Novel semiconductor-laser-integrated active AFM optical probe with ultrashort pulses and nanoscale aperture

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Abstract: Novel semiconductor-laser-integrated active AFM optical probe with ultrashort pulses and nanoscale aperture is demonstrated with 3.5 ps pulse width and 11.4 GHz repetition rate.

Actoprobe LLC is developing a novel class of active optical probes for combined AFM/NSOM/TERS measurements. The novel Ultrafast Pulsed AFM Active Optical Probes (UFP AAOPs) are expected to enhance characterization capabilities at the nanoscale. As envisioned, these unique optical probes will perform the functions of conventional AFM probes and, in addition, will simultaneously provide both space- and time-resolved information about the optical and chemical properties of the sample at the nanoscale.

Actoprobe has designed and fabricated a monolithically integrated active optical AFM probe from GaAs-based semiconductor diode laser wafers with InAs QD active region [1]. This approach avoids very complicated and costly hybridization and allows for high-volume manufacturing, resulting in a cost-effective, affordable product that can be adopted for use by all current AFM users. The technology combines both single-molecule spatial resolution and ultrafast time resolution for pulsed TERS measurements.

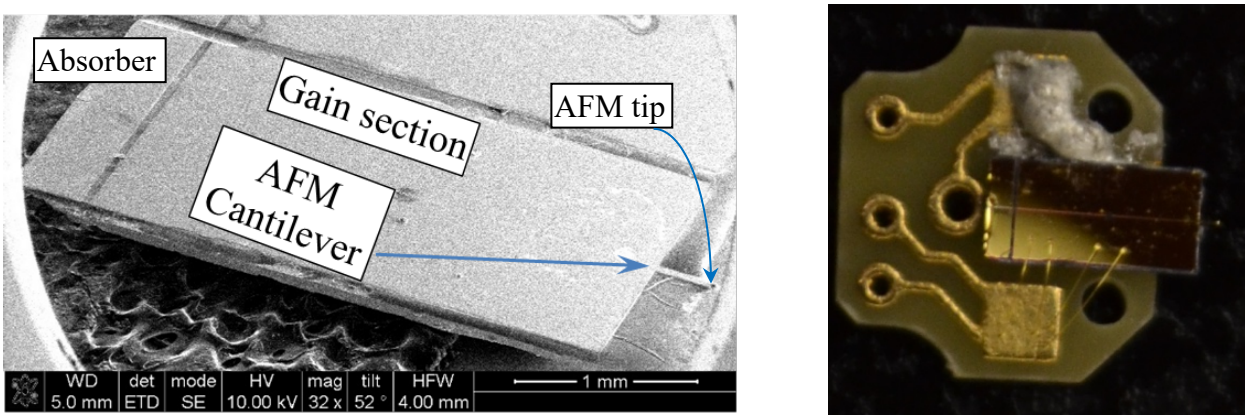

Fig. 1. SEM image of a two-section AAOP device (left) and a two-section AAOP device integrated into a customized AFM probe holder (right).

In the UFP AAOP design (Fig. 1), a two-section quantum-dot mode-locked laser is monolithically integrated with an SPM probe fabricated from GaAs, with a nanoscale opening at the apex of the tip as the output aperture. With UFP AAOP, the light is supplied through the tip; hence, there is no scattered far-field light and thus significantly reduced background. Furthermore, the difficulties associated with laser alignment onto the tip and with collecting the signal onto a detector are avoided with the UFP AAOP. The UFP AAOP provides pulses with less than 4 ps duration and spatial resolution better than 100 nm at 1240 nm wavelength. It is potentially possible to reduce the pulse width to ~ 0.3 ps [2] and to improve lateral resolution to ~ 1 nm.

A two-section AAOP device, designed for ultra-fast-pulsed mode-locked operation, with 5-µm-wide ridge-waveguide laser, 380-µm-long absorber section, and 3360-µm-long gain section is shown in Fig. 1. Laser emission from the AAOP device was obtained at 1240 nm. The L-I curves of the AAOP for various reverse bias on the absorber section are presented in Fig. 2 demonstrating the effectiveness of the absorber. The optical spectra shown in Fig. 2 verify the ground-state emission, when the device was under mode-locking conditions, and the large change of the spectral shape during mode-locking as compared to CW operation. Fig. 3 shows the pulse characteristics of a mode-locked QD laser of the same structure as the two-section AAOP device.

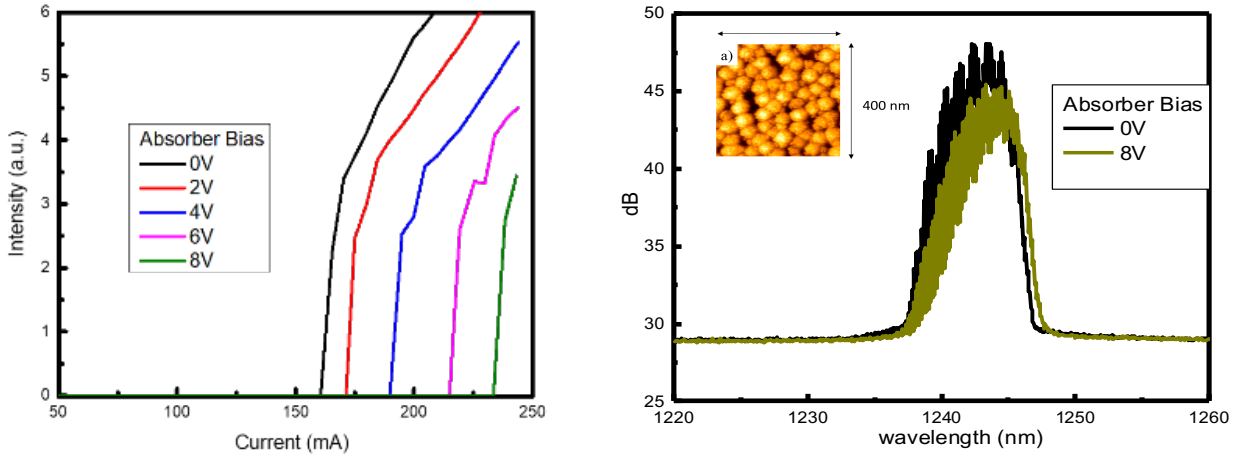

Fig. 2. Light-current characteristics measured at different bias applied to absorber section (left) and optical spectra measured for CW (0 V bias) and mode-locked (8 V bias) operation for the two-section AAOP (average QD diameter - 40 nm with average dot density - 310 dot/μm^2 ; center emission peak - 1245 nm) (right).

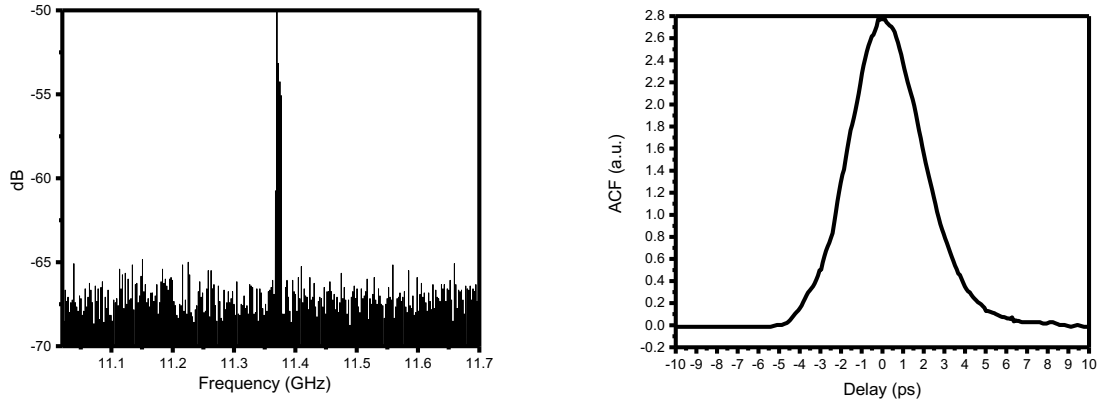

Fig. 3. Microwave power spectrum (left) and pulse shape (right) showing 11.37 GHz repetition rate and ~ 4-ps pulse width under the optimum bias condition of I_g = 100 mA and V_a = 10 V from a mode-locked QD laser of the same structure as the two-section AAOP.

In conclusion, we have demonstrated a novel type of AFM probe – Ultra-Fast-Pulsed AFM Active Optical Probe by monolithically integrating a mode-locked diode laser and cantilevered AFM tip. This novel optical AFM probe simultaneously focuses laser light in space and time and is capable of delivering significant amount of optical power to single-molecule scale, which is very attractive for nonlinear optical nanospectroscopy [3] and nanoscopy. The UFP AAOP capability of generating sub-picosecond optical pulses also makes it very attractive for single-molecule time-resolved spectroscopy [4]. UFP AAOP will facilitate the creation of a new microscopy/spectroscopy instrument with combined single-molecule spatial resolution and ultrafast time-resolved capability.

References

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