A Optisch induzierte Strukturen im SNOM

Lokale Strukturbildung

Wie in Kapitel 3.2.4 abgeschätzt beträgt die Temperatur an der SNOM-Spitze bei der Messung etwa 160^oC. Zeisel und Mitarbeiter erreichten bei Abtragungsexperimenten an der Spitze Temperaturen bis 400^oC. [268], Meixner berichtete über 470^oC [281].

Diese Temperaturen sind ausreichend, um organische Materialien **lokal aufzuschmelzen** oder Phasenübergänge zu induzieren [282] und so mit der SNOM-Spitze Strukturen zu erzeugen, die selbst als Träger von Information dienen können.

In der Literatur wurde im Zusammenhang mit optischer Strukturierung im SNOM hauptsächlich über Materialabtragung durch die SNOM-Spitze bzw. über die Belichtung einer mit Photolack behandelten Probe zur nachfolgenden externen Strukturierung berichtet [283–296].

Neben der Herstellung von Grabenstrukturen, die auf der Abtragung bzw. Aufschmelzung und mechanischer Verdrängung von Probenmaterial beruht, lassen sich auch **erhabene Strukturen** gezielt herstellen. Abb. A.1 zeigt die Entstehung von vier jeweils $10nm$ hohen Inseln aus einer glatten **Ph-T-F$_C$**-Schicht auf NaCl (100) (mittlere Rauigkeit der Probe $2nm$). An jeder der vier Stellen wurde die Probe bei $\lambda = 457.9nm$ mit einer Ausgangsleistung von $I_b = 30\mu W$ für $t_b = 1min$ bestrahlt.

Auch auf bereits bestehende Strukturen lassen sich mit hoher Auflösung weitere Strukturen aufbringen, wie in Abb. A.2 zu sehen ist ($\lambda = 457.9nm$, $I_b = 300\mu W$, $t_b = 1min$). Makroskopisch treten solche Effekte auf, wenn Material durch Adhäsion an einem Träger aus einer Schmelze herausgezogen wird und in dieser Form erstarrt. So lassen sich z.B. Fäden aus einer Kunststoffschmelze ziehen, und auch die Bildung von Lötnasen beruht auf diesem Effekt. Diese Argumentation setzt jedoch voraus, dass ein mechanischer Kontakt zwischen SNOM-Spitze und Fulgid-Insel besteht. Smolyaninov zeigte, dass es auch im shearforce-Betrieb des AFMs zu einer mechanischen Berührung zwischen Spitze und Probe kommen kann [297]. Alternativ ist bekannt, dass starke Lichtfelder attraktive Kräfte auf Materie ausüben können. Dies wird in optischen Fallen bzw. in optischen Pinzetten ausgenützt, um Partikel in einem durch Licht erzeugten Kraftfeld festzuhalten [298–301]. Welcher Mechanismus in den hier vorgestellten Fällen zum tragen kommt, konnte nicht entschieden werden.

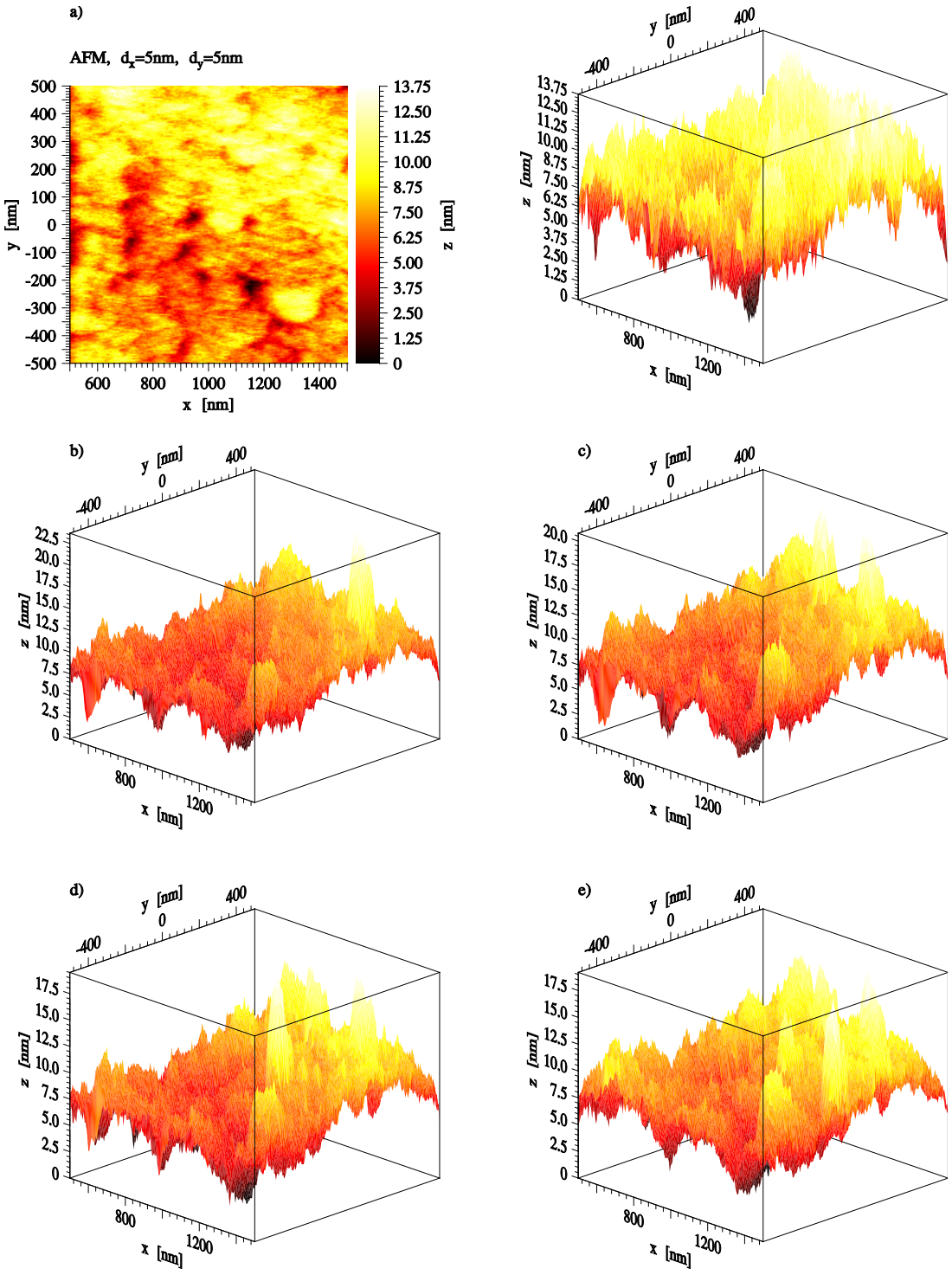

Abb. A.1: Ph-T-F_C auf NaCl(100), UHV-Aufdampfschicht; Generation von vier Inselstrukturen im SNOM ($\lambda = 457.9nm$, $I_b = 30\mu W$, $t_b = 1min$)

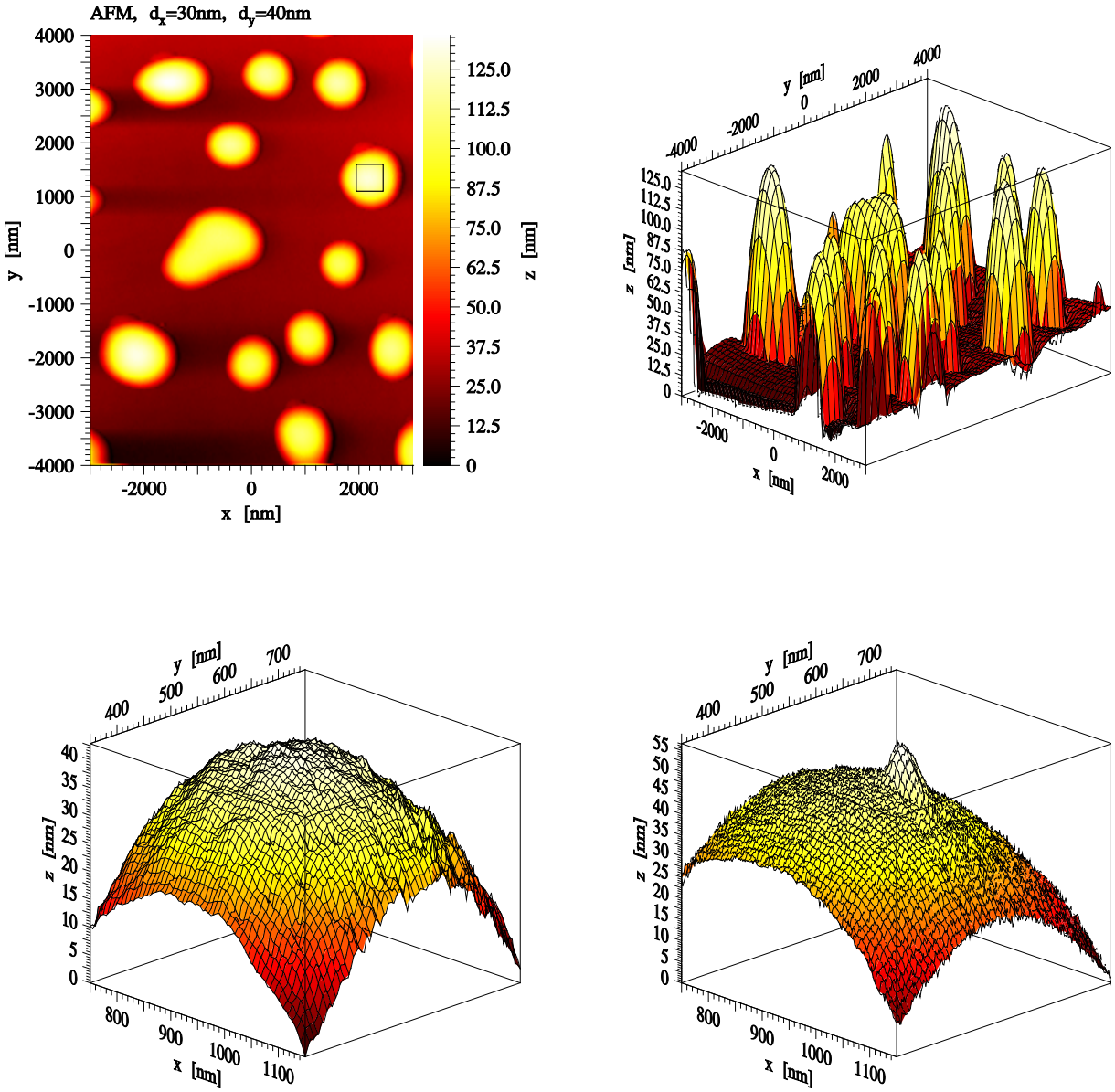

Abb. A.2: Ph-T-F_C auf Suprasil, UHV-Aufdampfschicht; Generation einer Substruktur auf einer Insel im SNOM ($\lambda = 457.9nm$, $I_b = 300\mu W$, $t_b = 1min$)

Nanochemie

Einen Schritt weiter gehen Experimente, die die **SNOM-Spitze** nicht nur als Wärmequelle sondern auch noch **als Initiator für chemische Reaktionen** nutzen. In Arbeiten von Bidlingmaier und anderen [302] wurde in Fernfeldexperimenten gezeigt, dass sich Aldehyde an wasserstoff-terminierte Siliziumoberflächen $Si(111) : H$ chemisch anknüpfen lassen. Die Reaktion wird durch UV-Licht initiiert und läuft am besten in einer Aldehyd-Schmelze ab. SNOM-Experimente zeigen, dass sich ein spin-coating-Film dieses Materials mit Hilfe der durch eingekoppeltes UV-Licht erwärmten SNOM-Spitze auf einer nm-

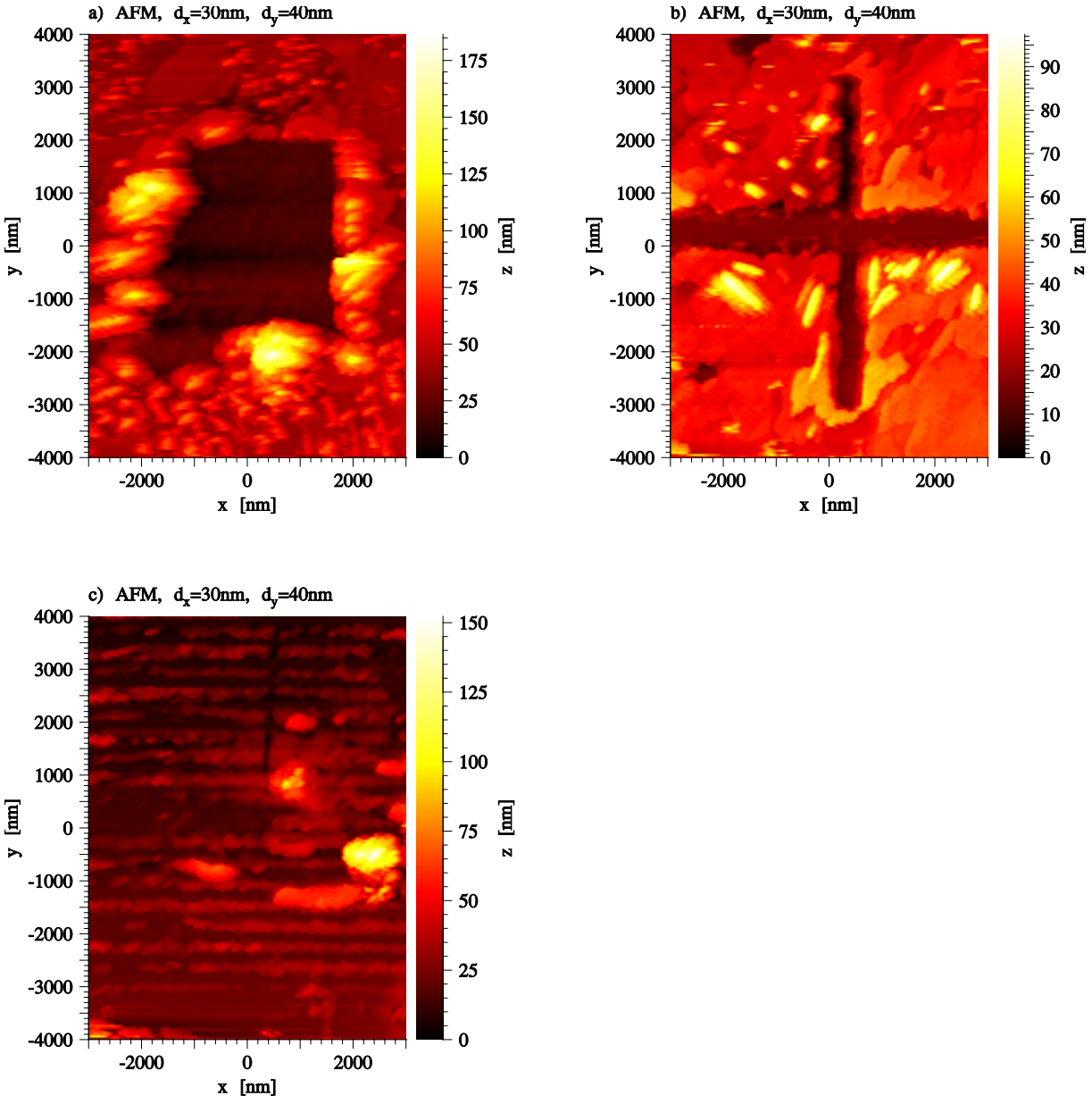

Abb. A.3: Octadecanal spin-coating-Filme auf wasserstoffterminiertem Silizium (Si(111):H), Strukturierung im SNOM $\lambda = 350.7nm$, $I_b = 3mW$, $t_b = 2ms$ pro Bildpunkt.

Skala aufschmelzen und strukturieren lässt. Abb. A.3 zeigt verschiedene in die Probe eingeschriebene Muster: a) Fläche b) Kreuz c) Linienmuster parallel zur x-Achse. Ob die Anknüpfungsreaktion bei diesen Experimenten tatsächlich stattgefunden hat, konnte bislang noch nicht nachgewiesen werden. Das Problem besteht darin, die strukturierten Bereiche, die nur wenige μm groß sind, nach der Entwicklung des Films, sprich Ablösen des überschüssigen Aldehydmaterials, auf der Probe wiederzufinden und die darauf eventuell vorhandene Monolage an angeknüpftem Material zu detektieren.

Ob sich damit eines Tages Speichermedien realisieren und nanoskopische organische Bauelemente an die Si-Halbleitertechnologie anschließen lassen, wird die zukünftige Forschung zeigen.

B Symbole und Abkürzungen

Symbol	Einheit	Verwendung
x,y,z	$[m]$	Koordinatenachsen
d	$[m]$	Schichtdicke
$\emptyset$	$[m]$	Durchmesser
h	$[m]$	Höhe
l	$[m]$	Länge
R	$[m]$	Krümmungsradius
$FWHM$	$[m]$	Halbwertsbreite
A	$[m^2]$	Fläche
ϑ	$[^o]$	allg. Winkel
λ_{ex}	$[nm]$	Anregungs-Wellenlänge
λ_{fl}	$[nm]$	Fluoreszenz-Wellenlänge
λ_m	$[nm]$	Mess-Wellenlänge bei Transmission
λ_{CE}	$[nm]$	$C \rightarrow E$ Schalt-Wellenlänge
λ_{EC}	$[nm]$	$E \rightarrow C$ Schalt-Wellenlänge
λ_b	$[nm]$	Bestrahlungs-Wellenlänge
OD		Optische Dichte
I,I_{fl}	$[cts]$	Detektierte Intensität
I_{ex},I_m	$[W]$	Anregungs-Intensität
I_{CE},I_{EC}	$[W]$	Schalt-Intensität
I_b	$[W]$	Bestrahlungs-Intensität
E_{ph}	$[J]$	Photonenenergie
ϕ		Quantenausbeute
$\Gamma_{A;B}$		optischer Kontrast A bezogen auf B
f		Dämpfungsfaktor (SNOM)
t	$[s]$	Zeit
t_b	$[s]$	Bestrahlzeit
t_m	$[s]$	Messzeit
τ	$[s]$	Zerfallszeit

Symbol	Einheit	Verwendung
ϵ	$[\frac{l}{mol \cdot cm}]$	Dekadische Extinktion
σ	$[cm^2]$	Wirkungsquerschnitt
a	$[\frac{1}{m}]$	Absorptionskonstante
ϱ	$[\frac{g}{cm^3}]$	Dichte
M	$[\frac{g}{mol}]$	Mol-Masse
$c_{A/B}$	$[\frac{mol}{l}]$	Konzentration der Substanz A in B
D	$[V]$	Dämpfungskonstante (AFM)
F	$[N]$	Kraft
k_F	$[\frac{N}{m}]$	Kraftkonstante
f_{res}	$[Hz]$	Ditherfrequenz
v_S	$[\frac{m}{s}]$	Scangeschwindigkeit
p	$[mbar]$	Druck
f_{SQ}	$[Hz]$	Frequenz (Schwingquarz-Waage)
T	$[K]$ oder $[^oC]$	Temperatur
T_{Sub}	$[K]$	Substrat-Temperatur
T_F	$[K]$	Flut-Temperatur
α	$[\frac{1}{K}]$	Thermischer Ausdehnungskoeffizient

Indizes	
C	C-Isomer
E	E-Isomer
F	Fulgid
P	Polymer

C Vollständige Verbindungsnamen

Phenyl-Thiophen-Fulgid **Ph-T-F**

Ph-T-F$_{\mathbf{C}}$:
4,7,7,7a-Tetramethyl-7,7a-dihydro-2-phenylbenzo[b]thiophen-5,6-dicarbonsäureanhydrid
Ph-T-F$_{\mathbf{E}}$:
(E)-2-Isopropyliden-3-[1-(2-methyl-5-phenyl-3-thienyl)ethylidenbernsteinsäureanhydrid
Ph-T-F$_{\mathbf{Z}}$:
(Z)-2-Isopropyliden-3-[1-(2-methyl-5-phenyl-3-thienyl)ethylidenbernsteinsäureanhydrid

Thiophen-Isopropyl-Fulgimid-Coumarin **T-iFm-Cou**

T-iFm$_{\mathbf{C}}$-Cou :
2-[4-isopropyl-2,8,8,8a-tetramethyl-8,8a-dihydrothieno[2,3-f]isoindol-5,7-dion-6-yl]ethyl-2,3,6,7-tetrahydro-11-oxo-1H,5H,11H-[1]benzopyrano-[6,7,8-i,j]chinolizin-10-carboxylat
T-iFm$_{\mathbf{E}}$-Cou :
N-(E)-2-[1-(2,5-Dimethyl-3-thienyl)isobutyliden]-3-isopropylidensuccinyl-2-aminoethyl-2,3,6,7-tetrahydro-11-oxo-1H,5H,11H-[1]benzopyrano-[6,7,8-i,j]chinolizin-10-carboxalat
T-iFm$_{\mathbf{Z}}$-Cou :
N-(Z)-2-[1-(2,5-Dimethyl-3-thienyl)isobutyliden]-3-isopropylidensuccinyl-2-aminoethyl-2,3,6,7-tetrahydro-11-oxo-1H,5H,11H-[1]benzopyrano-[6,7,8-i,j]chinolizin-10-carboxalat

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