5

Detection of Alkylating Agents Using Optical, Electrical and Mechanical Means

Yoav Eichen et al.*
[1]*Schulich Department of Chemistry, Technion-Israel Institute of Technology, Technion City, Haifa, Israel*

1. Introduction

Alkylating agents, such as methyl iodide, dichloromethane and epichlorohydrin, are commonly used in organic synthesis as reagents and solvents. The alkylating agents, such as methyl bromide, are still used as soil steriliers, while nitrogen mustards are being used as anticancer drugs. Alkylating agents are also dangerous byproducts of the water purification process. Unfortunately, due to their ease of production and storage, those materials are also used as chemical warfare agents. Owing to their ability to react with nucleophiles in our body, most of these materials are toxic, carcinogenic and mutagenic. The combination of simple synthesis with aggressive reaction with biological tissues makes many alkylating agents perfect potential chemical warfare agents for the underdogs and thus a perfect terror inflicting weapon. Therefore, there is a clear need for simple, sensitive and informative tools for the detection and identification of such agents, especially in the gas phase.

Tailoring selective receptors for small and reactive molecules is a non-trivial and challenging goal. In addition, it is much easier to synthesise a new toxic alkylating agent than to tailor a selective receptor for its detection, rendering this approach inefficient. Previous attempts to address this challenge resulted in two basic approaches. The first approach gave up selectivity, detecting all alkylating agents in a non-specific way, relying on a colour change of a nucleophile upon reacting with an alkylating agent (Hertzog-Ronen *et al.*, 2009). The second approach focused on a limited family of alkylators by detecting a specific mass or the presence of a specific atom it contains (for example the sulphur atom in sulphur-based mustard gas). Both approaches provide only a limited detection ability with the first having the potential of too many false positive alerts and the later having a very limited scope.

One possible solution to the detection of alkylating agents is the further development of the fist approach that uses a nucleophile as a trap for alkylating agents. An efficient nucleophile,

*Yulia Gerchikov[1], Elena Borzin[1], Yair Gannot[1], Ariel Shemesh[1], Shai Meltzman[1], Carmit Hertzog-Ronen[1], Shay Tal[2], Sara Stolyarova[3], Yael Nemirovsky[3] and Nir Tessler[3]
[1]*Schulich Department of Chemistry, Technion-Israel Institute of Technology, Technion City, Haifa, Israel*
[2]*Systems Biology Department, Harvard Medical School, Boston, MA, USA*
[3]*Department of Electrical Engineering, Technion-Israel Institute of Technology, Technion City, Haifa, Israel*

such as an amine group, is expected to react with all the reactive alkylating agents as they are essentially electrophiles as shown in Fig. 1. This reaction guarantees very high sensitivity, as the binding is not reversible.

Fig. 1. General equation for reaction of a nucleophile (Nu:) with an alkylating agent

The reaction of the nucleophile with the alkylating agent needs to be transformed into a measurable signal. For example, we have recently reported on using luminescence turn-on as well as luminescence shifts for the detection and identification of different alkylating agents (Borzin *et al*., 2010; Tal *et al*., 2006). The signal needs to be analysed in a way that offers identification ability as well as some ability to assess the risk from the detected alkylator.

This chapter is about the coupling of the reaction between a nucleophile and alkylating agents to optical (luminescence change), electrical (organic field effect transistors, OFETs), and mechanical (micro-cantilevers) signal transducers for the detection, risk assessment and identification of alkylating agents. The three complimentary methods demonstrate the potential embedded in using such reactions for the detection of reactive substances.

2. Results and discussion

2.1 Luminescence based detection of alkylating agents

The photo-induced electron transfer (PET) based detection of alkylating agents was reported. The detection is based on the quaternisation of a *Lewis* base nucleophile, usually a tertiary amine group that serves also as a quencher to the luminophore (De Silva *et al*., 1997). Owing to the very simple structure of these alkylators, despite the high sensitivity attained by this approach still missing is the ability to identify the presence of specific alkylating agents, as with PET systems, most alkylators yield a very similar spectral response. This originates from the fact that the amine group that undergoes quaternisation is not π-conjugated to the luminophore and since in most cases the reaction of this amine with the alkylating agent yields very similar new C-N bonds. Therefore, in all cases the effect of the binding of the alkylator to the amine is expected to be very similar.

One approach to overcome this limitation is to electronically couple the nucleophile that reacts with the alkylating agent to the π-skeleton of the luminophore/chromophore so that its electronic properties are best affected by the nature of the alkylating group as well as its counter ion, if formed as a result of the alkylation process. Furthermore, as most alkylators are very similar in nature, the identification method should rely on reacting array of sensing spots with the same alkylator, seeking for specific reaction patterns that are unique to specific alkylators.

In the film, or when adsorbed onto high surface paper, materials **1-7** react at room temperature with vapors of various alkylating agents such as 1-chloro-2-ethylsulfanyl-ethane (a close analog of the sulfur mustard gas), **8**, chloromethoxy-ethane, **9**, iodomethane, **10**, and even dichloromethane, **11**, according to Fig. 2.

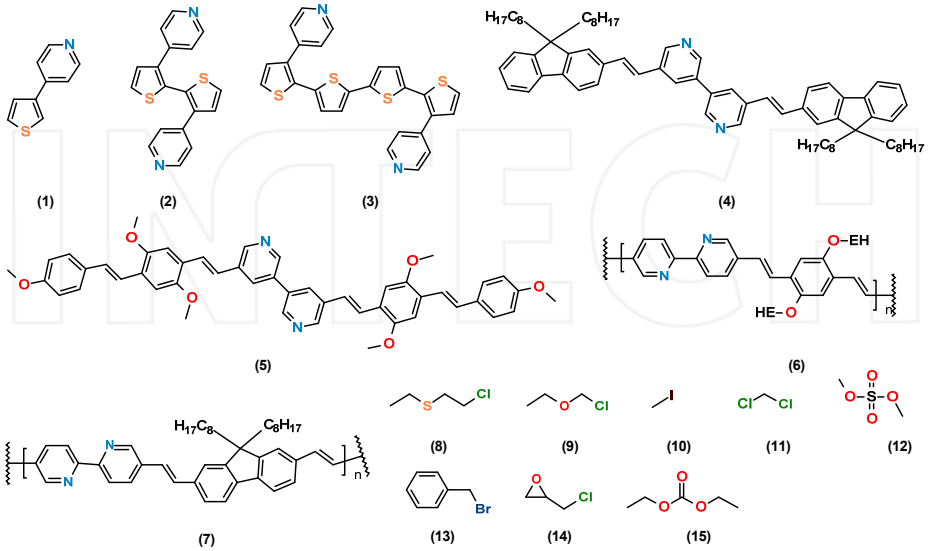


Fig. 2. Oligomers **1-7** and alkylating agents **8-15**

Fig. 3 shows the absorption and emission spectra of thin films of oligomer **5** and polymer **6** before and after alkylation with vapors of **8**. In both cases, the films of the nucleophiles readily react with vapors of the alkylator. Both the absorption and emission spectra of the nucleophiles are affected by the reaction with the alkylating agents. As in the product the alkylator is covalently bound to the film, the change in the optical characteristics does not revert when the concentration of the alkylator is lowered.

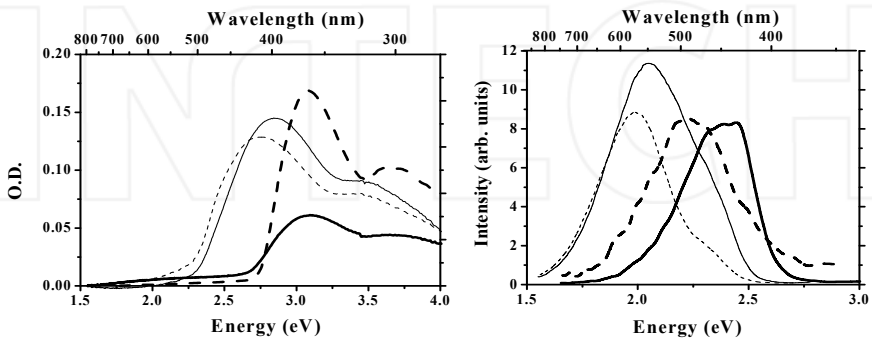


Fig. 3. Absorption (right) and emission (left) spectra of thin films of **5** (thick line) and **6** (thin line) on quartz before (continuous line) and after (dashed line) exposure to **8**

Inspired by the olfactory system (Dryer & Berghard, 1999) several groups developed artificial olfactory-like sensing arrays for detecting ions, volatile substances, amines, amino acids, proteins and carbohydrates where the identity of the target is defined by a response pattern of an array of low selectivity sensors. Similar approach was harnessed (Hertzog-Ronen *et al.*, 2009) for detection and identification of alkylating agents using a highly reactive and non-specific, multi-spot sensor system that relies on optical detection of luminescence spectral shifts for the identification step.

For that purpose, compounds **1-7** were adsorbed onto high surface filter paper squares (Whatman grade 50, low ash) and assembled into a seven-spot sensor array. Fig. 4 shows luminescence (λex=312 nm) pictures of the sensor array before (first row) and after (preceding rows) exposure to vapors of alkylating agents **8-15**. As can be seen from Fig. 4, one can clearly deduce the identity of the alkylating agent the sensor array was exposed to from the color pattern that is developed. For example, dichloromethane, **11**, and diethyl carbonate, **15**, produce a very similar response of luminescence shift upon reacting with **1**, **2**, **4**, **5**, **6** and **7**. With **3** the luminescence color shifts from RGB = [164, 84, 38] to [169, 135, 35] and [140, 152, 53], respectively. This colour difference is easily noticeable using a colorimeter and is even clear to the naked eye. Structurally similar **8** and **9** generate a very different luminescence shifts in all the spots.

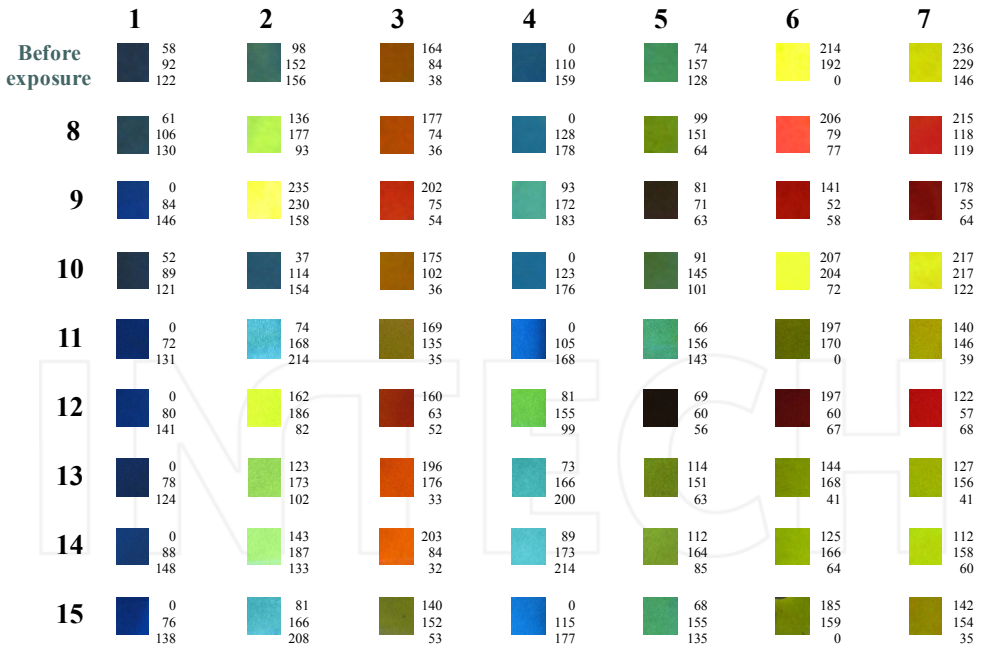


Fig. 4. A seven-spot sensor array of **1-7**, adsorbed on high surface filter paper, before (first row) and after (preceding rows) exposure to alkylating agents **8-15**. The figures on the right side of each square denote the RGB values of the spot when exposed to UV exciting light (λex=312 nm)

Principal component analysis (PCA) is a mathematical algorithm, useful for compression, classification and visualization of data. The purpose of this algorithm is to reduce redundant dimensionality of data by finding new trajectories, called principal components. These trajectories are orthogonal linear combinations of the original trajectories and along which the maximal variation in the data is retained.

The trajectories are chosen according to their descending sort order such that the first principal component (or trajectory) shows the largest variation and so on. The description along the new trajectories is more compact and can be referred as a shadow of the data when viewed from most informative viewpoint (Ringer, 2008). Datasets could be dramatically simplified using principal component analysis, Fig. 5.

A large scatter of the data is seen in the 3D plot of the delta RGB of the different alkylating agents with the different sensing spots of Fig. 4, Fig. 5 (left). This is expected to severely reduce the identification fidelity in real life applications, where data fluctuations originating from different sources are expected to contribute to the data scatter. To improve the identification ability of the system, PCA was applied to the data, Fig. 5 (right).

Not limited by association constant, this luminescence based sensing techniques for alkylating agents depend mainly on reaction rates. Such reactions can be easily accelerated by increasing mass transport, forcing the atmosphere to pass through or above the sensing unit, as well as by increasing the temperature of the sensing element. The sensitivity of the system depends solely on the number of reaction sites on the sensing element. This number is estimated to be $\approx 10^{14}/cm^2$, an equivalent of about 0.1 micrograms of mustard gas.

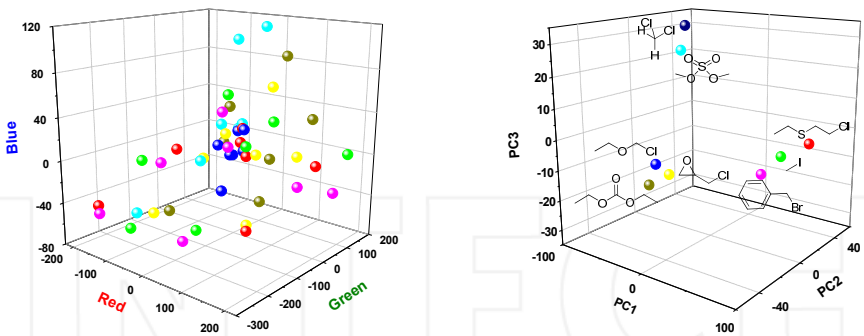


Fig. 5. (left) RGB plot for alkylating agent (8-20) and sensing spots (1-7) interaction; (right) Principal component analysis of 5 (left) data

2.2 Detection of alkylating agents using organic field effect transistors

Section 2.1 clearly exemplifies that monitoring the change in the optical signal of the molecule can be useful sensing tool for the detection of different alkylating agents. Still there is a need not only to sense the presence of a known material, but also to assess the toxicity of new molecules that produce unknown reaction pattern. Furthermore, machine reading of

luminescence based detection signals require elaborate optical equipment, consisting of at least a light source and a multi-spot detector such as a CCD and a CPU. These two limitations motivated us to explore the possibility of direct electrical detection of alkylating agents.

The approach for direct electrical detection of alkylating agents relies on organic field effect transistors (OFETs) that carry an organic semiconductor that bears nucleophilic reaction sites and is thus capable of reacting with alkylating agents, see Fig. 6. The OFET in Fig. 6 consists of a heavily doped silicon base (a) that serves as the gate. This silicon layer is covered by a thin silicon dioxide layer that insulates the gate from the electrodes and semiconductor (b). The organic semiconductor is spread in between the drain and source electrodes, atop the silicon dioxide (c). The electrical detection process is based on the ability of the organic semiconductor to react with the alkylating agent (d) and change measurable quantities, such as V_{gate}, $V_{drain\text{-}source}$.

Direct electrical detection of chemical substances may be achieved in a variety of methods, of which field effect modulation of the conductivity of an organic layer seems most promising due to the potential of signal amplification and gain of information on the captured substance from different types of gate manipulations. The ability of building arrays of field effect transistors, each bearing a different active material offers promising routes to the detection and identification of diverse substances in solution as well as in the gas phase (Chang *et al.*, 2006).

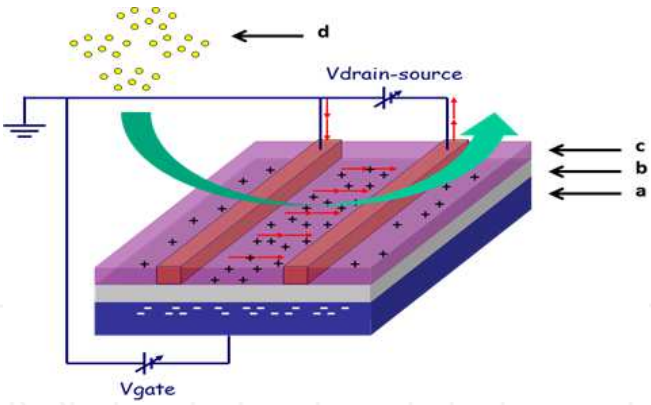


Fig. 6. Organic field effect transistor for detecting alkylating agents

Coupling of a nucleophile to an organic semiconductor was achieved by co polymerizing 4-[2,5-bis (2-thienyl)-3-thienyl] pyridine, **21**, with 3-hexylthiophene, **22**, to obtain co-polymer **23**, as shown in Fig. 7.

Co-polymer **23** was obtained as a bright red solid, Mn = 37000, Mw = 97000 (GPC), in 17% yield by co-polymerization of a 1:10 solution of **21** and **22** in chloroform in the presence of $FeCl_3$. NMR characterization reveals that co-polymer **23** is composed of $\mathbf{21}_n\mathbf{22}_m$ where n = 0.95±0.005 and m = 0.05±0.005 (Gannot *et al.*, 2010). Co-polymer **23** reacts with alkylating agents according to Fig.8, both in solution and as a film when treated with their vapors.

Co-polymer **23** is an excellent film forming polythiophene organic semiconductor. Bottom contact organic field effect transistors (OFETs) were fabricated by spin-coating a 50 nm film of the co-polymer atop the FET structure using a previously described procedure (Shaked *et al.*, 2003). Fig. 9 shows the electrical characteristics of the OFET having co-polymer **23** as the channel. Fig. 9 (left) shows the drain-source currents of the OFET as a function of drain-source voltage for several gate-source voltages (V_{GS} = 0, 10 and 20 V) before (black lines and inset) and after (gray lines) exposure to the alkylator methyl iodide (CH_3I, **10**). Fig. 9 (right) shows the drain-source current as a function of gate-source voltage for drain-source voltage of V_{DS} = 10 V measured the same OFET having co-polymer **23** as the channel and under the same conditions.

As can be clearly seen in the figure, prior to exposure to the alkylating agent the device exhibits standard FET output characteristics with a slight indication of doping, probably due to the exposure to atmospheric oxygen. The post exposure curves show considerably higher currents and a resistor like response while the effect of the gate bias is lost. This is a clear indication for high level p-type doping associated with the exposure to methyl iodide.

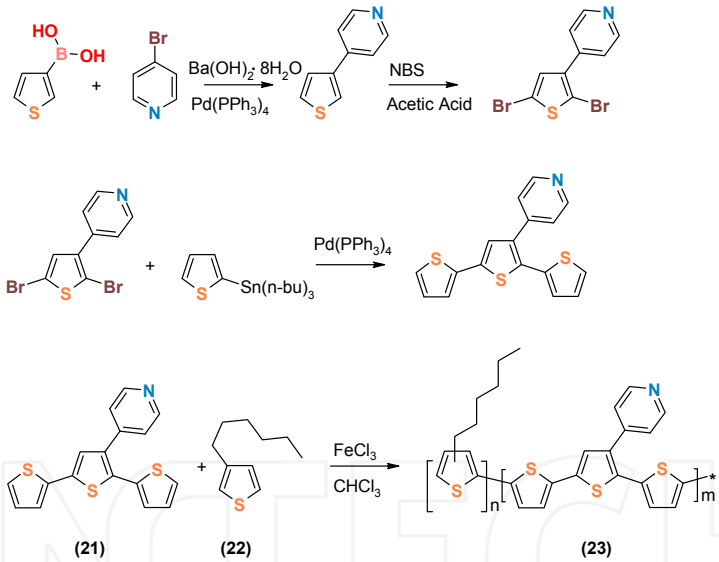


Fig. 7. Preparation of co-polymer **23**

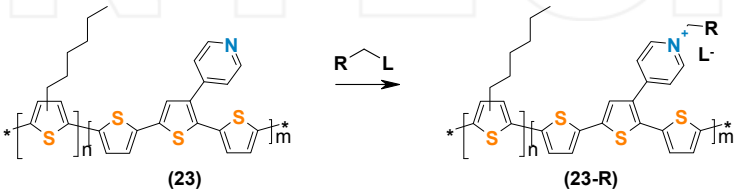


Fig. 8. Reaction between co-polymer **23** and an alkylating agent

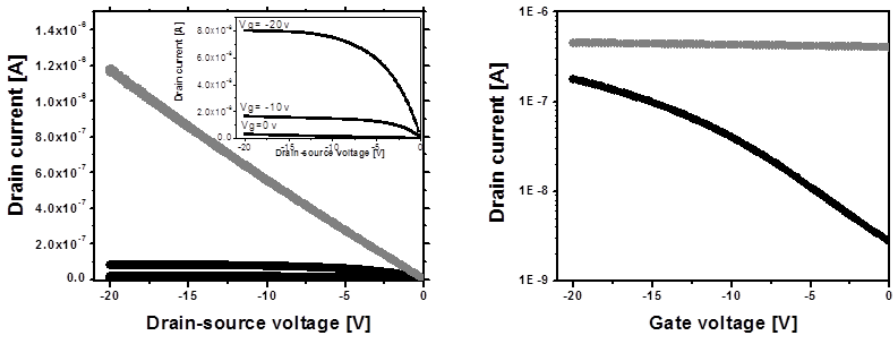


Fig. 9. Output (left) and transfer (right) characteristics measured on a FET having co-polymer **23** as the channel. The black lines and the inset show the device response prior to exposure while the gray (overlapping in a.) lines show the response after exposure to methyl iodide, **10**.

Consistent with the results presented in Fig. 9 (left), the transfer characteristics of the OFET prior to exposure show current modulation due to the gate-source voltage. The post exposure gray horizontal line shows almost no dependence on the gate voltage. At zero gate bias, $V_{GS} = 0$, the exposure of the OFET to methyl iodide enhances the current by almost two orders of magnitude while at $V_{GS} = -20$ V the factor is only 2-3.

The detection of alkylating agents using co-polymer **23** OFET, involves the formation of a new covalent bond between the alkylating agent and the co-polymer in the channel. As this process is not reversible, all available reaction sites are bound to react. The number of reaction sites (pyridine rings, see Fig. 8) represents also the upper detection limit of the device. The total weight of the polymer embraced by the source and drain electrodes, M, is 10^{-9} g. (assuming a film density of 1g/cm^3), Equation 1, where W is the width of the device, L is the length and h is the thickness of the polymer film.

$$M = W \times L \times h \times p = 1 \times 2 \cdot 10^{-4} \times 5 \cdot 10^{-6} \cdot 1 = 10^{-9}\ \text{g} \quad (1)$$

Co-polymer **23** consists of 5% (5×10^{-11}g) monomer **21,** which are equivalent to ~1.5×10^{-13} moles. Consequently, reacting the OFET with ~9×10^{10} analyte molecules will bring the system to saturation of all the active sites of the polymer.

The OFET of co-polymer **23** produced similar results when exposed to a variety of alkylating agents, such as chloromethoxy ethane, **9**, 1-chloro-2-ethylsulfanyl ethane (a close analog of sulfur mustard gas), **8**, and benzyl bromide, **13**. In contrast, exposure of the OFET to vapors of non reactive materials, (see Fig. 10), that are incapable of forming covalent bonds with co-polymer **23**, such as methanol, **24**, acetone, **25**, water, **26**, and isopropanol, **27**, resulted with the deterioration of the output and transfer characteristics, as can be seen in Fig. 11.

The effect of alkylation on OFETs having co-polymer **3** as the channel can be rationalised by following the effect of alkylation on the charge distribution in the polymer. Co-polymer **23** is composed of electron rich polythiophene skeleton with pendant pyridine groups. Upon reacting with an alkylating agent, the pyridine group is transformed into an electron

deficient pyridinium group. These electron poor groups attract charge density from the polythiophene skeleton, thus partially doping it.

As indicated above, the OFET readily reacts with any alkylating agent, producing the same type of reaction and thus cannot provide any straightforward information regarding the identity of the reacting alkylator. The OFET can provide valuable information regarding the reactivity of the alkylator. Fig. 12 shows the drain-source current as a function of the exposure time to vapors of methyl iodide, **10**, at a constant gate-source voltage of -10 V. When methyl iodide vapors are introduced into the atmosphere surrounding the OFET (marked with an arrow) the drain-source current drops, indicating the process of absorption of the vapors by the polymer and associated changes in its morphology and packing. Unlike "innocent" materials, that are incapable of reacting with the organic semiconductor, alkylating agents react in a way that increases the source-drain current at a given V_{gate}. This offers a simple and effective way of assessing the reactivity of the alkylating agent as the initial drop in source-drain current is a simple measure of the concentration of the guest in the semiconductor host while the rate of current increase at a fixed gate bias is a measure of the rate of alkylation.

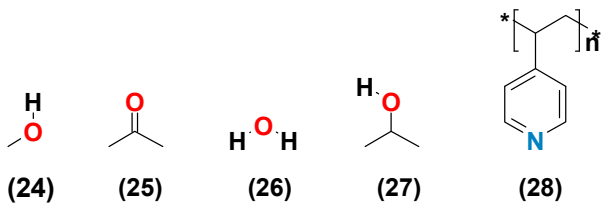


Fig. 10. Structures of non reactive materials, **24-28**

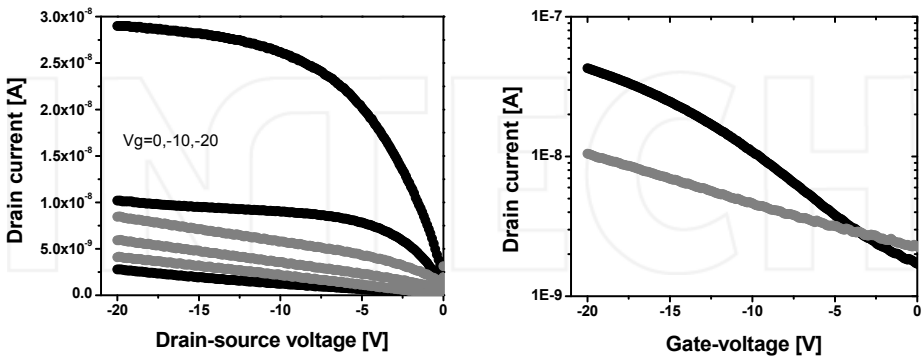


Fig. 11. Output (a) and transfer (b) characteristics of OFET having co-polymer **23** as the channel. The black lines show the device response at ambient conditions, while the gray lines show the response after exposure to methanol, **24**.

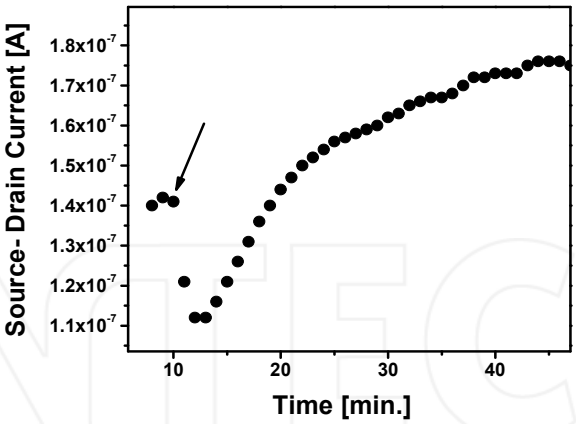


Fig. 12. Time response of an OFET having co-polymer **23** as the channel. Methyl iodide, **10**, is introduced at T=10min (arrow).

2.3 Detection of alkylating agents using chemo-mechanical asymmetric micro-cantilever devices

Alkylation of nucleophilic species is capable of inducing irreversible effects other than changes in electrical and optical signals. For example, the alkylation of a polyamine polymer may induce a volume change. This, in turn, may be translated into a macroscopic mechanical motion. The possibility of harnessing a chemo-mechanical signal transduction technique on micron-size micro-cantilevers for the detection of alkylating agents was explored.

Micro-cantilevers have gained much attention in recent years as a promising platform for biomechanical as well as chemo-mechanical sensors (Lavrik *et al*., 2004). Different groups have reported the ability to detect different chemical substances, including explosives and warfare agents (Stolyarova *et al*., 2010). Micro-cantilever based systems also allow label-free (Raorane *et al*., 2008) real time monitoring of chemical and biological processes such as sequence specific DNA hybridization (Wu *et al*., 2001) and drug-target binding interactions (Ndieyira *et al*., 2008). Recently, due to their high sensitivity, micro-cantilevers have been used to measure the physical properties of polymers near their glass transition temperature (Jung et al., 2008). Typically, micro-cantilevers can be operated both in static and dynamic modes. In the static mode, the bending (deflection) of the tip serves as a measure for the interaction between the micro-cantilever and the guest while in the dynamic mode the shifts in the resonance peak indicate the change in the mass and stiffness of the micro-cantilever. In a static bending mode it is essential to asymmetrically functionalize the micro-cantilever so a stress gradient across it can be developed and induce bending. Novel asymmetric porous-silicon-over-silicon (PSOS) micro-cantilevers made according to Fig. 13, using vapour phase stain etching (Stolyarova *et al*., 2008), offer inherently asymmetric, highly sensitive and easy to coat systems. The resulting micro-cantilevers are characterised by a rough surface on their lower side and an intact flat surface on their upper side, Fig. 13 (b) and (c), respectively.

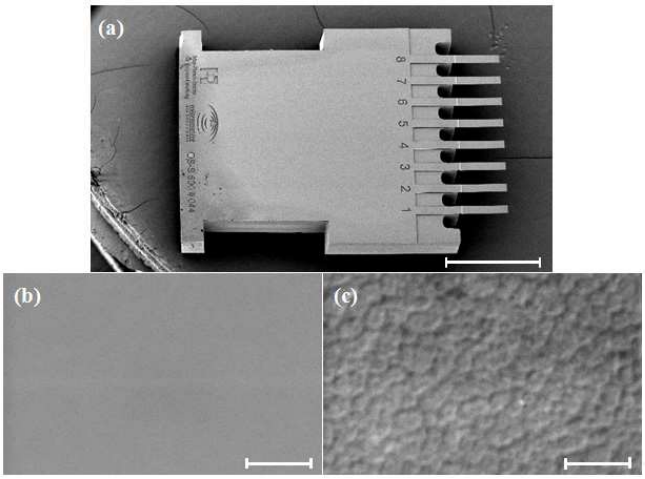


Fig. 13. (a) A SEM micrograph of a microcantilever array used in this study as the transducer. Representative SEM images of the upper (masked, b) and lower (unmasked, c) surfaces of the polymer coated microcantilever depicted in a. Bar size: 1 mm in a) and 5µm in (b) and (c).

Unlike other methods of polymer application including drip coating and evaporation, the PSOS microcantilevers offer a simple way of coating. Due to their inherent asymmetric surfaces, a coating polymer layer may be applied to the beams by simple dipping in a polymer solution, rinsing and drying. For the detection of alkylating agents, micro-cantilevers were coated with poly-4-vinylpyridine, **28**, serving as the sensing layer. Fig. 14 shows a side view of the polymer-coated micro-cantilever chip under gas flow. As can be seen, the dominant polymer layer resides on the lower surface of the micro-cantilever. This surface is characterised by rough porous silicon layer. The micro-cantilever chip was mounted in a flow cell where both the temperature and the flow were controlled. The bending of the micro-cantilever tip was monitored optically using optical profiling system capable of running time-resolved measurements. To monitor the effect of different analytes on the bending pattern, nitrogen served as an inert carrier gas and a special evaporation chamber allowed mixing the analytes with nitrogen. During baseline and desorption stages the polymer microcantilever chip was exposed to pure nitrogen, while during absorption to a mixture of nitrogen and one of the analytes (Shemesh *et al.*, 2011).

Fig**.** 15 shows the bending patterns of the micro**-**cantilever tip at absorption and desorption stages for two different analytes.The first one is vapors of methanol, **11**, and then vapors of methyl iodide, **10**, both in nitrogen carrier gas. As can be clearly seen**,** the absorption of coated microcantilever is fully reversible as ethanol is bound to the polymer only through weak and labile bonds. Concequently, ethanol readily desorbs from the micro**-**cantilever under an ethanol-poor atmosphere. The result of the desorption is that the bending of the micro**-**cantilever returns to its initial level, as it was before adsorption of the ethanol. In contrast, upon exposure of the same micro**-**cantilever to methyl iodide, **10**, reaction occurs between the polymer and the analyte. This reaction attaches the analyte to the polymer through a new and stable covalent bond. Since this reaction is not reverted at room

temperature, the bending is irreversible. This is reflected during the desorption stage as nitrogen flushes the system. The bending of the micro-cantilever reaches new bending level closer to the adsorption steady state level, indicating that some unreacted methyl iodide desorbs from the surface of the micro-cantilever but some of the methyl iodide had reacted with the polymer and cannot desorb.

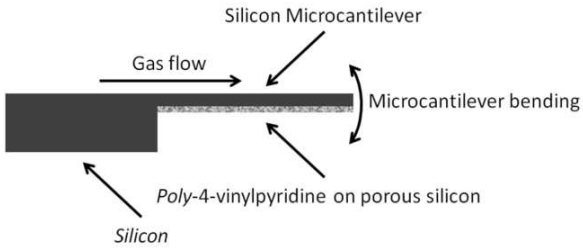


Fig. 14. Side view of the polymer coated microcantilever chip.

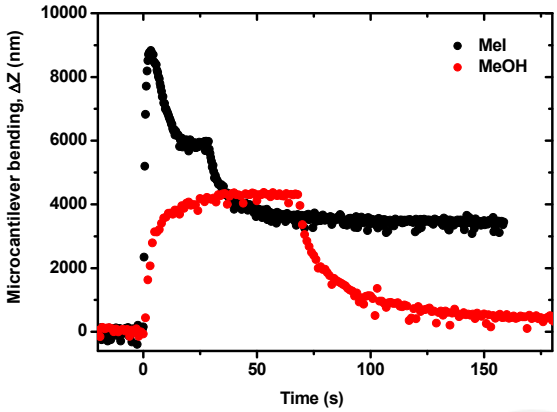


Fig. 15. Micro-cantilever bending curves for methanol, **11**, and methyl iodide, **10**,

3. Conclusions

Luminescent, electrical and chemo-mechanical detection schemes for the sensing (detection, identification and risk assessment) of alkylating agents were explored. A multiple-spot "chemical nose" array is shown to offer both detection and identification of different alkylating agents in the gas phase. The rate of colour development offers some risk assessment ability (not discussed here). Since the sensing element is based on a chemical reaction the sensitivity of the sensor is very high and depends mainly on mass transport of the alkylating agents and temperature.

In a similar way and based on very similar nucleophile-electrophile chemistry organic field effect transistors and micro-cantilevers were harnessed to the detection of alkylating agents.

Reaction of gas phase alkylators with a nucleophilic organic semiconductor in an OFET structure yields dramatic and irreversible changes in the transistor properties while other innocent molecules inflict reversible changes to the OFET parameters. Risk assessment was demonstrated by following the absorption of the analyte and its reaction with the organic semiconductor.

In a similar manner, gas phase alkylators that react with a nucleophilic polymer at the surface of a micro-cantilever induces its irreversible bending while for innocent materials, such as alcohols, the bending is reversible and depends on the momentary concentration of the guest in the atmosphere.

4. Acknowledgements

The research leading to these results received funding from the European Union Seventh Framework Programme under grant agreement No :2015180 [COMMONSENCE] and from the Technion Funds for Security Research.

5. References

Borzin, E.; Shemesh, A., Hertzog-Ronen, C., Gerchikov, Y., Tessler, N. & Eichen, Y. (2010). Towards an Omnipotent "Artificial Nose", Detection and Identification of Alkylating Agents Using an Optical Sensor Array. *Journal of Physical Organic Chemistry*, vol. 23, pp. 1108-1113

Chang, J.B.; Liu, V., Subramanian, V., Sivula, K., Luscombe, C., Murphy, A., Liu, J. S. & Frechet J. M. J. (2006). Printable Polythiophene Gas Sensor Array for Low-Cost Electronic Noses. *Journal of Applied Physics*, vol. 100, pp. 014506

De Silva, A.P.; Gunaratne, H. Q. N., Gunnlaugsson, T., Huxley, A. J. M., McCoy, C. P., Rademacher, J. T. & Rice, T. E. (1997). Signaling Recognition Events with Fluorescent Sensors and Switches. *Chemical Reviews*, vol. 97, pp. 1515-1556.

Dryer, L. & Berghard, A. (1999). Odorant Receptors: a Plethora of G-Protein Coupled Receptors. *Trends in Pharmacological Sciences*, vol. 20, pp. 413-417.

Gannot, Y.; Hertzog-Ronen, C., Tessler, N. & Eichen, Y. (2010). Sensing of Alkylating Agents Using Organic Field-Effect Transistors. *Advanced Functional Materials*, vol. 20, pp. 105-110

Hertzog-Ronen, C.; Borzin, E., Gerchikov, Y., Tessler, N. & Eichen, Y. (2009). Detection and Identification of Alkylating Agents Using a Bio-Inspired "Chemical Nose". *Chemistry - A European Journal*, vol. 15, pp. 10380–10386.

Jung, N.; Seo, H., Lee, D., Ryo, C. Y. & Jeon, S. (2008). Nanomechanical Thermal Analysis of the Glass Transition of Polystyrene Using Silicon Cantilevers, *Macromolecules*, vol. *41*, pp. 6873-6875

Lavrik, N. V.; Sepaniak, M. J. & Datskos, P. G. (2004). Cantilever Transducers as a Platform for Chemical and Biological Sensors. *Review Scientific Instruments*, vol. *75*, pp. 2229-2253.

Ndieyira, J. W.; Watari, M., Barrera, A. D., Zhou, D., Vogtli, M., Batchelor, M., Cooper, M. A., Strunz, T., Horton, M. A., Abell, C., Rayment, T., Aeppli, G. & Mckendry, R. A. (2008). Nanomechanical Detection of Antibiotic–Mucopeptide Binding in a Model for Superbug Drug Resistance. *Nature Nanotechnology*, vol. *3*, pp. 691-696.

Raorane, D. A.; Lim, M. D., Chen, F. F., Craik, C. S. & Majumdar, A. (2008). Quantitative and Label-Free Technique for Measuring Protease Activity and Inhibition using a Microfluidic Cantilever Array. *Nano letters,* vol. *8*, pp. 2968-2974.

Ringner, M. (2008). What is Principle Component Analysis. Nature Biotechnology, vol. 26, pp. 303-304.

Shaked, S.; Tal, S., Roichman, Y., Razin, A., Xiao, S., Eichen, Y. & Tessler, N. (2003). Charge Density and Film Morphology Dependence of Charge Mobility in Polymer Field Effect Transistors. *Advanced Materials*, vol. 15, pp. 913-916.

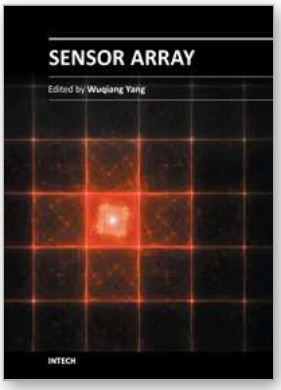
Shemesh, A.; Stolyarova, S., Nemirovsky, Y. & Eichen, Y. (2011). Isotope Effect in the Interaction between Gas-Phase Isotopologues and Polymer-Coated Porous Silicon Over Silicon Microcantilevers. *The Journal of Physical Chemistry C*, vol. 115, pp. 15980-15987.

Stolyarova, S.; Cherian, S.; Raiteri, R.; Zeravik, J.; Skladal, P.; Nemirovsky, Y. (2008). Composite porous silicon-crystalline silicon cantilevers for enhanced biosensing, *Sensors and Actuators B*, vol. *131*, pp. 509-515.

Stolyarova, S.; Shemesh, A., Aharon, O., Cohen, O., Gal, L., Eichen, Y., & Nemirovsky, Y. (2010). Vertically Integrated MEMS SOI Composite Porous Silicon- Crystalline Silicon Cantilever-Array Sensors: Concept for Continuous Sensing of Explosives and Warfare Agents. *NATO Science for Peace and Security Series B: Physics and Biophysics*, pp. 261-274.

Tal, S.; Salman, H., Abraham, Y., Botoshansky, M. & Eichen Y. (2006). Sensitive and Selective Photoinduced-Electron-Transfer-Based Sensing of Alkylating Agents. *Chemistry European Journal*, vol. 12, pp. 4858-4864.

Wu, G.; Ji, H., Hansen, K., Thundat, T., Datar, R., Cote, R., Hagan, M. F., Chakraborty, A. K., & A. Majumdar (2001). Origin of Nanomechanical Cantilever Motion Generated from Biomolecular Interactions. Proceedings of the National Academy of Sciences of the United States of America, vol. 98, pp. 1560-1564.



Sensor Array

Edited by Prof. Wuqiang Yang

ISBN 978-953-51-0613-5
Hard cover, 134 pages
Publisher InTech
Published online 23, May, 2012
Published in print edition May, 2012

Sensor arrays are used to overcome the limitation of simple and/or individual conventional sensors. Obviously, it is more complicated to deal with some issues related to sensor arrays, e.g. signal processing, than those conventional sensors. Some of the issues are addressed in this book, with emphasis on signal processing, calibration and some advanced applications, e.g. how to place sensors as an array for accurate measurement, how to calibrate a sensor array by experiment, how to use a sensor array to track non-stationary targets efficiently and effectively, how to use an ultrasonic sensor array for shape recognition and position measurement, how to use sensor arrays to detect chemical agents, and applications of gas sensor arrays, including e-nose. This book should be useful for those who would like to learn the recent developments in sensor arrays, in particular for engineers, academics and postgraduate students studying instrumentation and measurement.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Yoav Eichen, Yulia Gerchikov, Elena Borzin, Yair Gannot, Ariel Shemesh, Shai Meltzman, Carmit Hertzog-Ronen, Shay Tal, Sara Stolyarova, Yael Nemirovsky and Nir Tessler (2012). Detection of Alkylating Agents Using Optical, Electrical and Mechanical Means, Sensor Array, Prof. Wuqiang Yang (Ed.), ISBN: 978-953-51-0613-5, InTech, Available from: http://www.intechopen.com/books/sensor-array/optical-electrical-and-mechanical-detection-of-electrophiles-using-sensor-arrays

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821