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Note to interested suppliers:

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Canada does not intend to pay for the information solicited. Any and all expenses incurred by the suppliers in pursuing this opportunity.

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<u>TITLE: Design and fabrication of very sensitivity LIDAR detectors</u>

1.0 Generality

Defence Research and Development Canada - Valcartier Research Centre wants to acquire a detector able to provide spectrum of laser induced fluorescence from atmospheric aerosols. The detector must be connectable to a commercial spectrometer itself connected on a LIDAR platform comprising an emitter and a receiver. The objective of the project is to obtain by scanning spectral images of laser induced fluorescence (very low signal) as a function of the range from the LIDAR (very fast transient).

1.1 Laser induced fluorescence and optical system

Many of the molecules contained in atmospheric aerosols are susceptible to emit fluorescence when illuminated by ultraviolet light (UV). The emitted light depends on the characteristics and composition of the aerosols and is also influenced by the particle size. The signal level depends on the ability of aerosols to emit fluorescence (quantum efficiency) and by their concentration. Typically, the signal level in a given channel is in the order of a few photons at maximum for a range sample covering a band of 10nm located form 350 to 600nm. The dynamic range over which a detector shall be able to work is from 100kHz to 3GHz in terms of photon arrival rate. The technologies of interest shall be able to provide samples varying in range from 5 to 10 meters for ranges extending from 200 to 5000 meters.

1.2 Existing system

In the various detection systems presently used to provide measurements of spectral fluorescence, there are, ICCD (intensified Charge coupled Devices) and photon counting devices built with photomultiplier cells arrays. ICCD are not able to provide many samples in range along the same ray and the present photon counting detectors do not provide a sufficient dynamic range for the considered application.

1.3 Acronyms :

ICCD : Intensified Charge Coupled Device
LIDAR : LIght Detection And Ranging
RDDC: Recherche et Développement pour la Défense Canada
ROIC : ReadOut Integrated Circuit
SIPM: Silicon PhotoMultiplier
SPAD : Single Photon Avalanche diode
UV: Ultra Violet

2.0 Requirement description

2.1 Potential technologies

The proposed technologies shall provide measurements by estimating the photon counts number with the use of analog; digital or hybrid methods. Potential technologies examples are given below. The important parameters to be respected are the following: the capability to provide at least 32 spectral channels in the range from 350 to 600nm; the capability to provide samples in the range interval from 200 to 5000 meters with range intervals from 5 to 10 meters. A dark current or dark count rate lower than or equal to 100kHz for each channel and still be linear at 50% for a photon arrival rate in the order of 15GHz. The technologies described below are not limitative and are provided as potential technologies for the achievement of the required objectives of DRDC.

2.2 General system parameters

Table 1 below show the general parameters that a detection mean shall respect.

Parameter	Minimum value	Maximum value	Units
Resolution in range	1	10	meter
Range	200	5000	meter

Sensitivity per channel	0.1	---------------	MHz (photons)
Maximum count number for each channel	---------------	15000	MHz (photons)
Laser pulse repetition rate	200	10000	Hz
Dynamic range	45	--------------	dB
Quantum efficiency	20	--------------	%
Minimum wavelength	350	--------------	nm
Spectral range	350	600	nm
Crosstalk rate	0	10	%
Afterpulse rate	0	10	%
Dark counts for each channels	---------------	100	kHz
Sensor size	---------------	40	mm

2.3 Parameters definition :

Resolution in range: The sampling interval in range

Range: The interval in distance from the LIDAR for which it shall be able to acquire data;

Channel sensitivity: In steady state of the detector, the minimal ability to detect photons in exceedance of the noise of the detector

Maximum count number for each channel: For a 50% linearity the maximum number of photon arrivals in a given channel of the detector. Linearity of 50% means that at this level the signal variation is 50% lower than the corresponding variation at low signal level.

Laser pulse repetition rate: The frequency at which the laser is pulsed. This parameter is important because it imposes a requirement for the transmission of data from the detector to the external system. The ROIC could integrate a binning capability for consecutive laser pulses returns.

Dynamic range: The power interval over which the detector shall be able to respond. The minimum level is the sensitivity limit and the superior limit is the level at which the detector has a 50% linearity. As an example, a detector having a range resolution of 10 meters and 100kHz of dark count rate will have a spontaneous trigger rate of 0.67%. The standard deviation corresponding to that level is 0.082. This limit has to be established using a many measurements before confirmation that a signal level is truly above sensitivity limit

Quantum efficiency: The proportion of photons incident on the detector that effectively trigger detection events.

Minimum wavelength: The shortest wavelength at which the detector has 30% of the response it has at its maximum detection capacity.

Spectral range: The minimum range over which the detector is still functional meaning that it has 30% of the response it has at its maximum sensitivity.

Crosstalk: The proportion of detection that triggers detection events in neighboring detectors. When a detector such as a SPAD is triggered the avalanche process can emit photons of free electrons. These emitted particles can propagate and trigger detection event in adjacent detectors.

Afterpulse: Afterpulse is a trigger event that follows immediately and is directly related to a prior detection in the same detector. After quenching of a SPAD detector, there could remain trapped charges in the depletion zone of the detector. When released, these trapped charges can retrigger the same detector after rearming.

Dark counts per channel: A detector is susceptible to spontaneously be triggered because the detectors are biased above their breakdown voltage.

Sensor size: the largest dimension of the full detectors.

2.4 Analog method (SIPM: silicon photomultiplier)

SIPM are detector built upon SPAD (Single Photon Avalanche Diode). These avalanche diodes are biased above their breakdown voltage and could be triggered by for types of events: Spontaneously (dark current); by the arrival of a photon; by a crosstalk event and by an afterpulse event. Such detectors are commercially available but will likely have to be assembled differently for this application.

Should DRDC select an analog solution built with SIPM, do you believe you can provide solutions to the following problems?

a) Linear or bidimensionnal array assembly having a minimum of 32 channels:
In a spectral channel detectors could be added perpendicularly to the spectrum in order to increase the dynamic range of the detector;
b) Bias of the detector:
SIPM require to be biased above their breakdown voltage. The voltage is in the order of 30 to 35 Volts. This voltage has to be uniform and controllable by the user through an external system;
c) Signal processing electronic:
Transimpedance amplifier; Signal level adaptation amplifier; band limiting filter. Each channel has to be similar to its neighbour. The SIPM provide a current that depends on the incident light intensity. The transimpedance amplifier is a current to voltage converter and shall add as less noise as possible. The signal level adaptation amplifier and the band limiting filter are used to constrain the noise and adapt the voltage of the output in order to enable digital conversion.

d) Digital sampling:
   The sampling shall cover the full dynamic range of the signal which is close to 14 bits and shall not add too much noise to the signal.
e) Primary information processing system :
   The primary information processing system incorporates the components enabling the storage and the transfer of the information. In the cas of LIDAR operating at 200Hz over 5km with range interval in the order of 5meters; 32 channels sampled over 14 bits the transmission rate is close to 90Mbits/second and at 10kHz the amount of data is close to 4.5 Gbits/second. It is possible that information from many laser impulsions be combined and therefore linearization may be required on the data as well as correction required to diminish the impact of the dark current; the crosstalk and the afterpulses.

f) Data transfer system :
   The detector shall be connected to a computer to perform the data transfer. Since the required data transfer rate can be very high, an adequate data transfer process based on existing technologies shall be developed.

2.5 Photon counting approach (SPAD arrays)

SPADs are avalanche diodes that are commuted by the detection of a single photon. Once a SPAD has been triggered it has to be quenched prior to be set back in operation. This process can be passive or active depending on the requirements or on the particular design of the SPAD. Individual SPADs can be spontaneously triggered (dark count); they can also be triggered by afterpulses and are also susceptible to crosstalk with adjacent SPADs in an array. It is highly possible that different technologies be used to build an array of SPADs and a control circuit required for data transfer ROIC (ReadOut integrated Circuit). The contractor will have to provide a solution that is the most appropriate to the solution of that problem. The SPAD array built on a single integrated circuit could be made of individual detectors each having biasing contacts and signal contact. The ROIC will have the following functions:

At the individual SPAD level (pixel level)

A) Connection to the SPAD array through the biasing and signal contacts.
   The SPAD array if not directly integrated with its control circuit shall be connected on a ROIC.

B) SPAD switching detection capability.
   When a SPAD is triggered it becomes the analog of a current source a ciruit on the ROIC at the pixel level shall be built in order to detect that change of state.

C) SPAD quenching capability

After it has been triggered, a SPAD shall be be droiven in such a way that the current flowing through it stops. This process is called quenching. It can be passive or active. In a passive quenching circuit, a simple way to shut the current flowing through the SPAD shall be used. For example a rapidly charging capacitor that shuts the voltage drop through the diode. At this time the current stops and the diode discharge itself slowly. The capacitor being discharged slowly the bias voltage is progressively established. In an active process the bias through the diode is shut as soon as the state change is detected and a given wait time needs to be extended before biasing again the diode.

D) External command reception (activation or not)
To characterize the detector, which is the measurement of its performance, it is required to activate individually or in small groups each of the SPADs. The measurement of the dark counts; afterpulse rate, quantum efficiency require that each SPAD be individually controlled. Crosstalk rate can be evaluated through the activation of a small group of detectors.

E) Reception and use of a synchronization signal (clock)
It is possible that two clock signal be required. One of these signal would provide the cells a synchronization signal for them to do their internal tasks. The second signal, faster would be used to perform the data transfer from the SPADs if a synchronous solution would be retained.

F) Data transfer
The following signals represent the useful information that SPADs will provide.
   a. Detector active – no detection
   The SPDA was active during the preceding clock cycle and no detection event occured.
   b. Detector active - detection
   The SPAD was active during the preceding clock cycle and a detection event occured.
   c. Detector inactive
   The SPAD was inactive during the preceding clock cycle. The SPAD may or bot have been activated or it is in its quenching process.

This information is required because the estimation of the photon number incident on the global detector during a clock cycle requires the number of active detectors and amongst them the number of detectors that have been triggered.

At the higher ROIC level

A) Information collection from spectral channels
Information collection from spectral channels will provide for each time interval and for each spectral channel the number of SPADs that were active and the number of detection that occurred. Many methods based on combinatory or synchronous logic can be used to achieve that goal.

B) Primary level information processing
Primary information processing would consist in binning of multiple pulse returns adjacent in time in order to reduce the amount of data transfer.

C) Information transfer outside of the detector
Information transfer shall be performed quickly. For example, if in a given SPAD channel there is 1023 SPADs (2^{10} -1) = 31 * 3 *11, the output performed for each of the $N_C = 32$ channels; 1000 sampling intervals in range $N_I = 1000$; with 10 bits $N_b = 10$ for each detection intervals, this at the laser pulse repetition rate ($F = 200Hz$). It gives a data throughput of: $\frac{128Mbit}{s} = N_C N_I 2 N_b F$

In the case where DRDC would select the photon counting method, do you believe you can provide solutions to the following problems? :

1) Fabrication of a SPAD array that satisfies the requirements provided in table 1.
2) Verification if a microlens array shall or not be installed on the SPAD array to increase its sensitivity and determine an assembly procedure;
3) Superimposition (hybridation) of the SPAD array on the ROIC;
4) Implementation of the analog components required to control the SPAD on the ROIC;
5) Implementation of control logic for SPADs on the ROIC;
6) Implementation on the ROIC of the data collection interfaces for the SPADs;
7) Implementation on the ROIC of the primary information processing interfaces;
8) Implementation on the ROIC of the communication interface to the exterior.

3.0 DRDC requirements in the context of this RFI

Suppliers are invited to respond to the following questions

Answers to the following questions must provide information on the technical challenges and the major commercial and budgetary issues of the project described

Answers can be submitted in one of the two Official Languages of Canada (English or French)

NOTES :

- Suppliers who respond to this Request for information should identify their potential partners if there is a need to enhance the existing expertise of their company.
- Since this Request for information is not a request for proposal (RFP) and since no contract will be awarded solely because of the RFP, Canada reserves the right to see the responses upon receipt, ie, Canada wants to be able to consult the responses before the closing date.

Suppliers are invited to respond to the following questions:

1) Is the SIPM approach realistic, how would you try to solve the problem? What are the design and fabrication costs related to that approach? What are the delays before such a solution be produced?
2) The SPAD array which would be built with 32 channels each containing close to a 1000 SPADs. At the level of the SPAD array, each SPAD shall be individual. What approach would be the more susceptible to work? What are the modality for connecting the array on a read and control ROIC? What are the design and fabrication of the SPAD array? How much time would be required to achieve the design and fabrication?

3) Is the ROIC as it is presented in this document be realistic? How shall we approach the problem of individual SPAD control? How shall we approach the problem of data transfer from the individual detectors to the heart of the ROIC? What approaches for the transfer of the data from the ROIC to an external computer are to be privileged? What are the alternatives for operation of such a detector in the ROIC? What are the design and fabrication costs we should expect to achieve such a solution? What delay shall we expect prior to the fabrication of such a solution?

CLOSING DATE AND PRESENTATION OF THE SUPPLIER'S RESPONS

Suppliers interested in responding to this Request for information should send their response (preferably by email) to Céline Vaillancourt before the closing date and time for this RFI.

All answers and queries should be addressed to:

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Answers can be submitted in one of the two Official Languages of Canada (English or French)