  $DE_{FWHM} \sim 20$  eV at 0.3K. Our best results (Fall,1999) correspond to 1500 eV achieved at 0.65K. Two surmountable

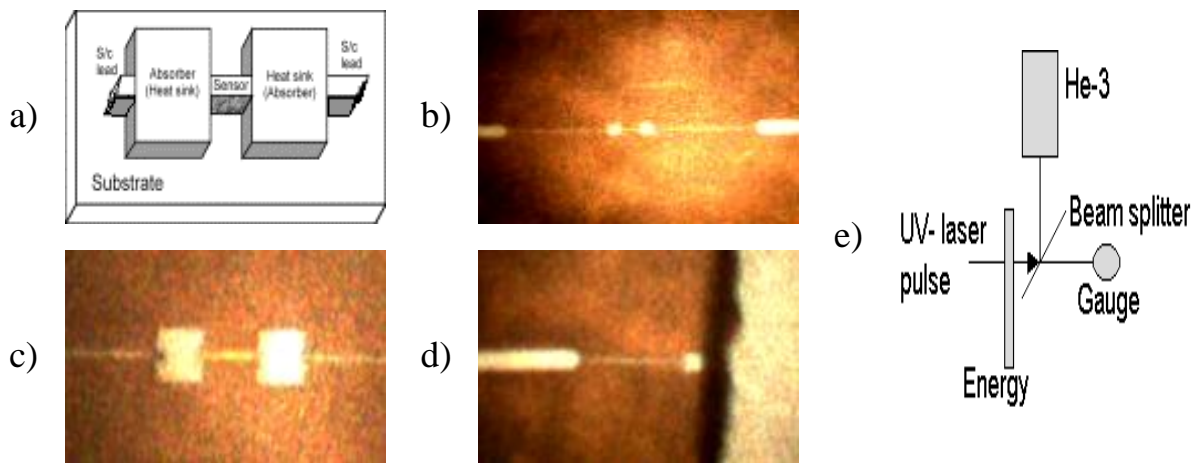


Fig.4

problems have delayed our reaching the theoretical resolution. The first reason is related to a fabrication problem, remnants (after ion milling) of

chromium on top of the sensor material, which was not only shorting the signal at  $T > 0.6\text{K}$ , but was becoming superconducting at  $T < 0.6\text{K}$ . (Reports exist in the literature on this effect, see, e.g., [2].) This prohibits further cooling down of the detectors in view of complete zeroing of the output signal. To avoid this drawback in the future we have completely eliminated the use of chromium in device fabrication.

The second obstacle is related to the impedance mismatch between the device and read-out electronics and will be discussed in the next section.

#### 4. Research areas under development

Understanding and applying in practice proper electronics is a crucial issue for optimal signal processing. Currently we use the scheme of signal acquisition shown in Fig.5.

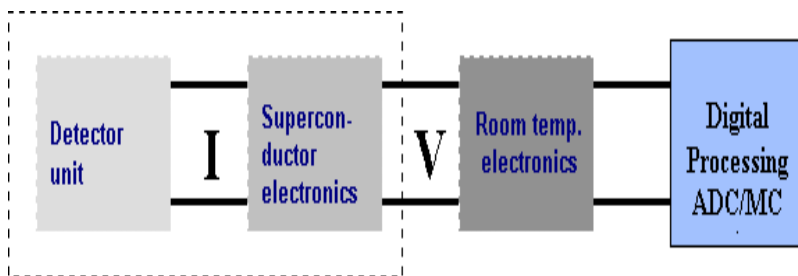
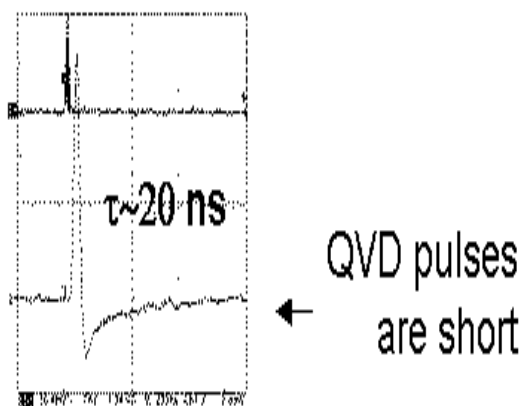


Fig. 5

The output impedance of the detector unit is  $Z_{\text{device}} \sim 0.1-1 \text{ W}$ . At the same time, the

inductance of the SQUID-array amplifier<sup>[2]</sup> input coil is  $L_{\text{SQUID}} \sim 1/4 \text{ m H}$ . For typical signals (see Fig. 6) this means the input impedance  $Z_{\text{amp}} \sim 30\text{W}$ . So the signal is reduced by two orders of magnitude in the current circuit (I-stage in Fig.5). We are now testing two more types of SQUID array amplifiers with  $L=25 \text{ nH}$  and  $L=4 \text{ nH}$ . Obviously they should provide lower values of  $Z_{\text{amp}}$ , though their high transimpedance gain at 10 MHz bandwidth still should be confirmed. To improve the second stage of amplification, we are planning to use a semiconductor amplifier which has input noise  $0.3\text{nV/Hz}^{1/2}$  [3] (this noise is below the Johnson noise of a 50 W resistor at room temperature). The next step should be to put the SQUID and QV-device onto the same substrate (HYPRES and TRW are potentially involved). This should help avoid signal losses and noise, and is more suitable for a megapixel design.



[Fig. 6](#)

The second major developmental area is the device-related material science, since 20eV is not our goal. For 1 eV and better resolution, one needs lanthanum-cerium hexaborate ( $\text{La}_{0.99}\text{Ce}_{0.01}\text{B}_6$ ) sensors (see

[Fig.2, b](#)). Thin film deposition, patterning, and testing is in progress now for this material. It should be mentioned that this material has not been tested in the form of thin films, so much work still needs to be done.

## 5. Conclusions: no showstopper

- QVD is a new class of single-photon detectors for hyperspectral imaging
- Advantages:
  - theoretical limiting resolution  $1/dl \sim 10,000$  at  $1 \text{ \AA}$ ;
  - straightforward fabrication of large arrays;
  - high quantum efficiency and focal plane area utilization;
  - high counting rates (up to 1 MHz per pixel) suitable for both intense and weak sources;
  - moderate operational temperatures  $T \sim 0.3 \text{ K}$ .
- Experimental progress:
  - prototype devices are getting closer to theoretical models, gradually improving the resolution;
  - no showstoppers uncovered so far.

## Acknowledgements

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## References

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[1] In those materials the enhancement is the result of magnetic impurities.

[2] We are very grateful to Dr. M Huber for providing SQUID-array amplifiers.