

Down memory lane with Frank Tittel

Flair Conference
Aix-Les-Bains, France
September 13, 2016

I am very grateful for this opportunity to honor my long time friend Frank Tittel.

Most of what I am going to say is a very brief semi-technical review of our joint papers. I will ignore almost all of the large number of papers we had that are not on the subject of FLAIR. I also will not talk about the large body of work by Frank that did not include me. This is the story of scientific bromance.

JOURNAL OF MOLECULAR SPECTROSCOPY 48, 72-85 (1973)

**Fluorescence Spectrum of Chlorine Dioxide Induced
by the 4765 Å Argon-ion Laser Line¹**

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I had been hungering for at least five years to use lasers in spectroscopy, but no frequency tunable lasers existed in those years. Raman spectroscopy could be done with a fixed frequency laser, but I was not interested in Raman.

In 1971, I heard a rumor that a guy named Frank Tittel in Electrical Engineering had developed a tunable laser source. So I went to visit him. It turned out that he was working on a cw parametric oscillator. In those days, lasers usually worked on Friday nights between the hours of 10 and 5, and that was certainly true of a cw parametric oscillator. It turned out Frank was an enthusiastic, welcoming person. I immediately decided that it would be fun to collaborate with him. In his lab space using his argon ion laser, one of his students Bissinger and one of mine Bennett went to work. I promptly went off to Ottawa on a years Sabbatical. But managed there to do some work there on the project.



Frank and I had some time for fun. I think we met on the slopes in Colorado by accident. Our younger son took this photo. From the photos of him then, he could not have been more than 15 making the date of this picture in one of the winters from 1974-75 to 1975-76.

You can't tell much about Frank looked then, but fortunately there is another.



This is what Frank looked like around age 40.

A few years and papers later

Magnetic Rotation

Sensitivity Enhancement of Laser Absorption Spectroscopy by Magnetic Rotation Effect. G. Litfin, C. R. Pollock, R. F. Curl, Jr., and F. K. Tittel, *J. Chem. Phys.* **72**, 6602-6605 (1980).

Rafał Lewicki, James H. Doty III, Robert F. Curl, Frank K. Tittel, and Gerard Wysocki, "Ultrasensitive detection of nitric oxide at 5.33 μm by using external cavity quantum cascade laser-based Faraday rotation spectroscopy," *Proc Natl. Acad. Sci.* **106**, 12587-12592 (2009).

Christian A. Zaugg, Rafał Lewicki, Tim Day, Robert F. Curl, Frank K. Tittel, "Faraday rotation spectroscopy of nitrogen dioxide based on a widely tunable external cavity quantum cascade laser." *Proc. of SPIE* **7945**: 500-1 (2011).

Our joint interest in magnetic rotation spectroscopy has lasted a long time at a low level. We worked on the methodology in 1980 and came back the subject in about 30 years in 2009.

I show the last reference because it is the last paper that Frank and I share. I retired in 2005 and really in 2008. After retiring, I've been interested in completely different subjects.

Tone-burst modulation

Sensitivity improvement of tone-burst modulated spectroscopy with a color center laser. Horst Adams, Jeffrey L. Hall, R. F. Curl, J. V. V. Kasper, and F. K. Tittel, *J. Opt. Soc. Am. B*, **1**, 710-714 (1984).

Earlier today, I discussed tone-burst modulation spectroscopy. I should mention that in addition the people shown here Richard Sakally developed this method at the same time.

We never pursued this because we became interested in other methodologies. That might partially have been because I fried an expensive lithium niobate EOM.

Trace gas monitoring

Using difference frequency mid-IR generation

Detection of Methane in Air Using a Diode-Laser-Pumped Difference-Frequency Generation Near 3.2 μm . K. P. Petrov, S. Waltman, U. Simon, R. F. Curl, F. K. Tittel, E. J. Dlugokencky, and L. Hollberg, *Appl. Phys B* **61**, 553-558, (1995).

Detection of CO in Air Using Diode-pumped 4.6 μm Difference Frequency generation in Quasi-Phase-Matched LiNbO₃. K. P. Petrov, L. Goldberg, W. K. Burns, R. F. Curl, and F. K. Tittel, *Opt. Lett.* **21**, 86-88 (1996).

Compact mid-infrared trace gas sensor based on difference-frequency generation of two diode lasers in periodically poled LiNbO₃, D. Richter, D.G. Lancaster, R.F. Curl, W. Neu, F.K. Tittel, *Appl Phys B* **67**, 347-350 (1998)

Atmospheric formaldehyde monitoring in the greater Houston area in 2002, J. H. Chen, S. So, H. S. Lee, M. P. Fraser, R. F. Curl, T. Harman, and F. K. Tittel, *Applied Spectroscopy* **58**, 243 (2004).

Frank and I did not get into trace gas monitoring until 1994. We used difference frequency generation to create a mid-IR beam. The list below is a nearly complete list of our **joint** publications using DFG for trace gas monitoring.

Quartz tuning fork photoacoustic

Quartz-enhanced photoacoustic spectroscopy, A.A. Kosterev, Yu.A. Bakhirkin, R.F. Curl, and F.K. Tittel, *Optics Letters* **27**, 1902-1904 (2002).

This is the first of many papers by Frank's group on QPAS.

Quantum Cascade Lasers

A. A. Kosterev, R. F. Curl, F. K. Tittel, C. Gmachl, F. Capasso, D. Sivco, J. N. Baillargeon, A. L. Hutchinson, A. Y. Cho, "Methane concentration and isotopic composition measurements with a mid-infrared quantum-cascade laser." *Optics Letters* 24: 1762-1764 (1999).

Review

Robert F. Curl, Federico Capasso, Claire Gmachl, Anatoliy A. Kosterev, Barry McManus, Rafal Lewicki, Michael Pusharsky, Gerard Wysocki, Frank K. Tittel, "Quantum cascade lasers in chemical physics," *Chem. Phys. Lett.* **487**, 1-18 (2010).

Frank's interest in DFG was quickly overshadowed by the exciting rapid developments in quantum cascade laser technology. In the years since 1999, he has developed the use of quantum cascade lasers in trace gas monitoring publishing by my standards an enormous number of papers in the area.

I believe that the review paper is a good way to get into the knowledge of quantum cascade lasers. I am the first author in the review because my job was putting together the works of the people who developed the field.

Thank you Frank
for 45 years of friendship

1971 to 2016
and counting