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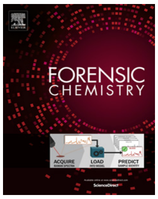

Reviews

Forensic potential of atomic force microscopy

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ABSTRACT

An important aspect of any crime scene investigation is to detect, secure and analyze trace evidence. Atomic force microscopy (AFM) is a nanotechnology that can be used to generate forensic information. This review aims to briefly explain principles of AFM and review potential forensic applications like age determination of bloodstains, fingermark examination, investigation of textile fibers, document forgery detection, gunshot and explosive residues analysis, and pressure sensitive adhesives investigation. Current techniques are highlighted and the usefulness of AFM is discussed. For the examination of gunshot, explosives and pressure sensitive adhesive residues AFM can determine elastic moduli, adhesion forces, energy dissipation, and dielectric properties of trace material, provide synoptic mapping of these characteristics and identify compositions. Phase imaging and force spectroscopy are important options but cannot unravel chemical identities. Forensic relevance of force spectroscopy for red blood cell age estimation is promising but remains to be fully explored. If not affected by surface roughness AFM height imaging may yield complementary information with respect to fingermark, textile and document examinations. For overlapping, (partially) erased marks or mixtures of biological traces phase imaging could provide composition information. If the chemical identity of trace components is important AFM may be combined with (surface/tip enhanced) Raman spectroscopy. Equipped with high resolution optical microscopy AFM(-Raman) technology may become a valuable forensic tool to characterize and understand trace transfer and persistence and to assess condition and age of evidence material. AFM could thus yield additional options for forensic association and assist in forensic analysis at activity level.

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1. Introduction

During a crime scene investigation it is essential to detect, secure and interpret biological trace evidence such as fingermarks, body fluids and hair but also non-biological traces like drugs, textile fibers, ammunition and traces of gunshot or explosive residues [1–4]. Key information regarding offences may thus be established and contribute to the reconstruction of crimes. Today a range of nanotechnology methods is available to characterize properties of materials at nanoscale and even at molecular level. Such methods can also assist in forensic examinations [5]. Moreover, today there is a variety of techniques available to characterize the unique properties of materials at nanoscales and even at molecular level. One of these techniques is atomic force microscopy (AFM) which is based on an extremely high resolution scanning probe microscope to sense intermolecular and interatomic forces between a sharp probe and the specimen under study. To date the use of AFM in forensic science has been limited to a few scientific studies. This is mainly due to the level of expertise required to perform AFM studies. The main question, also addressed in this review, is whether a technique for material characterization at the nanoscale can actually yield forensically relevant information. This is related to the principle of divisible matter as introduced by Inman and Rudin [6,7] and the associated insight that relevant forensic findings are to be found at the dimension at which the evidence was created. Studying forensic traces at insufficient resolution can lead to incorrect inferences. However, an excessive level of detail can obscure interpretation when the variation observed bears no relation to the evidence in the form of larger scale structures and patterns. After a brief introduction of the principles of AFM this reviews therefore aims to explore whether characterization with AFM can yield valuable information in criminal investigations. Potential forensic applications such as age determination of bloodstains, fingermark examination, investigation of textile fibers, document forgery detection, gunshot and explosive residues analysis, and pressure sensitive adhesives (PSA) are discussed. Advantages as well as disadvantages of the forensic use of AFM will be highlighted and compared with conventional and novel techniques that are used at the scene of the crime and in forensic laboratories.

2. Basic principles of AFM

Fig. 1 shows the basic components of an AFM, i.e. the probe (cantilever and sharp tip), laser, photodiode detector and piezoelectric scanner underneath the sample. In short, the sample is scanned by the tip at the end of the cantilever while attractive or repulsive forces between sample and tip molecules cause the cantilever to deflect towards or away from the sample. As illustrated in this figure the cantilever's deflection is measured by the reflection of a detection laser beam at the back of the cantilever which is subsequently converted into an electrical signal by photodiodes. Atomic force microscopy can be operated in different modes: *contact mode* (the tip is dragged across the surface at constant force), *intermittent contact mode* (the cantilever is oscillating and the tip will be repulsed at the lowest oscillation point and get out of contact at the upper part of the oscillation), *non-contact mode* (the cantilever is oscillating close to the sample but without contacting its surface) and *force modulation mode* (the tip is oscillating whilst remaining in contact with the sample surface) [8]. It should be noticed that in case of contact of the tip with the sample's surface frictional and adhesive factors may affect the overall results while samples can also be damaged. This is in contrast to the various dynamic, tapping modes with no or intermittent contact between tip and surface. Frictional and adhesive influences are usually decreased in these cases.

These AFM techniques allow imaging of the topography of surfaces at the nano-level. While the tip is moved over the surface by a piezoelectric scanner, the cantilever's deflection is detected and recorded. The deflection of the cantilever is directly proportional to the force and a feedback system is therefore commonly employed to monitor the cantilever's deflection (force). The feedback system adjusts the height of the cantilever in order to maintain a constant deflection (force) while the tip is moving across the surface. This way of imaging thus uses a *constant force* rather than a

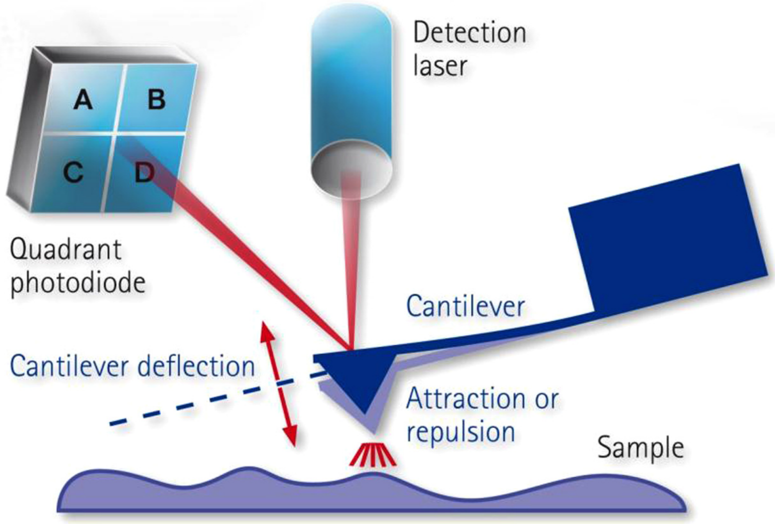

Fig. 1. Illustration of the basic components of an AFM such as a flexible cantilever (a spring) with tip, laser beam, photodiode and piezo-electric scanner. Typically, a cantilever is made of silicon or silicon nitride (optionally coated with gold or platinum) and measures between 7 and 500 μm in length and 2–50 μm in width and is 0.8–10 μm thick. The cantilever spring constant may vary from 0.007 to 2000 N/m and needs to be accurately calibrated. Depending on the roughness of the surface and type of measurements the tip can be pyramid-shaped (commonly consisting of silicon or silicon nitride) with a curvature radius ranging from 2 nm to 2 μm or spherical (0.5–2.5 μm in diameter and mostly made of titanium or silica) [8]. Force interactions between tip and surface molecules will result in a deflection of the cantilever that is recorded as the deflection of a laser beam aligned to the back of the cantilever. Quadrant photodiodes (with optically active areas A, B, C and D) will then convert the laser signals into an electrical output signal that is proportional to the deflection of the cantilever.