Filamentary, My Dear Watson!

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Abstract

Developments that took place in the area of sculptured–thin–film technology after *Bianisotropics '98* are reviewed here. Devices addressed include: optical filters of various kinds, laser mirrors, gas–concentration sensors, optical interconnects, interlayer dielectrics, and biosensors. Pulse bleeding is related to the circular Bragg phenomenon in chiral sculptured thin films. Acoustic research is also identified.

Light from a fluorescent street lamp filtered through the soft rain, and the leaves of an ornamental maple tree on the other side of Baker Street cast muted shadows on the wall opposite the bay window in the cavernous living room of 221 B. The September night was in full glory, as Sherlock Holmes smoked a meerschaum pipe another people's princess had sent him as a token of her gratitude more than a century ago. He sat quietly, absorbed in some deep thoughts. Only the frequency with which he released smoke rings indicated his phrenetic turmoil.

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But, what's time in our state now? Having left aside our mortal accouterments, Holmes and I still inhabit our beloved apartments in the metropolis. I continue to organize many of the cases that Conan Doyle, our literary agent in our former life, never published because they were then deemed inimical to public order. Not nowadays, however. Holmes often tells me of particularly horrid instances of murder that the modern criminal has the means and the desire to commit and does. That of a little girl in Boulder and that of a big girl in Los Angeles come to mind. Occasionally, Holmes is sufficiently intrigued to solve particularly infamous crimes, but Conan Doyle is no longer able to bring the criminals to book.

The great love of Holmes these days, however, is not crime but the science of materials. No longer able to experiment himself as he once did on the ashes of cigars of 34 different provenances and the herbs used by the Moluccans to shrink other people's heads, he spends many a night at the Imperial College library, poring over the pages of thousands of journals and other scientific and technological proceedings. He has an astonishing capacity to memorize diverse facts, and he synthesizes new constructs with uncommon fecundity. I have always felt that the gain of Victorian crime–fighters was the loss of Victorian natural philosophers. The recent discovery of materials with Möbiated bianisotropy — a truly bizarre material structure that promises a thorough rewrite of plane waves in physics textbooks — came of a suggestion Holmes had whispered in the ears of a visiting San Doggo del High physicist as he slept late one evening, in the Imperial College library, about two years ago. More often than not, he is unable to find a competent medium for his ingenious ideas; though Holmes did manage to masquerade as Daedalus for several years in the pages of *New Scientist*.

I remember clearly that in 1959 he came across a report in *Nature* by two Nottingham engineers working for a Swedish company.[1] These worthies had sought fit to outsmart nature by depositing a twisted film of fluorite on a flat glass substrate. Their method of inducing the twist was simplicity itself: just rotate the substrate while the fluorite adatoms fall obliquely on it. A stationary substrate results in columnar thin films that can act like biaxial crystals; a rotating substrate can give rise to sculptured thin films that are ever more complex.

Neither one of the Nottingham duo could have verified the true nature of their films as scanning electron microscopes had yet not made their *début*, though they did have an inkling that the microstructure was some limiting case of a Šolc filter. Holmes, who can see matters more clearly than scanning electron microscopes because he can perform wavelet transforms on his nebular personal wavefunction, returned that January dawn from the Imperial College library, declaring that he knew the microstructure.

"Filamentary, my dear Watson," he had loudly shouted for all to hear — but no person then alive did. The Nottingham paper gathered dust for many decades. Only two reports were filed over 35 years by the Baker Street Irregulars, now no longer confined to their corporeal sheaths but clad in black instead: A Scotsman living in Arizona once mentioned the paper during an antipodean seminar, and a Louisiana physicist wrote of something similar. And then in 1995, an engineer from Pencilmania and a mathematician from the nether Caledonia discussed the films in a Royal Society paper, not at all aware of the Nottingham paper. Shortly thereafter, impelled by the Pencilmaniac engineer, a Canadian undergraduate student was able to duplicate the 1959 feat and scrutinize the arrays of parallel straight curls that chiral sculptured thin films are. Two years later, the Nottingham report came to light again, and today occupies its rightful place in the scientific literature on thin films. What an amazing confirmation of Holmes' foresight!

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Cogitating for over an hour in complete silence, Holmes said out aloud: "What do you make of the prospects of sculptured thin films, my esteemed Watson?"

Taken aback, I mumbled: "How the deuce did you know that?"

"You know my methods, Watson. Apply them. After the last gawking humans left our abode in the evening, you were nowhere to be found. Looking at your desk, I saw the letters W I L Y traced in the dust on your table, and an American envelope with a coyote stamp lying on the floor. Clearly, our transatlantic friend John had communicated with you through an infernal countryman of his who spent almost the whole day here in 221 B. I called one of my men in black, who confirmed that you had been seen crossing the Brooklyn Bridge. On your return, I detected perfume clinging to you. You must have been looking over the shoulder of a copy–editor in New York."

"Yes, but how did you know that John's missive concerned sculptured thin films?"

"Obsessed with these films you have been for some months, haven't you?"

"Yes. It does sound so simple, Holmes, when you explain it. Anyhow, there is this new book being published,[2] and I sneaked a preview of Chapter 5, just to apprise you of the latest developments."

"Pray do," quoth he, as he slowly floated up to the top of the ottoman.

I began: "Well, it seems that matters have advanced quite considerably during the past two years. You may recall, Holmes, the addresses that the Pencilmaniac engineer had delivered at *Bianisotropics'97* in Glasgow and *Bianisotropics '98* in Braunschweig. In his first address, he

[1] N.O. Young and J. Kowal, "Optically active fluorite films," *Nature* **183**, 104–105, 1959.

[2] O.N. Singh and A. Lakhtakia (eds), *Electromagnetic Fields in Unconventional Materials and Structures* (Wiley, New York, 2000).

was quite speculative about sculptured thin films. Reliable methods of producing them were still in their infancy; and the optical rotation spectrum of only one chiral sculptured thin film had been measured by then — and that too was crude and incomplete. The Pencilmaniac engineer's group took many theoretical strides following the Glaswegian meeting, which were duly reported in Germany. The theoretical basis of optical devices — such as circular polarization filters, laser mirrors, and gas–concentration sensors — was also firmed up between those two meetings.

"Several developments took place after *Bianisotropics '98*, many of which are reported in Chapter 5 of this new book. Optical interconnects as well as interlayer dielectrics are among the emerging applications of the sculptured–thin–film nanotechnology. Some acoustics research has also taken place, but it is definitely in the theoretical stage only. Most importantly, at least three types of optical devices have been made with the new serial bideposition technique in New Zealand, in collaboration with the Pencilmania group.

"The first optical device is a circular polarization filter that allows either left– or right–handed plane waves to pass through, but not both. Of course, on enquiry both Williams bragged that they have known from Wilhelm's time that such filters can work only in relatively narrow wavelength–regimes.

"The next device combines the filtering action with polarization–inversion. The circular polarization filter is capped by a columnar thin film which functions as a half–wave plate at a certain wavelength within the Bragg regime. The device thus is really the first two–section sculptured thin film ever made, and fully justifies your confidence in the concept of sculptured thin films.

"Finally, the third device is a spectral hole filter. While a chiral sculptured thin films is being deposited, the substrate rotation is temporarily stopped and then resumed after a while. This results in the production of a reflection hole that punctures the Bragg regime, when all parameters are properly chosen. The bandwidth of the hole is 11 nm, which is comparable to the 10 nm holes produced commercially by holographic techniques."

Holmes interjected: "That is a three–section sculptured thin film then, isn't it? But they have done even better with reflection holes. Instead of stopping the rotation of the substrate, they now simply give a quick orthogonal twist. They have achieved the same type of hole with a two–section sculptured thin film."

"How do you know about that?" I asked, to which Holmes replied that he had sneaked into an editorial office at a London physics department. He was also tickled pink to find that an Imperial College lecturer had joined the Pencilmania–NZ collaboration.

Holmes continued: "I can see the possibilities of highly sensitive gas–concentration sensors in those spectral holes. Did you find any evidence in the book chapter?" My reply in the negative made him pensive for a while. "Anything else in that book?" he questioned, and I mentioned that the Pencilmania group had undertaken the incorporation of further verisimilitude in their research by assuming Lorentzian dependencies for the constitutive parameters. "Good," he went on, "Hendrik will be pleased. But we must find more on what's afoot in Pencilmania."

Dawn was about to break as he uttered those words. Soon the fog would roll out of Heathrow and aeroplanes would begin landing there, bringing another clutch of Holmesians to 221 B. It was time to retire for the day, but Holmes went out to speak to one of his men in black.

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The great merit of disembodiment is that the Baker Street Irregulars can travel quite fast. While speeds close to or more than a tenth of the speed of light are not advised, lest a blue glow be emitted, during the last few years the men in black have been able to go to almost anywhere in the world with the help of the Internet. Constantly bumping into copper atoms used to be a hazard, but optical fibers now provide them with a smooth Alpine slide, even to Papua Niugini. Holmes and I also use the same mode of travel, incidentally.

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As the shadows filtered in again, ushering a new twilight, Holmes began to receive reports from the Baker Street Irregulars who had combed through the editorial offices of a multitude of physics and engineering journals. That the Lorentzian route had been taken by the Pencilmaniac was confirmed not only from France but also from Germany and Italy. No less than three editorial outfits from the three countries had become the Pencilmaniacs' accomplices, so to say. Sound research had been conducted and reported.

An interesting development was the modeling of individual columns in chiral sculptured thin films as ensembles of inclusions laid out end–to–end, not unlike strings of sausages. Spectral maximums of various observable properties had been examined as functions of inclusion shape, volume fraction and orientation — for eventual use in computer–aided design.

Even more astonishingly, research had spilled over from the frequency into the time domain. After solving the Maxwell equations directly in the time domain, the spatio–temporal anatomy of the circular Bragg phenomenon exhibited by chiral sculptured thin films had been bared, much to the delight of the doctor in me. Pulse bleeding had been shown to occur in the Bragg regime under certain circumstances. Holmes rubbed his hands with glee, as he wondered about the encounter of femtosecond pulses with chiral sculptured thin films, and cautioned me to be careful: if these new materials were to be used for wavelength division multiplexing and demultiplexing, we would have to choose suitable polarizations for future Internet travel. "Better pack a few extra polarizations, Joseph, just to stand out from the hoi polloi." In some of his lighter moments, Holmes fancies himself as Sir Andrew Lloyd Webber giving stage directions!

"Watson, the Pencilmaniac engineer is moving just too fast. I fear I am unable to delve into his brain, because he never puts on the virtual reality headset I had surreptitiously suggested the head of his department to provide him with. But his thoughts cannot elude detection. Unable to remember anything for too long, he commits all his ideas to writing. Somewhere in his office, a blueprint of his plans must be hidden; and I must lay a trap for him." Holmes pronounced each word with deliberation, in his usual calm manner. Every comma and every semi–colon, not to mention full stops, were marked by pauses of the right duration. I could almost feel that gears were whirring and lights were flashing inside that powerful intellect of his. And then he went out .... with one of his men in black.

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Holmes did not come back in the morning, and was away the next night as well. Late in the following afternoon, as I reposed on a horsehair sofa in the attic away from the prying throngs of visitors, I became aware of a tall cylindrical object with a faint green glow making its way towards me. If I had a skin, I would have jumped out of it. Golly, whatever could that dreadful apparition be? I froze in terror, as peals of laughter rang out.

"What's up, Doc?" a guttural *patois* issued from that object. But Holmes couldn't fool me. He is certainly a master of mimicry, but long association with him helped me see right through him.

"What are you disguised as?"

"What else? A Pencil, of course."

"Aha! A pencil for the Pencilmaniac!!"

"Exactly! Let's be off to Pencilmania, where the day is just about middle–aged now. Our quarry must be working in his office, where we must corner him."

Hitching a ride on the telephone cable, we exited 221B. Milliseconds later, we swung over to a British Telecom fiber. A skip over the splicing with an MCI fiber, and we negotiated the Atlantic *via* a satellite faster than you can say 'WorldCom.'

As we were landing on the desk of the Pencilmaniac engineer through his computer, he began to raise his right hand from his lap. He opened the side–drawer. Nimble as a humming bird, Holmes slid into the pencil case lying inside the drawer. A piece of paper lay on the desk, covered with chemical symbols such as $[Ru(2,2'\text{–bipyridine})_3]Cl_2$ and $[Ru(1,10\text{–phenantholine})_3]Cl_2$, and with the letters A, T, C, G and U strewn all over. A firefly had been doodled in a corner, with the words *Lucifer — Son of Morning* written below in a cursive hand.

The Pencilmaniac's left hand took out a pencil and drew several parallel lines on another sheet of paper. Those lines glowed green! Holmes had been able to get inside the engineer's brain! The Pencilmaniac continued to make a schematic, occasionally labeling certain layers. I did not understand the diagram, but Holmes did.

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An hour later, after the Pencilmaniac engineer had closed shop for the day, and his office was bathed in vivacious darkness, Holmes emerged from the pencil case. Triumphantly, he declared, "I just want to say one word to you .... Biosensors."

Author's note: If you enjoyed the story, please write or call for the following publications:

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