increases by an order of magnitude over a period of 48h. The behaviour for the 3μm-diameter microdisk is also given in Fig. 2. There is a more dramatic increase in output power for this laser, AlGaAs microdisks at 400°C for 5min prior to optical pumping structures. As the laser continues to operate, it appears that the laser output was improved by an order of magnitude over a period of hours at pumping powers near 10kW/cm². These enhanced surface properties are especially important for optimising the properties of microlasers. These studies may also play an important role in passivating heterojunction bipolar transistors, vertical cavity surface emitting lasers, or the end facets of stripe lasers in order to prevent damage or aging problems.

Acknowledgments: The authors wish to thank L.J. Oster for his expert technical assistance and U. K. Chakrabarti for useful discussions.

© IEE 1993
Electronics Letters Online No: 19931453
W.S. Hobson, U. Mohiden, S.J. Pearton, R.E. Slusher, and F. Ren (AT&T Bell Laboratories, Murray Hill, New Jersey 07974, USA)

References


Spectral and temporal stabilisation of a diode-pumped ytterbium-erbium fibre soliton laser

D.U. Noske and J.R. Taylor

A diode-pumped ytterbium-erbium 'figure of eight' laser is stabilised by the inclusion of a bandwidth-limiting element inside the cavity. Transform limited solitons with durations of 1.35ps are generated, continuously tunable over 20nm. Temporal stabilisation is imposed through amplified feedback of light reflected by the nonlinear loop mirror.

Ultrashort optical solitons have been generated by passively mode-locked erbium and ytterbium-erbium fibre lasers implementing a variety of cavity configurations and modelocking techniques [1-13]. The spectral output of these devices includes a number of resonant sidebands whenever the solitons achieve a duration short enough such that their soliton period 2l is comparable to the cavity length z. Energy shed by the pulses builds up on successive cavity transits at wavelengths determined by a phase-matching criterion [6]. This resonance leads to instability that ultimately limits the duration of the pulses that can be produced. It also leads to the generation of CW radiation components that propagate with the solitons, causing enhanced soliton interactions and gain saturation when the pulses are amplified. Hence the resonant instability is detrimental to the transmission of solitons generated by a fibre laser, and should be avoided.

The instability can be prevented by designing the cavity such that its length is long compared with the soliton period of the pulses it is generating. Previous investigations have shown that fibre lasers typically operate in the range 0.25 < 2l/z < 0.7, where the effect of instability is large and limits the attainable pulse duration. By including a bandwidth limiting element in the cavity it should be possible to broaden the pulses to a point where 2l/z > 2l, so avoiding the resonance. If the cavity is generating gain-bandwidth limited solitons [7] this process occurs automatically without the inclusion of an extra filtering element, because the gain profile acts as a bandpass filter.

Fig. 1 Schematic diagram of stabilised FFL
The laser system, shown in Fig. 1, initially consisted of a standard ‘figure of eight’, F8L, cavity. The gain medium was a diode-pumped ytterbium-erbium doped fibre manufactured by IRE Polus. The laser output was through a 30% fibre coupler, OPC, in the feedback loop of the laser. Also included in the cavity was a Faraday isolator, FI, and two polarisation controllers, PCI and 2, for polarisation biasing of the nonlinear amplifying loop mirror (NALM). The overall cavity length was 74m with a path-averaged dispersion of 5.35ps nm⁻¹ km⁻¹. With the bandpass filter \( F \) excluded from the cavity the laser generated pulses of 600–800fs duration, depending on the settings of PCI and 2. The corresponding soliton period \( z_s \) was calculated to be 26.9–47.8 m, leading to a maximum \( z_s/z_r \) ratio of 0.64. A typical pulse autocorrelation and spectrum are shown in Fig. 2a. The spectrum clearly displays the resonant sidebands, which is to be expected in this regime because \( z_s < z_r \). The time-bandwidth product was measured to be 0.31. A photodiode trace revealed the pulses to be randomly spaced, repeating at the cavity round-trip frequency, which is behaviour typical of such fibre lasers.

The laser system, shown in Fig. 1, initially consisted of a standard ‘figure of eight’, F8L, cavity. The gain medium was a diode-pumped ytterbium-erbium doped fibre manufactured by IRE Polus. The laser output was through a 30% fibre coupler, OPC, in the feedback loop of the laser. Also included in the cavity was a Faraday isolator, FI, and two polarisation controllers, PCI and 2, for polarisation biasing of the nonlinear amplifying loop mirror (NALM). The overall cavity length was 74m with a path-averaged dispersion of 5.35ps nm⁻¹ km⁻¹. With the bandpass filter \( F \) excluded from the cavity the laser generated pulses of 600–800fs duration, depending on the settings of PCI and 2. The corresponding soliton period \( z_s \) was calculated to be 26.9–47.8 m, leading to a maximum \( z_s/z_r \) ratio of 0.64. A typical pulse autocorrelation and spectrum are shown in Fig. 2a. The spectrum clearly displays the resonant sidebands, which is to be expected in this regime because \( z_s < z_r \). The time-bandwidth product was measured to be 0.31. A photodiode trace revealed the pulses to be randomly spaced, repeating at the cavity round-trip frequency, which is behaviour typical of such fibre lasers.

In conclusion, we have demonstrated both spectral and temporal stabilisation of a continuously tunable diode-pumped fibre laser generating transform-limited solitons. Spectral stabilisation was achieved by the introduction of a bandpass filter which broadened the generated pulses to a point where they did not experience the resonant soliton instability. Harmonic modelocking was achieved by including an amplifying feedback path that, when set correctly, led to stable fourth harmonic modelocking. Higher harmonic modelocking could be achieved through further improvements of the cavity design.

Acknowledgment: We gratefully acknowledge the SERC for the overall financial support of this research programme.
Anisotropic etching of deep trench for silicon monolithic microwave integrated circuit

T.C. Lo and H.C. Huang

The anisotropic etching of deep trenches in bulk Si for isolating global buried collectors in Si monolithic microwave integrated circuits has been successfully developed with SF6/C2CIF5 gas mixtures. Using photoresist as the etching mask, deposition of polymer thin film on the sidewalls of the trench occurred, hence inhibiting lateral etching and making the process anisotropic. Under optimal processing conditions, an etching anisotropy of 0.98 and an etching selectivity of silicon to photoresist higher than 28 were observed.

Reactive ion etching (RIE) for the generation of deep trenches in bulk Si has been developed with applications to Si monolithic microwave integrated circuits (Si MMICs) [1]. Deep trenches are used in these devices for isolating a global buried collector to replace the recessed oxide isolation. In comparison with recessed oxide isolation, trench isolation requires less space and hence lower collector parasitics [2].

There are several criteria that a good trench etch process for Si MMICs must meet. In the batch environment, the etch uniformity must be good to maintain minimum trench depth for isolation. The trench shape must also follow a clean breakdown characteristic with low leakage current. Moreover, for good metal interconnection across the trench, the profile of the trench needs to be tightly controlled so that it can be refilled with dielectrics for planarisation.

Normally a trench RIE process uses an oxide mask because of its high etch selectivity with respect to silicon [2-4]. Anisotropic etching of Si trenches using photoresist as the direct etching mask was also reported [5]. With proper plasma chemistries, the photoresist mask can produce polymer deposition on the sidewall of the trench, hence inhibiting the lateral etch and making the process anisotropic. In this Letter, we report the RIE processing of Si deep trenches with a geometry of $2 \times 10^3 \mu m^2$ which has a leakage current less than 5 AU at 15V for isolating local collectors in Si MMICs. The system (Dry Tek DRIE-102) employed in this work was a batch type reactor consisting of five parallel plate electrodes which had an electrode spacing of 2.4 cm. RF power at 13.56 MHz was applied to the target electrode which was a water-cooled cathode. The system was pumped by a blower pump aided by a mechanical pump.

The samples prepared for the experiments were 100 mm diameter, <100> oriented, N-type (5×2cm) silicon substrates. For electrical isolation measurement, wafers with N-type epilayer on P-type substrate were used. A 1.2 μm thick positive resist was spun, soft-baked at 95°C and then exposed. After development, the wafers were then hard-baked at 115°C for 30 min.

Indexing terms: Reactive ion etching, Silicon, MMIC

Fig. 1 Etch rates of silicon C2ClF5 content at pressures of 50, 100, and 150 mtorr

Fig. 2 Etch selectivity (Si/photoresist) against C2ClF5 content at pressures of 50, 100, and 150 mtorr

The gases used for the etching were SF6 and C2ClF5 gas mixtures. The etch rate of resist was measured using an ellipsometer and Nanometrics optical reflection system. The etch rate of Si was calculated from the etch depth measured by a surface profilometer. Etch selectivity between Si and photoresist was defined as the ratio of Si etch depth and the photoresist thickness lost. The degree of anisotropy ($A$) of the etch was defined as $A = 1 - (R_l/R_s)$, where $R_l$ and $R_s$ are the lateral and vertical etch rates, respectively.

The etch rates of Si and photoresist, the etch selectivity of Si to photoresist, and the etched profile were found to be dependent on the ratio of concentrations and the total pressure of SF6 and C2ClF5 mixture. The etch rates and selectivity as a function of C2ClF5 content at three different pressures (50, 100, and 150 mtorr) are shown in Figs. 1 and 2, respectively. Under the same etching conditions, the trench profiles change from an anisotropic when using a photoresist mask to isotropic when using an oxide mask as shown in Fig. 3. It is evident that the photoresist mask actually causes the deposition of a polymer thin film on the sidewall of the trench which inhibits the lateral etching. Auger analyses on the sidewall of the trench, as shown in Fig. 4, reveal contents of...