Articoli references notes

# A Miniaturised, Fully Integrated NDIR CO2 Sensor On-Chip

* CO2 long term exposure by humans can affect the organism: cognitive abilities, bones demineralization and kidney calcification
* Ventilation air quality dictated by sensors
* Also a low cost sensor can sometimes make the effect (electromechanical sensors and NDIR ones)
* ELECTROMECHANICAL SENSORS: measurement of gas concentration by measuring the change in electrical properties
  + Resistance
  + Capacitance
  + Electric potential

Induced by the absorption of a gas.

* ELECTROMECHANICAL SENSORS:
  + advantageous because of easy of fabrication
  + low cost
  + high sensitivity to wide range of compounds
* ELECTROMECHANICAL SENSORS: poor long-term stability and cross-sensitivity to other gases = less attractive in the CO2 sensor market
* NDIR CO2: superior long-term stability and high gas specificity: significant absorption strength of CO2 in mid-IR region.
* NDIR CO2: very high absorption coefficient of CO2 in mid-infrared: a path length of few centimeters is sufficient to detect small changes in CO2 concentration
* NDIR CO2: the 83% of the total advanced CO2 sensors are based on the NDIR technique
* NDIR CO2: are also bulky: long (several cm) interaction length is required for achieving ppm detection
* NDIR CO2: the cost is high because they are typically based on discrete co-assembled optical elements… in last years price and dimension changed giving them more interest in industry and academia
* NDIR CO2: decreasing the cost depending on the design of miniaturized ones, which can use a multi-pass cell or an optical cavity with various shapes.
* NDIR CO2: pre-concentrator coatings can be employed to effectively amplify the gas concentration in the vicinity of the optical field  the optical path length can be reduced
* NDIR CO2: broadband infrared source + reflective gas tube + 2 optical detectors that are sensing and reference … the overall mechanism allows for autocalibration
* NDIR CO2: mid-IR led has a relatively narrow emission spectrum such that the need for optical filters can be eliminated without introducing notable cross-sensitivity by other gases
* NDIR CO2: why integrating cylinder? Multiple reflections can be experienced by the sensor before reaching the detector and thus a long effective path length on a small sensor footprint
* NDIR CO2: the response time of the sensor usually depends on the level to measure in ambient (usually few hundreds of ppm), usually it could be long but there’s not a big problem for applications such as air quality monitoring
* NDIR sensor accuracy: can vary depending on the presence of water molecules (it depends on relative humidity RH in the air): the water vapor has a broad absorption in the infrared wavelength range that can be significant for some specific wavelength depending on the spectral overlap between the absorption band of the target gas and the water molecules
  + Different water interference characteristics
  + It is negligible in common ranges
* All sensors: characteristics curves used for determine some points of concentrations dependent on T and RH (that are made variable during the measurement)
* Stability of a sensor: deals with the degree to which the sensor’s characteristics remain constant over time. The drift can be attributed to factors such as temperature fluctuations and component aging.
* Sometimes it could happen that the reference signal and the sensing signal change in opposite directions during this drift (led photodiode characteristics): strong correlation between the ambient temperature and the sensing signal whilst the worse correlation of the reference channel is not yet fully understood

# Quartz-Enhanced Photoacoustic Spectroscopy: A Review

* Quantitative and qualitative gas sensors categorization: analytical sensors (gas-chromatography and spectrometry), electrochemical, semiconductor and laser optical absorption sensors  they are mainly classified based on the physical mechanism used
* Analytical techniques: no real time response, costly, invasive and with a large spatial footprint
* Electromechanical: relatively specific to individual gases, with usable resolution of less than one part per million of gas concentration and operate with a very small amount of current
  + Suited for portable, battery powered instruments
  + But there’s the influence of hysteresis and water humidity
  + Slow time response: fluctuations of gas and power up can make minutes for the sensor to reach 90% of tis final output value
* Laser absorption spectroscopy (LAS): response is < 1s and they are faster and part per quadrillion detection sensitivity (small traces detection)
  + Molecular absorption principle: transitions that an electromagnetic wave cause in a chemical species
  + If a molecule is irradiated by infrared light, it is excited to a rotational vibrational energy level manifold.
* Semiconductor lasers as light source for sensors: limited by the available optical power
* Mid-IR and previous analyzed NDIR are the common choice
  + Quantum cascade lasers (QCLs)
  + Interband cascade lasers (ICLs)

High output power

* LAS-based techniques: excellent sensitivity and selectivity and long effective optical pathlengths, compactness, mechanical stability, versability and cost effectiveness
* cavity ring down spectroscopy (CRDS): optical cavity with low loss and high reflectivity (>99.9%): long optical path of up to several kilometers. Multiple reflections occur on mirrors after a pulse
* Cavity enhanced absorption spectroscopy (CEAS): it is a modification of CRDS: radiation is injected at a very small angle respect to the cavity axes. It results in the formation of a dense structure of a weak optical axial modes that makes the system more robust against instability in both cavity and laser spectrum.
* Cavity output spectroscopy (ICOS): similar to CEAS: measurement procedure is the comparison between signal amplitude both at input and output of cavity.
* Photo-acoustic spectroscopy (PAS): one of the most robust and sensitive trace-gas optical detection techniques. Extremely high detection sensitivities with compact and relatively low cost absorption detection module (ADM)
* PAS: is based on optical absorption procedure as ICOS, CEAS and CRDS as well. It differs in the physical phenomenon used for the detection of the absorption signal.
* PAS: .when light at a specific wavelength is absorbed by the gas sample, excited molecules will subsequently relax to the ground state either through emission of photons or by the means of non-radiative process: it produces localized heating in the gas which in turn results in an increase of the local pressure. If incident light intensity is modulated, generation of thermal energy in the sample will also be periodic and a pressure wave (a sound wave) will be produced having the same frequency of the light modulation.
* PAS signal: can be amplified by tuning the modulation frequency to one of the acoustic resonances of the gas sample cell.
* PAS: in this strategy no optical detector is required and the resulting sound waves can be detected by a commercial hearing aid microphone.
* PAS: In the adopted logic of calculus, there’s a linear relationship between the sample concentration and the photo-acoustic signal.
* PAS: also the noise can affect measurements as well. This noise is assumed to be independent from the optical excitation.
* PAS: the same technology of lasers and optical parameters oscillators of the near-IR and QCLs in mid-IR have been successfully applied to PAS
* PAS and 3 main noise sources:
  + caused by the radiation that is incident upon the walls of the PAS absorption cell
  + non selective absorption of the gas cell window
  + external acoustic noise
* PAS and signal to noise ratio improvement (SNR): different designs for PAS cells have been proposed and implemented including a resonant cell with acoustic buffers, windowless and a differential cell
* PAS and differential cell: it includes 2 acoustic resonators equipped with microphones having same responsivity at the resonance frequency of the cell. Since the laser light excites only one of the 2 resonators, difference between the two signals removes noise components that are coherent in both resonators
* PAS and trace gas sensing applications: atmospheric chemistry, volcanic activity, agriculture, industrial processes, workplace surveillance and medical diagnostics.
* PAS and other substances than CO2: nitric oxide (NO) from vehicle exhaust emissions, medicine and drug diffusion rates in skin and to detect trace concentrations of disease biomarkers such as ethylene (C2H4), ethane (C2H6) and pentane (C5H12) which are emitted by UV-exposed skin. NH3 for monitoring respiratory emission from cockroaches as well as detection of intake prohibited substances by athletes
* PAS low cost detectors on market: smoke detectors, toxic monitoring gas and oil sensors for monitoring hydrocarbons in water.
* Quartz-enhanced photoacoustic spectroscopy (QEPAS): alternative approach to photo acoustic detection of trace gas utilizing a quartz tuning fork (QTF) as sharply acoustic transducer. It detects weak photo acoustic excitation and allowing the use of extremely small volumes
* QEPAS: restrictions imposed on the gas cell by the acoustic resonance conditions are removed.
* QEPAS: the quartz crystal is low-loss and low-cost piezoelectric material
* QEPAS: QTF is a quadrupole which provides good environmental noise immunity
* QEPAS: the excitation laser beam passes through the gap between the prongs without touching them
* QEPAS: if a rotational-vibrational state is excited, a collision-induced vibrational to translation (V-T) relaxation follows with a time constant that for a particular molecule is dependent on the presence of other molecules and intermolecular interactions. This process is more sensitive for this technology compared with the PAS one.
* QEPAS: wavelength of laser is varied by changing the driving current when the temperature of the laser is fixed. DFB QCL is the light source applied in this case, EC-QCL: is used when both temperature and current are fixed and the optical frequency can be scanned by applying a modulated voltage to a piezoelectric translator attached to the diffraction grating element of the EC-QCL.
* QEPAS: sometimes wavelength modulation (WM) is employed to improve the QEPAS SNR, minimizing external acoustic noise for a QEPAS based sensor system (those are the WM QEPAS)
* QEPAS (WM): the wm description is based on an intensity representation of an optical wave, so that only the absorption of the sample is considered and dispersion effects due to the sample can be neglected. Those results are obtained after various modulation steps.
* Amplitude Modulation (AM) QEPAS: introduced because the vibrational spectra of most molecules consisting of more than five atoms are so dense that infrared absorption spectra consist in 100-200 cm-1 broad bands and spectroscopic identification of these species requires laser excitation sources with a wide spectral coverage
* Amplitude Modulation (AM) QEPAS: on a laser radiation. This is operated at f0 by means of square wave amplitude current modulation and QEPAS signals are detected by a lock-in amplifier at the same f0 frequency.
* Amplitude Modulation (AM) QEPAS are not background free. Residual radiation absorbed inside the gas cell produce a sound at the TF resonant frequency thus generating a coherent background.
* Amplitude Modulation (AM) QEPAS: background subtraction can be applied because generally it is stable over several hours. This is done also by the mean of normalization of signal and background for every spectral point and in post processing.
* Various architectures have been designed and implemented for the QEPAS realization (OB On-Beam QEPAS and Off-Beam QEPAS, which are characterized respectively by a perpendicular and parallel laser tube with respect to the QTF plane probing the acoustic vibration excited in the gas contained inside the ADM)
* And the fiber coupled QCL-QEPAS:
* QEPAS ranges of application in conclusion: they are demonstrated to be effective and mature for numerous real-world applications:
  + environment monitoring (CO, CO2, CH4, H2CO, C2HF, C2HF5, N2O, NO2)
  + industrial emission measurements such as at combustion sites and gas pipelines (Hcl, CO2, CH4, CO, Nox, CH2O)
  + urban emission coming from automobile traffic (Nox, Sox)
  + rural emission such as a horticultural greenhouse and fruit storage (C2H6, C2H4, CH4, N2o)
  + control for manufacturing processes (SF6, Hcl)
  + detection of medically important molecules (NO, CO, NH3, C2H6, H2S)
  + toxic gases (CH2o, Hcl, HCN, N2H4 etc.)
  + planetary science (H2O, CH4, CO, CO2, N2H4, C2H2)
  + environmental monitoring
* QEPAS have been for instance installed in a mobile laboratory to perform atmospheric CH4 and N2O detection near 2 urban landfill sites located in Houston: they recorded concentration values in a very good agreement (<5% difference) with those measured by the Aerodyne Research Inc. “QCL mini monitor” multi-pass optical sensor having a CH4 detection sensitivity of 300 ppt and N2O detection sensitivity of 60ppt, both in 1 s which demostrates the precision, stability and applicability of the QEPAS sensing technique.

# Analytical determination of load resistance value for MQ-series gas sensors: MQ-6 as case study

* MQ sensors: high sensitivity and low cost
* MQ sensors: process of load resistance selection is a matter not well studied
* MQ sensors: parametrical investigation of load resistance and power dissipation on LPG
* MQ sensors: metal oxide (MOX) semi-conductor gas sensors: wide applications in gas concentration sensing and detection because of their high sensitivity and low cost
* MOX sensors: consists of a micro AL2O3 ceramic tube, a sensitive layer of tin dioxide (SnO2) and Nickel-Chromium alloys which serve as a heater coil
* MOX sensors: 6 pins, 4 of which are for signal and electrodes, remaining 2 for heating coils
* MOX sensors: tin dioxide (SnO2) semiconductor is the sensor gas sensitive portion with a low conductivity in clean air
* MOX sensors and their principle: based on variation of their resistance when they come in contact with the gas to be sensed. Magnitude of the sensor output signal depends on the concentration and nature of the gas and the type of metal oxide used for the sensor sensing surface
* MOX sensors: made up of 2 elements, namely the heating and the sensing elements. These elements are normally powered independently either form the same or separate voltage surface
* MOX sensors: heater voltage will allow it to generate the required heat for maintaining the sensor in the active state while sensor voltage will allow the sensor to convert the sensed gas concentration to an appropriate voltage level across the load resistor connected in series with the sensing element
* MOX sensors: because of the characteristic of the sensing element a simple electrical equivalent circuit can be used to convert the sensed gas concentration to a corresponding signal usually voltage across the load resistor
* MOX sensors and their calibration: those parameters must be known:
  + Vcc: sensor calibration voltage
  + VRL: sensor electrical equivalent circuit output voltage
  + R0: sensor resistance for referent gas concentration and environmental conditions (temperature and humidity)
  + RS: sensor resistance
  + RL: load resistance
* MOX sensors and R0: this resistance is not explicitly given in the datasheet and has to be determined experimentally
* MOX sensors and R0: it must be determined for every sensor to be used because it is practically impossible to have similar gas sensors with the same value of R0
* MOX sensors: the value of R0 affects the results in general. This is because it is impossible to secure the reproducibility and stability of this class of sensors as a result of the impossibility of keeping the consistency of the manufacturing environment. It assures some variation in the sensor behaviour from one sensor to another and from one production batch to another.
* MOX sensors: after the R0 has been determined, it is possible to determine the sensor resistance at different gas concentrations value for various gases and different conditions (temperature and relative humidity (RH))
* MOX sensors: the sensor circuit sensitivity and the sensor power dissipation are both functions of the load resistance.
* MOX sensor, example of the MQ2 sensor: the 20 kohm load resistance as given in the sensor datasheet is used
* MOX sensor MQ sensors and selection of load resistance: it should be selected in such a way to optimize the alarm threshold value and keep the sensor power dissipation below the maximum allowable value. In some datasheet the manufacturer provides data on the value of load resistance to be used so that the resolution would be sufficient around the alarm point
* MOX sensor: the load resistance should be selected wisely: a lower value will result in less sensitivity while a higher value will give less accuracy

# Application of MQ-Sensors to Indoor Air Quality Monitoring in Lab based on IoT

* Indoor air quality: refers to the building’s residents’ air quality. State of bad or good content inside a building (residence, hospital, lab) that can impact the occupants’ health, comfort, performance and physical reactions
* Better indoor air quality is known as chemical (gaze) or biological (bacteria and fungi) or physical contaminants such as dust and the concentration of air pollutants in building does not exceed the environmental threshold.
* 2 categories for air pollutants: primary and secondary categories. Primary: polluting elements directly generated by air contamination. An example is CO because is produced by combustion
* Secondary contaminants: created when main pollutants react in the atmosphere: photochemical smog produces ozone, which is one example of secondary contamination
* IoT technology: can access information about the availability of indoor air quality monitoring in lab (IAQML) in real time by using Wireless Sensor Network (WSN) based monitoring systems.

A new approach to realize UART

* UART protocol: it is asynchronous as the name reports
* UART: can be customized for be synchronized, talking about some other protocols
* UART protocol: usually includes start bit, parity bit, stop bit and idle state
  + START BIT: the beginning of transmission: when the transmitter sends a character data, a logic “0” signal is firstly send: start bit, time width is a baud rate clock cycle
* UART protocol: data bits after the start can be usually from 5 to 8
* UART protocol: data bit from least significant bit (LSB) begin to sent
* UART protocol: data bits can be parity bit (odd or even parity) as well as no parity bit
* UART protocol: after the parity bit some stop bits can occur: they are logic “1” signal containing 1, 1.5 or 2 bits. Those bits are the end of data
* UART protocol: idle state is a logic “1”. This data format is adopted by the start and stop bit to achieve character synchronization
* UART: one internal configuration register: the user here can set the data bits, whether there is parity bit as well as the type of parity and stop bits.
* UART includes the transmitter, the receiver and a baud rate generator. Transmitter performs parallel-to-serial conversion
* UART baud rate generator generates the required clock signal
* UART serial transmitter section consists of an 8-bit transmitter hold register (THR) and transmitter shift register (TSR)
* UART: parallel data is stored in THR which received form the CPU, then it is transferred to the shift register and send out in the serial data, at same time parity bit is generated and transmitted by TSR, when the whole character is removed from TSR, CPU Interrupt signal is generated
* UART: serial receiver section also contains an 8-bit receiver buffer register (RBR) and receiver shift register (RSR)
* UART: serial data received is stored in the RSR and when it receives the whole character, automatically sent to RBR status register will be set and generate CPU interrupt signal
* UART: parallel data will be transmitted to the CPU in the read command of the CPU, serial-to-parallel conversion is performed
* UART: data latches four parts are comprised in the architecture, along with the already mentioned elements
* UART: data is latched by flip-latch and the input and output data is controlled through the door control and output enable pins
* UART: when the door control signal is effectively, the data is latched into the data device and when output enable signal is effectively, data is output
* UART: the baud rate clock of which the baud rate of 16 times of baud rate block frequency are generated by the baud rate generator
* UART: transmitter performs parallel-to-serial conversion and the receiver performs seral-to-parallel conversions which are realized by state machine
* UART transmitter: realized by a state machine of 6 states. When the UART is reset by the reset pin, the transmitter will be reset to start state, waiting until the start bit will be asserted.
* UART: start bit is asserted as soon as the THR is not empty
* UART: once a low SOUT (start bit) is asserted, the FSM will switch to shift state
* UART: when the FSM is in shift state, it is simply waiting for the last (most significant) data bit to be shifted out
* UART: after the last data bit is shifted out, the FSM will switch to parity state if parity is enabled, otherwise it is switched to stop\_1bit state. When switching to this state the last data bit is still in transmission
* UART: when the transmission is completed, the FSM will assert the parity bit
* UART: once parity bit is asserted, FSM switch to stop\_1bit and this is independently to the stop bit configured to be 1, 1.5, or 2 bits.
  + The FSM is here waiting for a baud rate clock cycle and then assert the stop bit(s)
  + 1 STOP BIT - UART: for 1 stop bit, the FSM switches back to start state and waits to assert the start bit of another frame
  + 1.5 STOP BIT: the switch is for stop\_half bit state and stays there for just half the baud clock cycle before switching to start state
  + 2 STOP BIT: it switched to stop\_2bit state then switches back to start state.
* UART: the stop bit(s) are asserted at the time when the FSM is leaving the stop\_1\_bit state
* UART: stop\_halfbit: is for 5 bit data bits with 1.5 stop bit. The FSM will stay in this state for only half baud clock cycle and then switch to start state
* UART stop\_2bit: the first stop bit is in transmission, there’s the waiting for a baud clock cycle then asserts the second stop bit and switches to the start state
* UART: stop bit is the ending of data, when stop bit is asserted an interrupt signal will be sent and the pin will be low for one baud rate clock cycle

# Design and Simulation of UART Serial Communication Module Based on VHDL

* UART – universal asynchronous receiver transmitter: kind of serial communication protocol
* UART: used for short-distance, low speed low-cost data exchange between computer and peripheral
* UART: 3 kernel modules are included: the baud rate generator, receiver and transmitter
* UART: asynchronous serial communication has advantages of less transmission line, high reliability and long transmission distance 🡪 this makes it widely used in data exchange between computer and peripherals. This is also implemented by UART
* UART: full duplex communication in serial link: widely used in data communication and control system
* UART: often implemented in FPGA using VHDL
* UART (basic): only 2 lines communication: RXD and TXD to complete full-duplex data communication
* UART TXD: it is the transmit side, the output of UART
* UART RXD: receiver side, the input of UART
* UART: 2 states in the signal line, using logic 1 (high) and logic 0 (low)
* UART: when the transmitter is idle, the data line is in the high logic state, when a word is given to the UART for asynchronous transmission, a bit called “start bit” is added to the beginning of each word that is to be transmitted
* UART: start bit: used to alert the receiver that a word of data is about to be sent and force the clock in the receiver into synchronization with the clock in the transmitter
* UART: the 2 clocks of transmitter and receiver must not be a frequency drift higher than 10% during the transmission of the remaining bits in the word.
* UART: after the start bit, the individual data bits of the word are sent with the least significant bit (LSB) being sent first
* UART: each bit in the transmission is transmitted for exactly the same amount of time as all of the other bits
  + The receiver looks at the wire at approximately halfway through the period assigned to each bit to determine if the bit is a 1 or 0
  + For example, if it takes 2 seconds to send each bit, the receiver will examine the signal to determine if it is a 1 or a 0 after one second has passed, then will wait 2 seconds and then examine the value of the next bit and so on
* UART: after the entire data word has been sent, the transmitter may add a parity bit that the transmitter generates, this will be used by the receiver to perform simple error checking
* UART: at least one stop bit is sent by the transmitter
* UART: when the receiver has received all of the bits in the data word, it may check the parity bits (both sender and receiver must agree on whether a parity bit is to be used)
* UART: then the receiver looks for the stop bit, if stop bit does not appear when it is supposed to, the UART consider the entire word to be garbled and will report a framing error to the host processor when the data word is read
* UART and usual cause of a framing error: sender and receiver clocks were not running at same speed or that the signal has been interrupted
* UART: in both correct reception or not cases, start parity and stop bits are automatically discards and not passed to the host
* UART: if another word is ready for transmission, the start bit for the new word can be sent as soon as the stop bit for the previous word has been sent. Because asynchronous data are self-synchronizing, if there’s no data to transmit the transmission line can be idle.

A diagram of a data

Description automatically generated

* Implementation of UART of the paper
  + Top down strategy with the UART serial communication divided in 3 sub-modules
    - Baud rate generator
    - Receiver module
    - Transmitter module
* UART baud rate generator: used to produce a local clock signal which is much higher than the baud rate to control the UART receive and transmit
* UART receiver module: receive the serial signal at RXD and convert them into parallel data
* UART transmit module: converts the bytes into serial bits according to the basic frame format and transmits those bits through TXD

A diagram of a person's relationship

Description automatically generated

* In the rest of the paper there’s the model of those 3 components
* In general programming VHDL for FPGA and UART is significant in the field of electronic design, where SOC technology has recently become increasingly mature, this design shows great significance.

# All links

* https://www.mdpi.com/1424-8220/21/16/5347
* https://www.mdpi.com/1424-8220/14/4/6165
* http://telkomnika.uad.ac.id/index.php/TELKOMNIKA/article/view/17427/9978
* <https://ieeexplore.ieee.org/abstract/document/9615333>