Let there be light

Piezo-photomotion devices were studied by Kelvin Probe Force Microscopy.

Andrea Cerreta, Zeinab Eftekhari, and Rebecca Saive

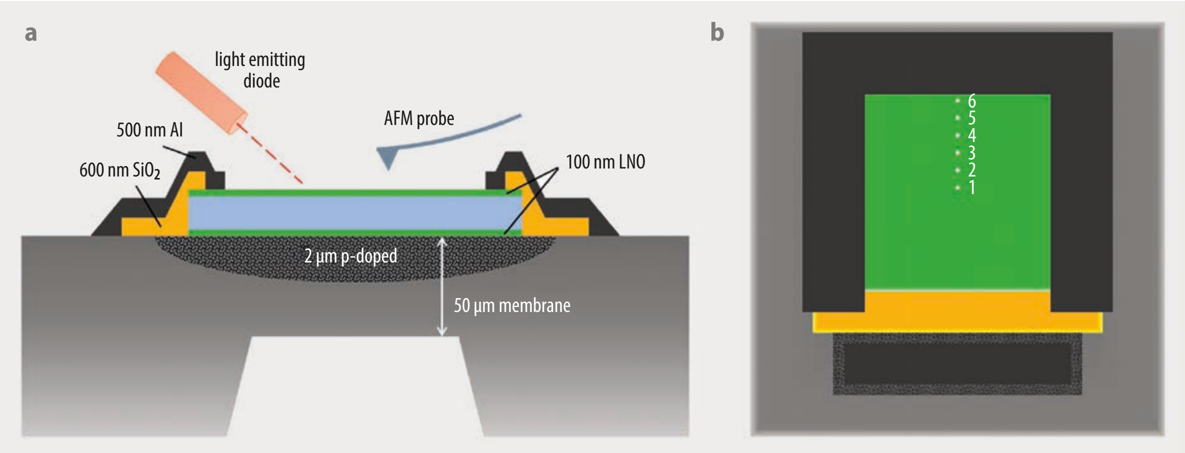

Fig. 1 A light emitting diode activates the piezo-photomotion devices under study. The cross-section of such a device is shown in a), the top view in b).

The ability of converting energy from natural sources into measurable electrical quantities and vice versa is at the basis of modern-day technologies. For example, photodiodes produce a voltage from light and piezo actuators transfer a voltage into a movement. But what if we could put the two pieces together, and use light to activate motion in a single device? This is one of the topics of Rebecca Saive and her research group from the Inorganic Materials Science (IMS) department (University of Twente, The Netherlands), where so-called piezo-photomotion devices [1] are developed for potential uses in the field of micro- and nanorobotics for biomedical applications [2].

Here, we present results of a collaboration between Park Systems, a major manufacturer of Atomic Force Microscopes (AFM), and IMS, with the goal of establishing AFM as the ideal platform to study such innovative devices. Combining high resolution and the possibility of probing electrical properties at nanoscale, Atomic Force Microscopy provides unique time- and position-dependent information.

Such devices consist of a silicon photodiode integrated with piezoelectric lead zirconate titanate (**Fig. 1**) and are activated through intermitting illumination with a pre-determined frequency using a light-emitting diode. The light reaches the photodiode through the transparent piezo layer, creating a potential difference that causes the piezoelectric layer to deform.

Experiments were performed using a Park Systems NX10 micro-

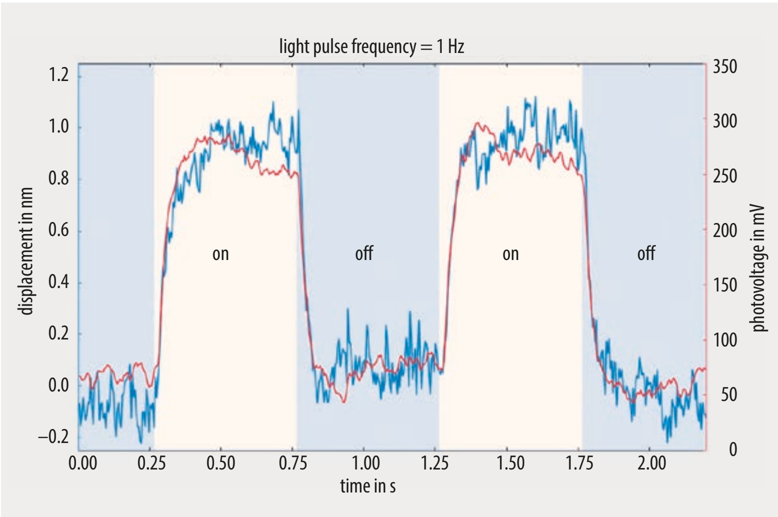

Fig. 2 After the excitation with a light pulse frequency of 1 Hz, a vertical displacement and a photo-induced voltage versus time can be observed.

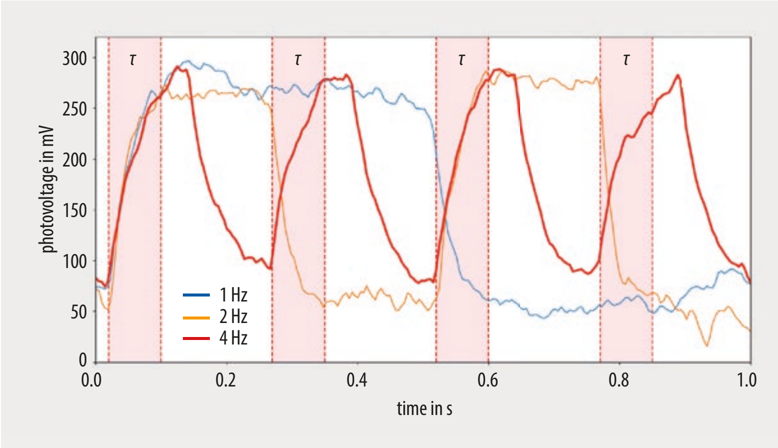

Fig. 3 The photovoltage as a function of time varies for different light pulse frequencies of 1, 2, and 4 Hz, respectively. The transient time τ measured at 4 Hz is highlighted in red.

scope operated in Sideband™ KPFM mode. Kelvin Probe Force Microscopy (KPFM) is a technique which allows measuring the topography and surface potential of samples simultaneously, with high quantitative and lateral accuracy. Initially, the AFM probe was landed at the center of the membrane (position 1 in **Fig. 1b**). The scanned area was reduced to a point of zero lateral dimension to avoid topographic crosstalk, and signals were acquired as a function of time.

Fig. 2 shows results when applying the light excitation at a frequency of 1 Hz. Illuminating the membrane resulted in a vertical displacement of 1 nm upwards and an increase in the surface potential of about 200 mV demonstrating the basic principle of the device: the voltage generated by the photodiode via illumination causes the expansion of the piezoelectric layer. A transient time τ of about 80 msec after light switching occured at different frequencies (**Fig. 3**). This response time may be linked to the quality of the interface between the photodiode and the bottom electrode.

Tests performed in six different positions (**Fig. 1b**) using an 8 Hz pulse frequency showed a decrease of the displacement from the center to the side of the membrane (**Fig. 4**) which could stem from mechanical restriction at the edges. The photovoltage remained constant at the different positions due to the homogeneity of the photo-sensitive layer providing the same response everywhere.

In summary, we have shown that AFM is the appropriate choice to study the properties of piezo-motion devices. It allows to quantify the light-induced displacement of the membrane and the generated photovoltageas well as to estimate the response time and position-dependent motion. The totality of these measurements enables the study and optimization of these and other types of light-driven devices.

[1] *W. M. Luiten* et al., AIP Adv. **10**, 105121 (2020)
[2] *Z. Zhan* et al., Nanotechnol. Rev. **7**, 555 (2018)

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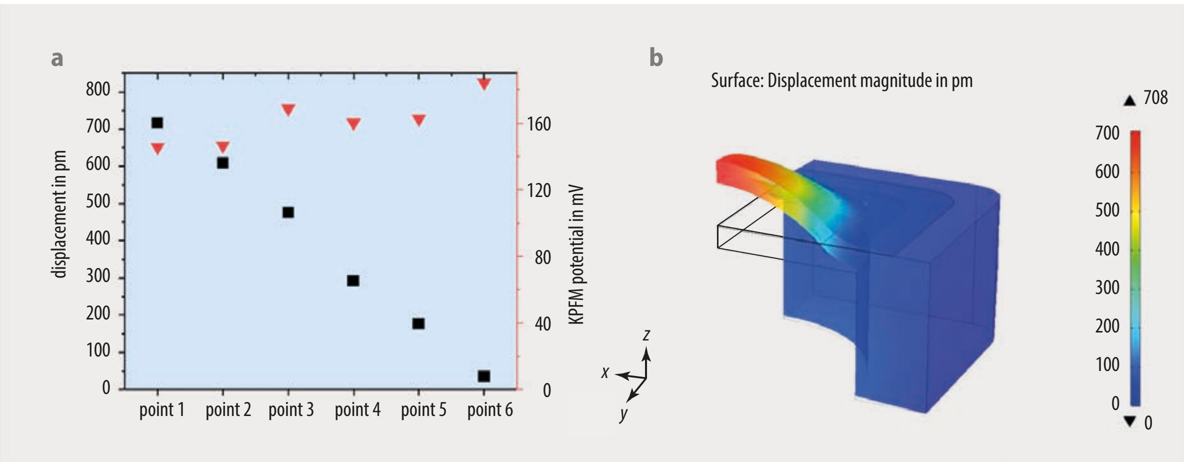

Fig. 4 During tests in six different positions, the displacement decreased from the center to the side of the device (a), while the surface potential remained constant. The 3D rendering shows the displacement on one quarter of the device (b).