large detector received only a constant level, and it was used to cancel laser noise. The sample in this experiment was a Mitsubishi AlGaAs cranked transverse junction stripe laser [7]. It was prebiased below threshold \( I_b = 20 \, \text{mA} \) and \( I_0 = 22 \, \text{mA} \) and a 2-mA, 100-MHz sine wave signal was used to modulate the charge density within the cavity. The optical probe beam was focused onto the top of the AlGaAs laser sample, and \( x-y \) scanned across its surface. The measurements show uniform charge density along the edges of the laser cavity, and longitudinal spatial hole burning within the laser cavity center. A spatial rate equation analysis, including carrier diffusion, qualitatively agrees with the experimental results.

The temporal variation of carriers within the laser cavity was also observed by focusing the picosecond 1.3-μm laser probing spot to the center of the device. The AlGaAs laser sample was again biased below threshold and pulsed with a comb generator 10, 15, and 30 mA above threshold. The measurements demonstrate that the internal charge level overshoots and then clamps at the threshold level, where the amount of overshoot is proportional to the overdrive current.

In the future, shorter pulse laser systems will allow us to non-invasively observe picosecond carrier dynamics with micrometer spatial resolution over the entire length of the laser cavity.


The material of choice for guided wave electrooptic devices has been LiNbO\(_3\), rather than semiconductors, because of its larger electrooptic coefficients, lower coupling loss to fibers, lower propagation loss, and the ease of device fabrication. Nevertheless, there has been a steady shift in interest away from LiNbO\(_3\) toward semiconductors because of the possible integration of electrooptic devices with photodetectors, transistors, and lasers. In spite of the obvious benefits, integration of semiconductor and LiNbO\(_3\) devices has not been seriously considered before because of the disparity between the two materials. We report here on the application of epitaxial lift-off [1] to achieve the first integration of a semiconductor device with a LiNbO\(_3\) optical waveguide and on the optical interaction between the two. The semiconductor device is a GaAs metal-semiconductor-metal photodetector [2] that was processed entirely after the epitaxial lift-off. Because of the high index of refraction difference between the two materials, light evanescently couples readily from the low-index waveguide into the high-index GaAs photodetector.

The detector material was grown by molecular-beam epitaxy on GaAs and consisted of 250 nm of undoped GaAs above a 50-nm sacrificial AlAs layer. The GaAs epilayer was lifted off from the GaAs substrate using HF, which selectively etches the AlAs layer, and the 3 mm × 7 mm epilayer film was placed directly on a LiNbO\(_3\) substrate where it is held by van der Waals forces. The LiNbO\(_3\) had a planar waveguide formed by proton exchange before the epilayer transfer. After the transfer, we formed an array of MSM detectors on the GaAs by patterning Schottky metal. The array completely covered the GaAs and consisted of 100-μm-wide metal lines separated by 5-μm gaps. The metal lines extended completely across the GaAs film and ran perpendicular to the direction of light propagation so that the active region of each photodetector absorbs light for about 5 μm. We did not attempt to optimize the electrical and optical parameters as the main purpose of this work was to establish optical interaction between the waveguide and photodetector.

HeNe laser light (\( \lambda = 633 \, \text{nm} \)) was prism coupled into the waveguide. Light was totally extinguished within ~ 1 mm from the edge of the GaAs film. The photocurrent of the first detector, which was about 150 μm behind the leading edge of the GaAs, was 6 μA.
with 0.5-mW incident laser power. The second detector, 100 μm behind the first, gave 4 μA of photocurrent. These photocurrents correspond to a waveguide-detector absorption coefficient of 40 cm⁻¹, in agreement with estimates based on the effective index approximation.

We have demonstrated the feasibility of integrating a semiconductor photodetector with LiNbO₃ waveguides. All fabrication steps for the photodetectors are done after the epitaxial lithoff allowing the photodetector size and placement to be matched to the waveguides with photolithographic accuracy. Light couples from the LiNbO₃ waveguide to the GaAs photodetector indicating the two are in good optical contact with little or no intervening low index material such as air. It is expected that, with the present technique of integrating and optically coupling semiconductor and LiNbO₃ devices, high-performance optoelectronic integrated circuits that take advantage of the strengths of each material will be possible.

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Room-temperature continuous-wave oscillation with emission power in excess of 1 mW was achieved in vertical-cavity surface-emitting lasers containing a 0.5-μm-thick GaAs active layer sandwiched between a distributed Bragg reflector (DBR) and a metal-DiB mirror reflector grown by MBE. The threshold current is 40 mA for a 15-μm-diameter device. The temperature dependence of the threshold current gives Tₜh = 115 K.

VIB-1 InGaAs Superconducting JFET's with Nb Electrodes—A. W. Kleinsasser, T. N. Jackson, D. McInturf, G. D. Pettit, F. Rammo, and J. M. Woodall, IBM Research Division, T. J. Watson Research Center, Yorktown Heights, NY 10598.

A field-effect transistor can exhibit superconducting properties if the source and drain contacts are superconductors [1]. It is only recently that such effects have been observed experimentally, and the most significant result published to date is the report of 0.1-μm Si MOSFET's with Nb electrodes [2]. We have fabricated InGaAs injection FET's having Nb source and drain electrodes with submicrometer spacings. The devices exhibit gate-controlled supercurrents as large as 8 mA/mm at 4.2 K. This value of controlled supercurrent is larger than any previously reported for superconducting field-effect devices. The channel material was n-type In₀.₅Ga₀.₅As, epitaxially grown by MBE on InP substrates. Gate control was achieved using a p-n junction which was buried below the channel. This structure allowed the Nb superconductor to be deposited directly onto the freshly grown channel layer to insure a clean superconductor–semiconductor contact, which is essential for obtaining optimum superconducting properties. The superconducting electrodes were patterned by RIE.

From the materials systems for which viable FET technologies exist, InGaAs was chosen because it offers two significant advantages: 1) A low (≈0.2 eV) Schottky-barrier height at the source and drain contacts and small carrier mass result in a large tunneling probability, allowing a strong proximity effect coupling of superconducting properties into the channel region. 2) A large mobility and small effective mass result in a large coherence length in the channel. This allows relatively long source-drain separations for a given supercurrent density, which enabled us to achieve record lev-

els of controlled supercurrent in structures defined by optical lithography. The use of InGaAs lattice-matched to InP allowed us to fabricate p-n junctions in the GaAs layers with excellent properties. This is important in avoiding junction leakage, which would otherwise complicate the device measurements due to nonequilibrium effects. Experimental device results and comparison with theory will be presented.


We have integrated both a SQUID sensor and a superconducting feedback circuit on a single chip [1]. Such an integration is useful for constructing multichannel SQUID system because it eliminates the need for the massive feedback circuit outside the chip and many electrical cables connected them to the SQUID sensors.

In this report, we improved the dynamic range of the single-chip SQUID by more than two orders of magnitude and obtained high sensitivity.

In the single-chip SQUID, the sensor is ac biased and produces a pulse sequence. The superconducting feedback circuit consists of a superconducting loop and a write gate, a two-junction interferometer. The gate adds a flux quantum to the loop when it receives a pulse from the sensor. The stored flux is fed back to the sensor through magnetical coupling. This feedback maintains the sum of the input flux and the feedback flux at zero, and we can know the input flux by measuring the feedback flux. Thus, the dynamic range of this SQUID is limited by the capacity of storing flux quantas in the loop.

In the new design, we increased the loop inductance from the previous 20 nH to 30 μH. The estimated capacity becomes ±1.5 × 10⁻³. As it is necessary to decrease the stray coupling between the loop and the pickup coil or the other SQUID chip, we divided the loop into 32 spiral coils, and wound each coil inversely to cancel each magnetic flux at the distance. The feedback coupling is designed so that one flux quantum, Φ₀, in the loop is coupled to the sensor as 5.6 × 10⁻⁵ Φ₀, that is nearly the same as the thermal noise of the sensor, (SₜΔf)¹/₂, where Sₜ is the flux spectral density and Δf is the frequency bandwidth.

The chip was fabricated using Nb/AlOₓ/Nb junction technology, Mo resistor, and SiO₂ insulation [2]. The minimum line width is 2.5 μm and the chip size is 9.4 mm × 5 mm. We operated the chip when a large input was applied, the loop stored flux quantas up to ±2 × 10⁻⁴. This number is more than two orders of magnitude larger than the previous value, ±10⁻¹⁰; however, it is reduced from the design value, ±1.5 × 10⁻⁴. This reduction is due to the circulating current in the loop caused by the flux trappings. So, we consider that the dynamic range can be further improved by protecting the flux from the flux trapping or at least by releasing the circulating current. The sensitivity was 10⁻⁶ Φ₀/Hz¹/₂ that is nearly the same level of the conventional dc SQUID. These results, wide dynamic range and high sensitivity, show that the single-chip SQUID is available as a key element for constructing multichannel SQUID system in biomagnetic application.