Polarized Wavelength-Tunable Narrow Linewidth Emission from a Diode-Pumped Mid-IR Microspherical Laser

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Abstract

We demonstrate and study wavelength-tunable narrow linewidth (< 50pm) polarized mid-IR (2.7 µm) emission from a diode-pumped microspherical laser made from heavily-doped Er: ZBLAN glass.

Introduction

Compact narrow-linewidth tunable mid-infrared (MIR) sources are needed for molecular sensing applications ranging from trace level detection of water vapor in semiconductor integrated circuit and fiber preform manufacturing processes to detection of trace levels of NH$_3$, CO, H$_2$S, NO$_2$, NO, AsH$_3$, ethylene and ethanol for agricultural monitoring, environmental sensing, and health care (eg, breath analysis) systems [1]. The proposed 2.7 micron laser source operates by optical pumping of whispering gallery modes (WGMs) in ultracompact (< 200 μm diameter) high-Q spherical mid-IR microresonators based on the Er:ZBLAN material system [2,3].

Characteristics of the source:

- Compact *(<0.005mm^3)*
- Wavelength tunable *(discrete thermal tuning over 2nm and fine power tuning over 280pm)*
- Narrow linewidth *(<50pm measured linewidth, Limited by OSA resolution)*
- Low threshold *(50-250µW)*
- Simple fabrication process
- Relatively low cost
- Natural candidate for intra-cavity sensing *(Evanescence field interacting with gas molecules)*

Fabrication of High-Q Mid-IR Microspheres

Due to complex phase transition of ZBLAN glass during melting and solidification, fabrication of high-Q (crystal free, defect free and cylindrically symmetric) microspheres, requires enforcement of a special temperature variation profile. Fig.1 (a) shows the qualitative temperature variation profile for fabrication of high-Q ZBLAN microsphere. Heat transfer processes cause a temperature rise in the molten glass (black curve), so that its temperature rises above its glass transition temperature, Tg, and its melting point, Tm. At $t > t_m$, given appropriate conditions of viscosity, surface tension, and rate of heat influx, the mass of the molten material acquires a spherical shape, with a continuous evolution of this shape due to changes in the viscosity and tension, depending in part on the symmetry of the heat input from the driving thermal source. At $t=t_{off}$ the heater turns off and to avoid crystallization of glass, a neutral gas flows around the sphere to rapidly decrease its temperature. This process yields to fabrication of absorption limited ZBLAN microspheres [4].

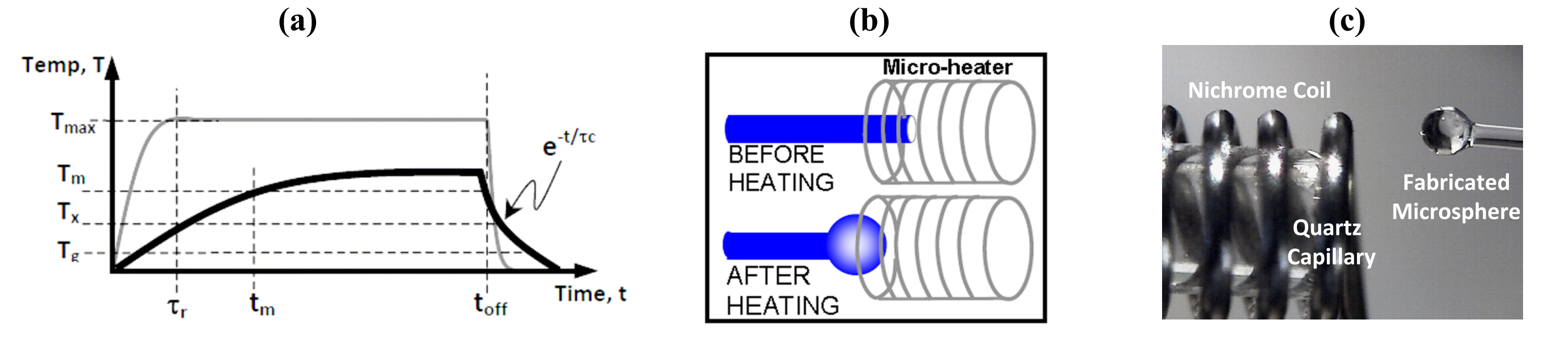


Fig. 1. (a) Qualitative variation profiles depicting heating of glasses for microsphere formation. The gray curve corresponds to the thermal "driving function" of the source -- such as a laser or heater current -- and the black curve is the temperature of the glass. **(b)** Schematic diagram of the cylindrical heater and the melting process **(c)** Photograph of fabricated microsphere in home-made microheater.

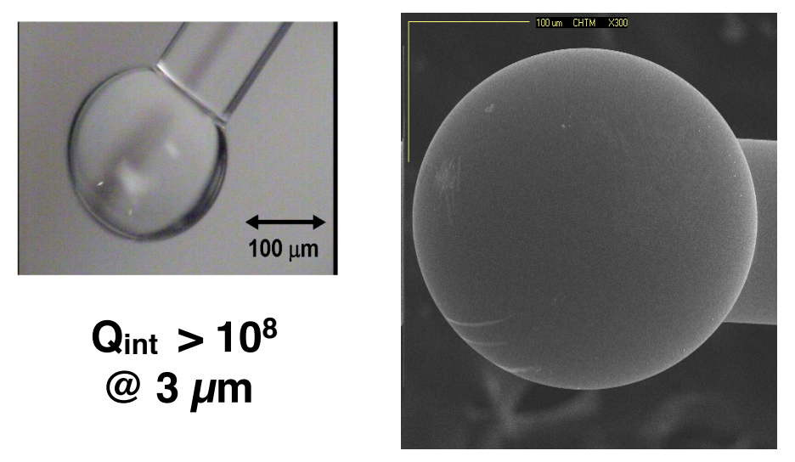


Fig. 2. Photograph and SEM image of fabricated ZBLAN microsphere, showing its extremely smooth surface. The measured optical quality factor for ZBLAN spheres are 4×10^7 which is corresponds to absorption limited quality factor for ZBLAN spheres. The quality factor of over 10^8 expected for ZBLAN microspheres at $3\mu m$ wavelength.

Experiment and Characterization

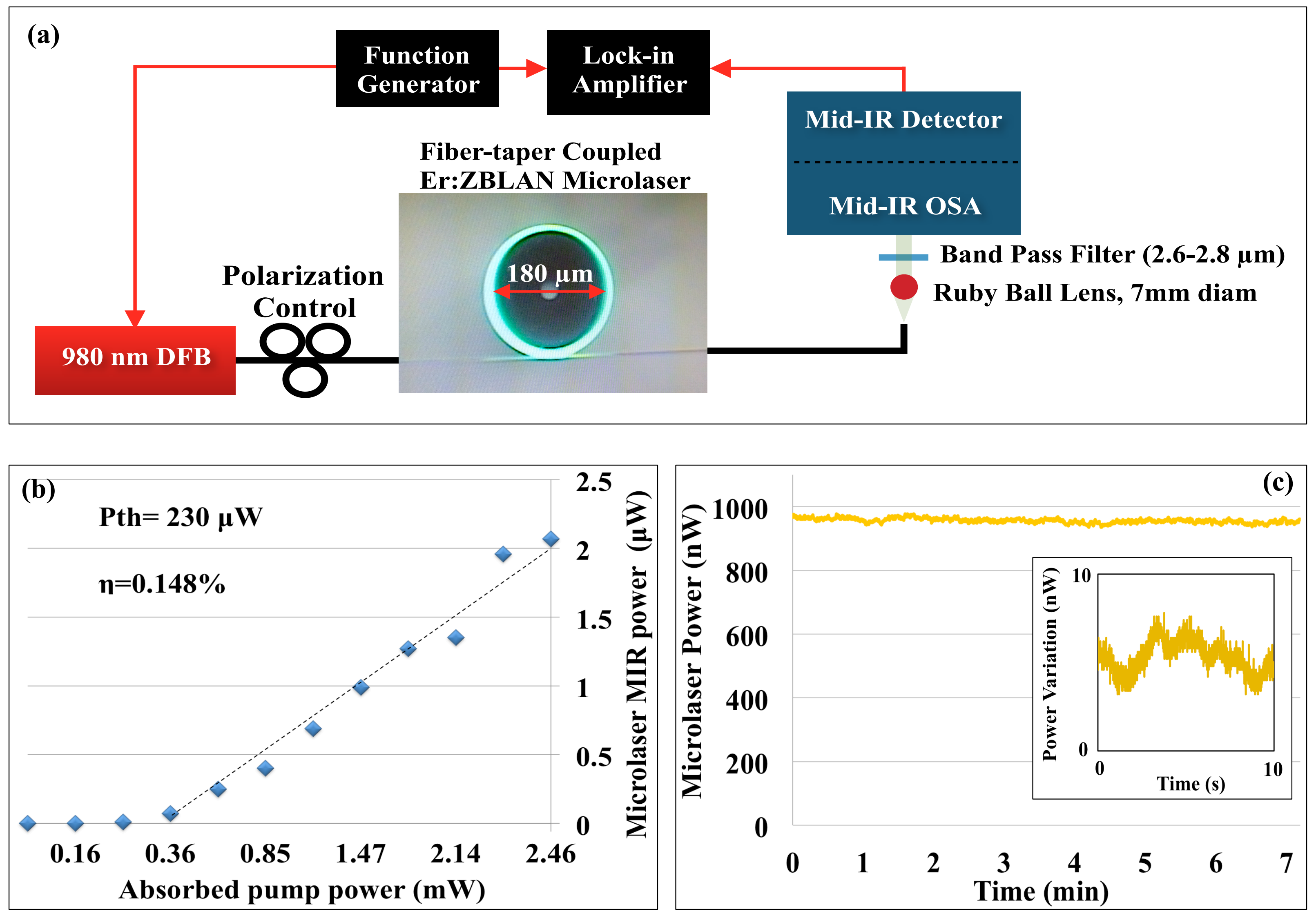
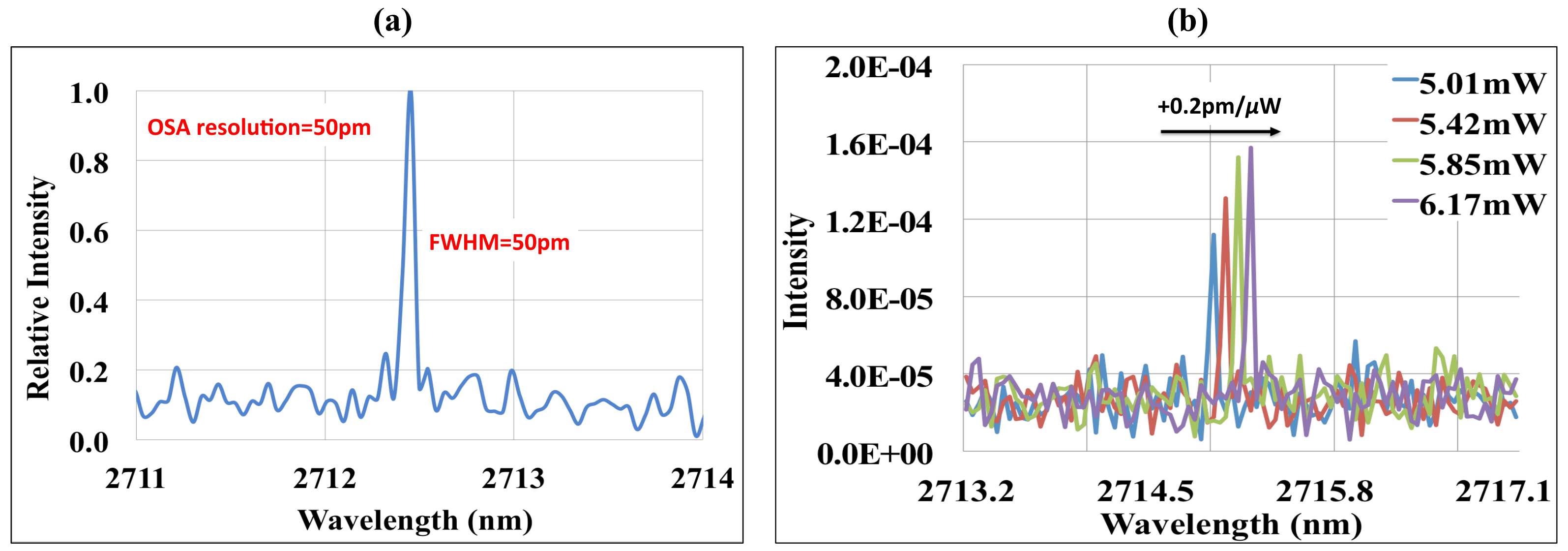


Fig. 3. (a) Schematic of the experimental setup of our Er:ZBLAN microlaser. **(b)** A plot of the microlaser output power as a function of the absorbed pump power. **(c)** Long-term stability of the microlaser (Inset: Power stability for shorter durations) corresponds to S/N ratio of 23dB.

A commercial narrow linewidth single mode DFB diode laser at 978 nm (FWHM < 0.05nm) was used to pump a heavily erbium-doped ZBLAN (8 mol %) glass microsphere (175-200 mm diameter) via a low-OH silica fiber taper coupler [3,5], whose waist was chosen to be less than 2 microns for close-contact coupling of the pump power into the microsphere and of the mid-IR emission back to the fiber. The quality factor, Q, of the unloaded ZBLAN microspheres at the laser wavelength was typically > 10^7 due to the unique thermal fabrication method used [2]; as such, despite reduction of the Q due to "loading" of such a contact-coupled tapered fiber coupler, it was high enough in most cases to enable low-threshold, narrow linewidth operation with relatively high stability.



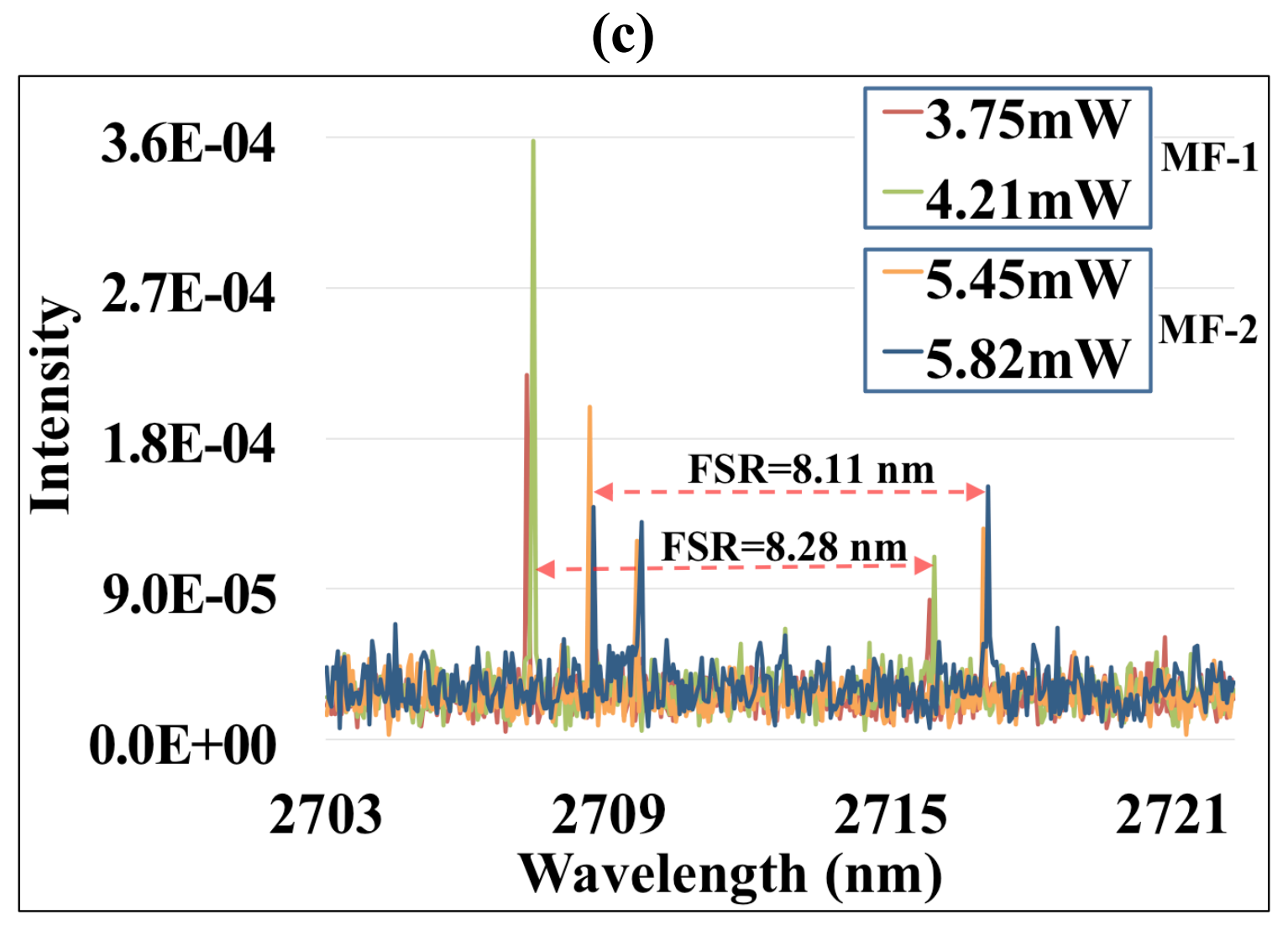


Fig. 4. (a) The measured linewidth of Er:ZBLAN microlaser limited by resolution of OSA (50pm or 2GHz).
(b) Tuning of single-mode microlaser by varying the pump power. The spectrum finely tuned by 0.2pm/μW absorbed pump power that corresponds to cavity temperature increase of +0.01$^{\circ C}$/μW absorbed pump power.
(c) Spectrum of the multi-mode microlaser showing mode hopping between different mode families (MFs) as a function of the pump power.

Amplification and Further Study

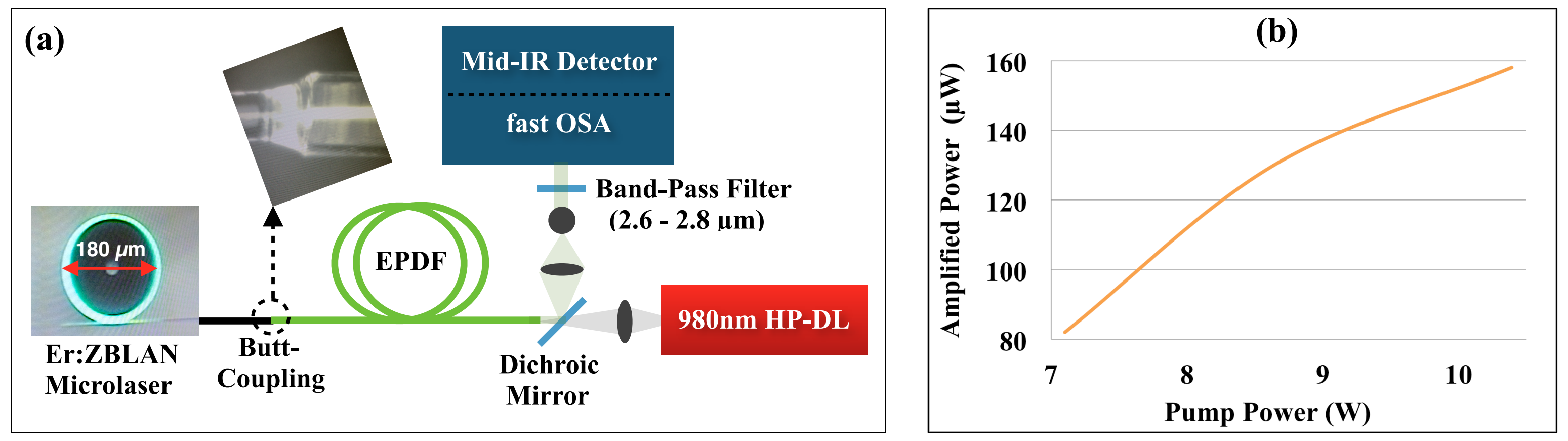


Fig. 5. (a) Schematic of experimental setup for Er^{3+}– Pr^{3+} :ZBLAN fiber amplifier (EPDFA) for amplifying mid-IR microlaser **(b)** Amplified power of microlaser against mid-IR fiber amplifier pump power.

For further study of the Mid-IR microlaser, a highly efficient for EPDFA (2mol% Er^{3+}–0.5mol% Pr^{3+} doped ZBLAN) with over 30dB gain was made. The linewidth of amplified single mode microlaser regardless of amplification was 50pm (2GHz), limited by the resolution of OSA.

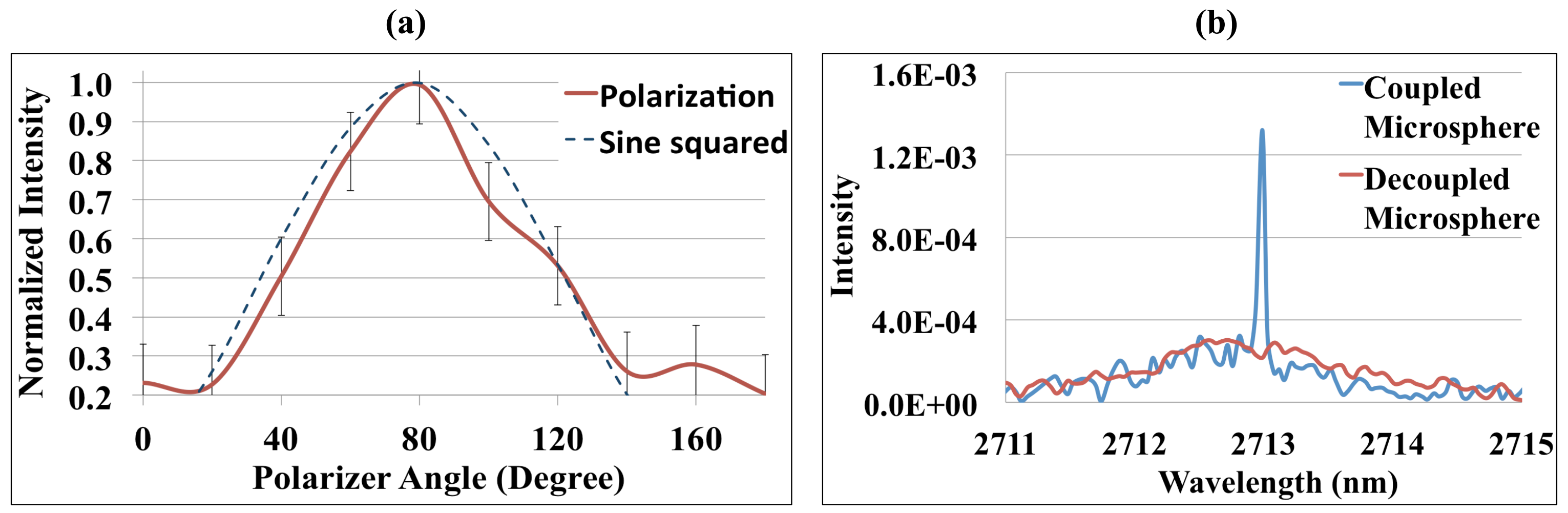


Fig. 6. (a) Measurement of the polarization state of a single mode microlaser; **(b)** Spectrum of amplified microlaser operated "slightly above threshold" and of the mid-IR fiber amplifier without any microlaser radiation (microsphere was "decoupled" from the taper coupler)

The polarization state of the laser (under single mode operation) was checked using a linear mid-IR polarizer. Fig. 6(a) shows the output power as a function of the polarizer angle. When the fiber taper is in contact with microsphere, the TM modes experience lower coupling losses than the TE modes (due to the smaller depth of their evanescence fields). As such, the microlaser is most likely to operate in a TM mode, thus yielding a linearly polarized laser emission quite naturally. We were also able to observe the spectrum of the microlaser when it was just barely above threshold by using an Er: ZBLAN fiber amplifier with a 30 dB gain [5,6]. Fig 6(b) shows the spectrum of such an amplified microlaser (6 nW). As stated earlier, the upper estimate of the "instrument-limited" value of the linewidth of our microlaser is 50 pm. By applying the Schawlow-Townes linewidth relation [8], we estimate a lower limit of the mode quality factor of our "coupling-loaded" microlaser to be above 12,500; we can also infer that a linewidth of ~ 3MHz should be achievable at output power levels of ~ 2 microwatts.

References

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