Development of Distributed Readout Imaging Detectors based on Superconducting Tunnel Junctions for UV/optical Astronomy

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ABSTRACT

Superconducting tunnel junctions (STJs) have been demonstrated as photon counting detectors in the UV-NIR wavelength range (100-1000 nm). They combine a modest wavelength resolving power with fast response and high detection efficiency over a broad wavelength band. This makes this type of detector an interesting alternative to the present generation of detectors used in UV/optical astronomy, such as CCDs and micro-channel plates. Practical applications require imaging detectors with large sensitive area and good spatial resolution. While the feasibility of small arrays of closely packed STJs which are individually biased and read-out has already been demonstrated, the development of large format arrays is limited by the large number of electronics chains and wire connections to the cold detector which would be required. An alternative approach is to use a large area absorber combined with a few STJs at the edges or corners. A photon's energy as well as its absorption position in the absorber can be derived from the signal amplitudes measured in the STJs.

In this paper the performance in terms of wavelength resolving power and position resolution of four different linear geometries of Ta absorbers, read out with Ta-Al STJs, is investigated and compared with single STJs. The UV and optical spectra obtained with the absorbers show resolving powers within a factor of two of the theoretical limit. In particular, a measured resolving power at $\lambda=300$ nm of ~ 16 with a position resolution of ~ 9 μm is achieved with a 100×50 μm^2 absorber in between two 50×50 μm^2 STJs.

Keywords: Superconductivity - tunnel junctions – imaging detectors - spectroscopy

1. INTRODUCTION

The present generation of detectors in UV/optical astronomy ($\lambda \sim 100$ -1000 nm or $E=1.2$ -12 eV) is based on semiconductors (CCDs) or micro-channel plates (MCPs). CCDs combine large sensitive area (several cm^2) with high resolution imaging and excellent QE in the optical, but no photon-counting capability and marginal QE for $\lambda < 300$ nm. In the UV, MCPs are most widely used because of the better QE of 10-40%, depending on wavelength and photo-cathode material. In addition, they provide photon-counting capability with time resolution < 1 μs , but without wavelength resolution.

Recent developments in cryogenic detectors, such as superconducting tunnel junctions^{1,2} (STJs) and microcalorimeters based on transition edge sensors³ (TES), have added a third dimension to UV/optical detectors: simultaneous with the position information, they can provide each photon's arrival time and wavelength. Combined with their high detection efficiency (50-70% over the range $\lambda \sim 115$ -700 nm), this makes them the ideal detectors for applications such as fast spectrophotometry or deep-field imaging. Combined with adequate field coverage, their existing performance may already be such that they could allow the simultaneous measurement of broad-band low-resolution spectra of very faint extragalactic sources to be obtained for all objects in the field. Such spectra containing emission line complexes or continuum absorption features (the Lyman edge) in very faint extragalactic objects may allow the direct determination of red-shifts^{4,5}.

Major developments are still required to fabricate STJs in large format imaging detectors. A number of approaches can be considered to ensure an adequate field coverage for such detectors. The simplest is to package individual devices into a close packed pixel array, as has been demonstrated with a 6×6 pixel format with S-CAM⁶, in the first astronomical application of

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STJs⁷. The major drawback to this approach is that each individual junction requires its own wiring and signal processing electronics.

A second approach – the matrix readout⁸, connects the base film of all devices in an array from the same row and the top films from the same column. Events are then read out and localised using a coincidence technique between signals from the base and the top films. Such an approach reduces the amount of wiring for individual devices and the signal processing chains of a $M \times N$ format array to only $M+N$, rather than $M \times N$ for the conventional approach. The feasibility of this concept is demonstrated elsewhere in this conference⁹. The drawback of this concept is that the capability of handling high countrates is reduced, since each preamplifier will see the signals from N or M pixels. Similarly, the requirements for suppression of the IR background are more severe. Furthermore, in case of a FET-based preamplifier, the voltage noise will increase due to the larger capacitance represented by the M or N pixels.

Another alternative is the use of large area absorbers which are read out with a few STJs. This distributed readout concept was first tested by Kraus et al.¹⁰ for a linear absorber between two STJs. In this approach, an event is characterised by two signals from the two STJs, which are more or less coincident in time. The sum of the two amplitudes is a measure of the original photon energy, whereas the difference of the two amplitudes provides information on the position of the absorption. This type of detector has similar disadvantages in handling high countrates and requirements on IR suppression as the matrix approach. Encouraging results have been obtained in X-rays with Ta absorbers combined with Al STJs¹¹. Recently, also the first UV results have been reported with absorber/STJ structures^{12,13}. In this paper we investigate different linear geometries of Ta absorbers with Ta/Al STJs as imaging detectors in the UV and Visible. X-ray results obtained with these detectors are presented elsewhere during this conference¹⁴.

Figure 1: A schematic of a tunnel junction together with the orientation in a parallel magnetic field necessary to suppress the Josephson current. The device is operated in the ultraviolet in a back illuminated mode where the UV response is limited by the cut-off of the substrate.

2. THE STJ PRINCIPLE OF OPERATION

The absorption of a photon of wavelength λ (or equivalently energy E) in a superconductor is followed by a series of fast processes in which the photon energy is converted into a population of free charge carriers known as quasiparticles. For typical transition metal superconductors this conversion process is of order of a few nanoseconds¹⁵. At sufficiently low temperatures (typically about an order of magnitude lower than the superconductor's critical temperature T_c) the number density of thermally excited quasiparticles is very small and the number of excess carriers N_0 created as a result of the absorption of a photon of wavelength λ (or energy E) is inversely proportional to the photon wavelength (or proportional to E). In general N_0 can be written:

$$N_0(\lambda) = \frac{7.1 \cdot 10^2}{\lambda \Delta} \quad \text{or} \quad N_0(E) = \frac{E}{1.7 \Delta} \quad (1)$$

Here the wavelength λ is in nm and the photon energy E and the energy gap Δ are in eV. Thus in a tantalum superconductor at a temperature well below the critical temperature, $T_c \sim 4.5$ K and $\Delta_{Ta} \sim 0.68$ meV, the initial number of free charge carriers $N_0(\lambda)$ created by the photoabsorption of an ultraviolet photon is of order $\sim 5 \cdot 10^3$ for a photon with $\lambda \sim 200$ nm.

The quasiparticles produced after photoabsorption in a superconducting thin film can be detected by applying a d.c. potential across two such films separated by a thin insulating barrier; forming a superconducting tunnel junction (STJ). This potential favours the transfer of quasiparticles from one film to the other through quantum-mechanical tunneling across the barrier. The detector signal is therefore represented by the current developed by this tunnel process. The situation is shown schematically in Figure 1. The superconducting films are deposited on a highly polished substrate which for optical and ultraviolet applications is sapphire but could be magnesium fluoride if a shorter wavelength response below the sapphire cut-off of 145 nm down to 115 nm is required. Illumination of the device is through this substrate onto a high quality epitaxial film. While front illumination is possible for single devices it is not favoured for large format arrays where the top surface is coated with a dielectric necessary to insulate the large amount of top wiring. Note a magnetic field also has to be continuously applied in the plane of the barrier to suppress the Josephson current (the tunneling of Cooper pairs at zero bias voltage (see Figure 1).

Within its effective life time, a quasiparticle can be transferred back and forth across the tunnel barrier several times, each time contributing positively to the overall signal¹⁶. Hence, if on average each quasiparticle will contribute $\langle n \rangle$ times, the number of charge carriers N which appears to be detected is $N = \langle n \rangle N_0$. The initial fluctuation in the number of charge carriers created in the photoabsorption process combined with the tunnel noise, associated with the multiple tunnelling of charge carriers across the barrier, leads to an overall limiting resolution for a symmetrical junction of the form^{17,18},

$$\delta \lambda_T = 8.8 \cdot 10^{-2} \sqrt{\lambda^3 \Delta \left(F + 1 + \frac{1}{\langle n \rangle} \right)} \quad \text{or} \quad \delta E_T = 2.355 \sqrt{1.7 E \Delta \left(F + 1 + \frac{1}{\langle n \rangle} \right)} \quad (2)$$

Here the Fano factor F can be assumed to be ~ 0.22 , considered typical of many of the transition metal elemental superconductors such as tantalum¹⁵. Thus for a tantalum based STJ the tunnel limiting resolution for the case when $\langle n \rangle \rightarrow \infty$ is ~ 7 nm for $\lambda \sim 200$ nm.

Figure 2: The tunnel limited resolving power of a number of elemental superconductors at ultraviolet and optical wavelengths. Experimental data for a tantalum device is also shown.

At least two other components due to the readout noise of the analogue electronics ($\delta\lambda_e$) and spatial non-uniformities ($\delta\lambda_s$), must also be added in quadrature reducing somewhat the resolving power. Figure 2 illustrates the theoretical limiting resolution based on equation 2 for niobium and tantalum as well as for lower energy gap materials such as molybdenum and hafnium. Also indicated is the measured resolution at ultraviolet to near-infrared wavelengths for devices based on Ta. Clearly, the measured resolution approaches the theoretical tunnel limited resolution in the UV, whereas the electronic noise still dominates in the NIR. At 200 nm the theoretical tunnel limited resolution for a device based on molybdenum or hafnium is only 2 and 1 nm respectively compared to ~ 7 nm for tantalum.

The detection efficiency of an STJ is completely determined by the optical constants of the materials involved. In particular for the case of back illumination of a Ta based STJ through a sapphire substrate, the relevant quantities are the reflection coefficients at the vacuum-sapphire and the sapphire-Ta interfaces, as well as absorption in the sapphire. The detection efficiency of such a detector in the UV-NIR, as calculated from the optical constants¹⁹, is shown in Figure 3, together with some measured efficiencies which confirm the predictions. For completeness, also the calculated efficiency for front-illumination is indicated.

Figure 3: The predicted detection efficiency in the UV/visible for a Ta-based STJ on sapphire in the back-illumination mode (solid line) and front-illumination mode (dashed-dotted line) Also indicated are experimental data in the UV for illumination through the sapphire.

3. DETECTOR DESCRIPTION

The detectors used for the present work are fabricated by Oxford Instruments Scientific Research Division (Cambridge, UK). The detector chip consists of a sapphire substrate on which several different configurations of single STJs and absorber-STJ structures are made. All structures are made from a symmetrical Ta/Al/AlOx/Al/Ta multilayer with 100 nm thick Ta and 65 nm thick Al layers. The base Ta layer is epitaxial (RRR=45), whereas the top Ta layer is polycrystalline. The relevant structures for this paper are rectangular absorber strips with a STJ detector at either end. Four different geometries have been investigated: $20 \times 100 \mu\text{m}^2$, $20 \times 200 \mu\text{m}^2$, $50 \times 200 \mu\text{m}^2$ and $50 \times 400 \mu\text{m}^2$. The first two include two $20 \times 20 \mu\text{m}^2$ STJs and the last two include two $50 \times 50 \mu\text{m}^2$ STJs. Figure 4 shows a schematic of such a structure. A Nomarski microscope photograph (see figure 5) of part of the chip shows the layout of the different structures. All devices on the chip have electrically connected base films, such that only a single wire is needed for the ground contact of the chip. The contacts to the top electrodes and the absorbers/base electrodes are made through $2 \mu\text{m}$ wide vias etched through an insulating SiO_2 layer (see Figure 4). They are fabricated in Nb so as to prevent the diffusion of quasiparticles out of the lower energy gap Ta electrodes.

Figure 4: Schematic of a $50 \times 400 \mu\text{m}^2$ Ta absorber with $50 \times 50 \mu\text{m}^2$ STJs on either end. Illumination with UV/VIS photons is through the sapphire substrate. Each photon generates a cloud of charge carriers (quasiparticles) which is detected in both STJs, with amplitudes dependent on the position of absorption.

Figure 5: Nomarski photograph of a $50 \times 50 \mu\text{m}^2$ single STJ (left) and two $50 \times 400 \mu\text{m}^2$ Ta absorbers with $50 \times 50 \mu\text{m}^2$ STJs on either end. The light-coloured tracks represent Nb wiring. The top electrodes are connected to separate contact pads outside the upper part of the photograph and the base electrodes and absorbers are connected to a common ground contact pad.

The energy gap Δ at the barrier, as measured from the I-V curves at $T=300 \text{ mK}$, is 0.42 meV , as opposed to 0.68 meV for bulk Ta. This significant reduction in energy gap is due to the proximity effect between the Ta and the lower gap Al layers ($\Delta_{\text{Al}}=0.18 \text{ meV}$). The reduced energy gap near the barrier effectively enhances the tunnel rate and reduces loss rates, by confining the quasiparticles close to the barrier, away from possible loss sites such as the surfaces, interfaces or perimeter. The AlOx tunnel barriers have resistivities of about $2.5 \mu\Omega \text{ cm}^2$ and typical leakage current densities, as measured at $T=300 \text{ mK}$, of $<100 \text{ fA}/\mu\text{m}^2$. The magnetic field ($B=0.008 \text{ T}$) required to suppress the Josephson current is applied parallel to the plane of the tunnel barrier along the diagonal of the square STJs (the 'diamond' orientation).

4. EXPERIMENTAL CONFIGURATION

All experiments have been performed in a ^3He cryostat with a base temperature $T=0.30$ K. The detector chip is clamped to a cold finger in the inner vacuum chamber of the cryostat. A superconducting magnet provides the magnetic field parallel to the plane of the tunnel barrier, which is required to suppress the Josephson current and Fiske steps. The light source is a Xenon lamp combined with a grating monochromator. Additional filters are used if the suppression of light in higher orders of the monochromator is desired. A UV-grade silica fiber is used to couple the light into the cryostat and onto the detectors. The fiber limits the available wavelength range to 200-2000 nm. In the present experiments, the end of the fiber was in close contact with the backside of the sapphire substrate, thus illuminating the base electrode of the detectors. Since the sapphire is transparent and the 100 nm thick Ta absorbs >98% of the light in the available wavelength range, essentially only the base electrode is stimulated in this experiment. Alternatively, the optical configuration could be rearranged to directly illuminate the top electrode (front-illumination). This configuration would be required if illumination at photon wavelengths shorter than the sapphire cut-off wavelength ($\lambda \sim 145$ nm) is performed.

The STJs are read-out with a charge sensitive amplifier at about 1 m distance and a shaping stage (shaping time ~ 30 μs), both at room temperature. Each detected photon gives rise to a pulse at the output of the preamplifier. The amplitude and the rise time of this pulse correspond to the total number of tunneled electrons (charge output) and the decay time of the signal, respectively, and are stored on a PC. The limiting noise level of the electronics chain with open input is ~ 400 electrons rms. The electronic noise is monitored through the width of the response to an electronic pulser fed into the electronics. In case of the absorber with 2 STJs, a multi-channel system is used which additionally records the time of arrival of each photon signal. At sufficiently low photon rates, pulses from the two STJs which are (nearly) coincident in time can be assigned to a single photon, and be processed accordingly. This approach has been chosen instead of the more elaborate full digitisation of the coincident current pulses from the preamplifiers, which would provide, however, more detailed information on quasiparticle diffusion and loss processes.

Figure 6: Spectrum at $\lambda=995$ nm obtained with a single $50 \times 50 \mu\text{m}^2$ STJ. The peak at the end of the pulse height range represents the response to an electronic pulser.

5. EXPERIMENTS

Each of the four absorber-STJ structures as well as two single STJs of the corresponding size ($20 \times 20 \mu\text{m}^2$ and $50 \times 50 \mu\text{m}^2$) have been illuminated with monochromatic light at wavelengths in the range $\lambda = 225$ -1000 nm. The spectra obtained with the $50 \times 50 \mu\text{m}^2$ single STJ represent the best resolving power and lowest noise levels obtained to date with Ta-based STJs. Figure 6 shows the spectrum at $\lambda = 995$ nm ($E = 1.25$ eV), with a resolving power ~ 11 , obtained with this device. Note the response to

such photons is such that the spectral distribution is well out of the noise. A long wavelength limit of $\sim 7 \mu\text{m}$ is implied for this device.

The result and evaluation of a typical acquisition with a STJ-absorber structure ($50 \times 200 \mu\text{m}^2$, $\lambda = 295 \text{ nm}$, $E = 4.20 \text{ eV}$) is shown in figure 7. The top left panel shows the scatter plot of the measured pulse height $S1$ from one STJ against pulse height $S2$ from the other STJ. In the top right panel the same events are shown in summed pulse height $S1+S2$ against normalised difference in pulse height $(S1-S2)/(S1+S2)$. The quantities $S1+S2$ and $(S1-S2)/(S1+S2)$ are measures for the energy of the absorbed photon and the relative position of absorption, respectively.

Figure 7: Measurement at $\lambda = 295 \text{ nm}$ ($E = 4.20 \text{ eV}$) with a $50 \times 200 \mu\text{m}^2$ absorber-STJ structure. Top left: signal $S1$ from one STJ versus $S2$ from the other STJ. Top right: the same data plotted as summed pulse height $S1+S2$ ($\sim$ energy) versus $(S1-S2)/(S1+S2)$ ($\sim$ position). The solid line represents a polynomial fitted to the selected events (between the dashed lines). Lower left: same data, but corrected in pulse height for the selected events, using the fitted polynomial. Lower right: the resulting spectrum for the selected events. A measured resolving power of 16 is obtained at $\lambda = 295 \text{ nm}$.

The following structures can be recognised in the scatter plots:

- 'STJ' events absorbed in those parts of the absorber which are covered by the two STJs appear at the right and left side in the scatter plots. The presence of such events implies that quasiparticles are not very efficiently trapped in the proximised Ta/Al layers of the STJs, in spite of a considerable difference in energy gap between the STJs ($\Delta = 0.43 \text{ meV}$) and the uncovered absorber ($\Delta = 0.68 \text{ meV}$).
- In between the two groups of 'STJ' events appear the events absorbed in the uncovered part of the absorber. The 'absorber' events show a clear nonuniformity in the summed pulse height along the absorber, with in particular, a lower signal in the middle of the absorber. This is partly due to a different response of the electronics chain to the different pulse shapes which are associated with events absorbed at different positions, and partly due to a localised loss channel for quasiparticles at the Nb contact in the middle of the absorber (see Figure 4). The latter mechanism is more obvious in X-ray measurements on these detectors¹⁴.

The combination of imperfect quasiparticle trapping in the STJs, localised losses in the absorber and STJs, and the role of the electronic response function greatly complicates an analytical description as in ref. 10. Therefore, at this stage an empirical approach was chosen, in which a 10th order polynomial function was fitted to the observed relation between the quantities $S1+S2$ and $(S1-S2)/(S1+S2)$. This fit is only applied to the uncovered absorber part of the structure, as indicated with the dashed lines in the scatter plots. The fitted polynomial (indicated with the solid curve) is then used to correct the summed pulse heights (normalised to the value of the polynomial at $(S1-S2)/(S1+S2)=0$). The resulting scatter plot is shown in the lower left panel of Figure 7. Finally, the pulse height histogram is constructed for the events of the selected part of the structure (between the dashed lines) and shown in the lower right panel.

5.1 Signal amplitudes and noise levels

The responsivities (in electrons/eV), pulse decay times and baseline noise levels for single STJs and absorber-STJ structures as derived from the measurements are listed in Table 1. The responsivities for the single STJs are larger than those from the STJs on the absorbers, indicating that some charge carriers are lost in the absorber. The baseline noise levels (in eV) for the absorber spectra are significantly higher than for the single STJs, partly because of the lower signals and partly because the noise of two signals is combined.

For the absorber-STJ structures, the responsivities for events in the absorber, as well as in the STJs are quoted. The responsivity for the STJ on the absorber is clearly larger than from the adjacent part from the absorber, typically by about 30% (see also figure 7). This implies that the initial number of quasiparticles N_0 created in the absorption process (see equation 1) was larger, and corresponds to an effective energy gap in the STJs which is about 30% lower than in the bulk Ta absorber; $\Delta_{\text{eff}}=0.52$ meV, but not as low as the measured gap at the barrier ($\Delta=0.42$ meV). These observations are in agreement with the predictions by Poelaert et al.²⁰ Pulse decay times for the absorber signals are similar to those of the single STJs, but the pulse shapes vary widely with the absorption position, due to the finite time for diffusion across the absorber length.

The present readout scheme requires both amplitudes from the two STJs to be detected independently above the analog electronics threshold. Therefore, longer wavelength photons cannot always be detected, especially in case of an absorption close to one of the STJs, where the signal from the faraway STJ may be below the detection threshold. In this respect, the imperfect trapping of quasiparticles by the STJs is an advantage, since it gives rise to relatively large signals in the faraway STJ. The wavelength above which more than 50% of the events in the STJ-absorber structure are no longer detected for this reason is listed as the cut-off wavelength in Table 1. Note that this is a direct consequence of the electronic configuration, which could be improved by dropping the requirement of independent detection of the two signals from each event (albeit probably at the expense of resolving power).

Table 1: The measured characteristics for all STJ-absorber structures and single STJs presented in this work.

Device size [μm^2]	Responsivity (e-/eV)		Pulse decay time (μs)	Baseline noise (eV)	Cut-off wavelength (nm)	Resolving power @ $\lambda=300$ nm	Position resolution [μm] @ $\lambda=300$ nm	Equiv. nr. of pixels on absorber
	STJ	absorber						
20x20	0.31e5	-	10	0.081	-	14.0	(20)	(1)
20x100	0.23e5	0.17e5		0.17	1050	13.6	8.5	7
20x200	0.20e5	0.14e5		0.21	650	11.4	14	11
50x50	1.64e5	-	50	0.085	-	22.8	(50)	(1)
50x200	1.22e5	0.93e5		0.16	1200	15.8	9	11
50x400	1.12e5	0.78e5		0.19	550	11.9	23	13

5.2 Energy/Wavelength Resolving Power

The measured energy resolutions as a function of photon energy for the single STJs and the absorber-STJ structures are plotted in figure 8. In the case of the absorbers, the numbers refer to the largest possible event selection window, as indicated in figure 7. Also indicated is the electronic noise level in each measurement and the 'device limited' resolution which is obtained if the electronic noise is subtracted from the measured resolution. This device limited resolution is expected to approach the tunnel limited energy resolution (see equation 2) in the case of a uniform response from the entire structure. Note that this is clearly the case for the 50x50 μm^2 single STJ, which even approaches the tunnel limit derived from the energy gap at the barrier. Also the 50 μm wide absorber structures approach the tunnel limit for bulk Ta. The 20x20 μm^2 single STJ and the 20 μm wide absorber structures, however, are far off from the tunnel limit, suggesting that these structures suffer more from a nonuniform response.

The resolving power at $\lambda=300$ nm ($E=4.13$ eV), as measured for the entire absorber, is summarised in Table 1. Locally, however, the resolving power can be better as is shown in figure 9. In particular in the middle of the absorber, where the base contact forms a loss site for quasiparticles, and in the regions close to the STJs the resolving power is degraded.

Figure 8: Measured energy resolution for single STJs and STJ-absorber structures as a function of photon energy. Also indicated are the electronic noise and the device limited resolution, obtained after quadratic subtraction of the electronic noise. The solid and dashed lines represent the tunnel limited energy resolution for bulk Ta ($\Delta=0.68$ meV as, in the absorbers) and proximised Ta/Al ($\Delta=0.42$ meV, as in the STJs), respectively.

Figure 9: Measured energy resolution versus relative position at $\lambda=295$ nm ($E=4.20$ eV) with a 50x400 μm^2 absorber-STJ structure. The degraded resolution at the Nb base contact in the middle of the absorber, as well as in the vicinity of the STJs is clearly visible.

5.3 Position Resolution

In case of perfect trapping in the STJs and no losses in the absorber, the energy E and absorption position x of the photon are given by Kraus et al.¹⁰ as $E \sim Q_1 + Q_2$ and $x = 0.5L(Q_1 - Q_2)/(Q_1 + Q_2)$, with $Q_{1,2}$ the detected charge in the two STJs and L the absorber length. The relation between position resolution and energy resolution is given as $\delta x = 0.5L \cdot \delta E/E$. The effect of imperfect quasiparticle trapping in our case is an apparent compression of the relative position scale given by $(Q_1 - Q_2)/(Q_1 + Q_2)$, which no longer extends from -1 to $+1$ (see figure 7). Consequently, the position resolution in our case will be degraded by the factor corresponding to the observed compression of the position scale. Ignoring the fact that there are losses in the absorber, and the effects introduced by the electronics, a coarse estimate of the position resolution for our devices is found from the above equation for δx , corrected for the observed compression of the relative position scale. The results for $E=4.13$ eV ($\lambda=300$ nm) are listed in Table 1. The computed position resolutions have also been converted into the equivalent number of pixels on the uncovered part of the absorber. Note that the position resolution will change with wavelength, due to its relation to the energy resolution.

5.4 Countrate capability

The $50 \times 200 \mu\text{m}^2$ absorber-STJ structure has been illuminated with $E=4.2$ eV ($\lambda=295$ nm) photons at event rates up to about 3000 cts/s. The measured FWHM energy resolutions are shown in Figure 10. No significant degradation of energy resolution is observed up to ~ 1000 cts/s. However, a significant amount of pile up events occurs in the spectra, due to the relatively long signal processing time ($\sim 350 \mu\text{s}$) of the pulse height analysing electronics.

Figure 10: Measured energy resolution at $E=4.2$ eV ($\lambda=295$ nm) versus detected event rate for the $50 \times 200 \mu\text{m}^2$ absorber-STJ structure. Noise levels as measured from the electronic pulser width are also indicated. The dotted line represents the tunnel limit (see eq.2) for this structure. The insert shows the fraction of single (i.e. non pile-up) events versus event rate. The solid line is the predicted fraction for a total event processing time of $350 \mu\text{s}$, as in the present signal processing electronics.

7. CONCLUSION

We have demonstrated the potential of Ta-based linear absorber-STJ structures as photon counting imaging detectors with a modest wavelength resolving power in the UV/visible. All tested structures exhibit wavelength resolving power within a factor of two from the theoretical limit. In particular, the structures with $50 \mu\text{m}$ wide absorbers operate close to this limit. A measured resolving power of ~ 16 at $\lambda=300$ nm, in combination with a position resolution of $9 \mu\text{m}$ on a $100 \mu\text{m}$ long absorber

between two $50 \times 50 \mu\text{m}^2$ STJs is achieved. Longer absorbers are found to have slightly worse wavelength resolving power, but relatively better position resolution. The present devices and readout scheme do not allow for event rates >1 kHz, without serious pile-up problems. Such structures could be the building blocks of an imaging detector for UV/visible applications, with the advantage of considerably reducing the number of wires per spatial resolution element albeit at the expense of event rate capability. Further improvements in the geometry are possible, in particular by changing the position of the electrical contact to the absorber. The use of lower energy superconductors (e.g. molybdenum) could further improve the resolving power. Epitaxial molybdenum would have the additional advantage of fast diffusion of charge carriers¹⁴, which allows for larger absorbers.

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