Self-confined metallic interconnects for very large scale integration

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A novel method to produce narrow metallic lines is presented. Lines of $NiSi_2$ lithographically formed on SiO_2 substrates are oxidized. The formed SiO_2 layer consumes most of the Si from the silicide, leaving a metallic Ni line fully confined by SiO_2. The associated problems together with the potential utilization are discussed.

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The scaling of devices to micron size imposes severe requirements for the interconnection lines on a chip. The need for a low resistivity and process compatible material has generated interest in, and extensive exploration of, silicides. Silicides are, generally speaking, process compatible. They can sustain high temperatures, form a SiO_2 layer upon oxidation, and resist electromigration. But their electrical resistivity is about one order of magnitude higher than that of elemental metals. Metals, on the other hand, are incompatible with high temperature, chemical etching, and are more difficult to pattern accurately.

We have explored the possibility of oxidizing a silicide on a SiO_2 substrate to combine low metal resistivities with the process compatibility of the silicides.[1] While forming a protective SiO_2 layer during oxidation, the Si content in the silicide film decreases. The idea is to carry out the process to its limit and to transform the silicide film to an elemental metal layer with a SiO_2 coating. We first investigated extended $CoSi_2$ and $NiSi_2$ films on SiO_2 or Al_2O_3 substrates that were very large (~ 1 cm^2) in extent.[1,2] We found that upon continued thermal oxidation the films become morphologically unstable as they turn increasingly metal-rich. Metallic islands form, imbedded in SiO_2, yielding a discontinuous film incapable of electrical current transport. Actually, this morphological instability results in an overall sheet resistance that is never lower than that of the original silicide.[1]

We next investigated the behavior of narrow silicide lines as would be used for interconnections in very large scale integrated (VLSI) chips. This delineation of the film imposes a confinement that is not present in the extended films. Figure 1 shows optical micrograph of parts of an oxidized $NiSi_2$ test pattern on a SiO_2 substrate. Two contact pads are depicted as well as a part of a 5-μ-wide interconnect line. The detailed preparation procedures are reported elsewhere.[3] Silicon was patterned first using the lift-off technique. The Ni was deposited next, following by vacuum annealing at 400 °C to form NiSi (with some Si remaining), and by selective etching of the excess Ni. A final annealing step at 800 °C transformed the NiSi to $NiSi_2$. Thermal oxidation in wet oxygen ambient at 900 °C for sufficiently long time (~ 8 h) resulted in SiO_2 layer that contained more than 95% of the original Si in the silicide, as was established by backscattering spectra taken on a large area pattern prepared similarly on the same substrate. The formation of metallic islands in the large area pads is again observed. However, the narrow lines have very long (exceeding 100 μm) segments of uninterrupted connection.

The width of the resulting metal island line is about 50% of the original linewidth. An x-ray diffraction pattern taken from these samples discloses the presence of coarse Ni grains. Because our long lines are not continuous and are coated with SiO_2, a direct measurement of their resistance has not been performed, but we expect them to be good metallic conductors.

The process described might be successfully utilized for narrow interconnects on VLSI chips, but first, the nature of the instability and its relation to the metal reactivity with

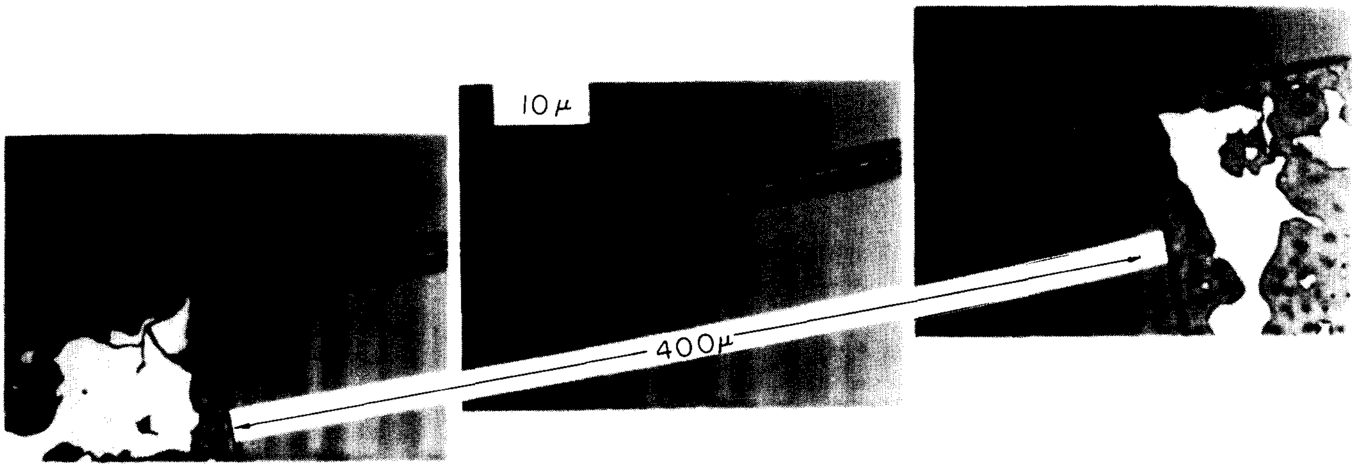

FIG. 1. High magnification of patterned $NiSi_2$ following extended oxidation. Metallic islands are formed in the large unconfined areas while long metal stripes are generated in the narrow lines.

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SiO_2 (Ref. 4) has to be explored and understood, in this and other transition metal silicides. The linewidth, initial thickness, and composition should be optimized to ensure continuous lines. The resistivity of these lines is not determined yet. Also, the relative role of the induced stress due to volumetric changes in the films has to be taken into consideration. In reporting this preliminary observation, we want to demonstrate the feasibility of, and stimulate further work on, the idea of generating narrow metallic conductors confined by and imbedded in SiO_2.

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Optical and electrical oscillations in ferrofluids induced by constant electric fields

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A sudden application of constant electric field across a thin planar cell containing nonaqueous ferrofluid leads to oscillatory, damped electrical and light scattering signals. This surprising phenomenon is associated with the coherent bouncing motion of charged iron oxide particles between cell electrodes. These particles likely undergo charge reversal at the electrodes and their transport is assisted by fluid motion.

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Ferrofluids[1] are relatively stable dispersions of small (100–1000 Å in diameter) superparamagnetic particles suspended in aqueous or nonaqueous liquids. These magnetic colloids are stabilized against agglomeration with organic surfactants even though electrostatic stabilization may also play a role in preventing agglomeration.

When a constant electric field is suddenly applied across a thin planar capacitor containing nonaqueous ferrofluid, a surprising oscillatory electrical current is observed,[2] as indicted in Fig. 1. This letter deals with the investigation of the physical origins of this unusual phenomenon.

Application of the electric field E across a colloid leads to motion of charged species which may include ions, charged particles, aggregates, micelles, polymers, and others. In the one-dimensional conduction case, the current density $I(t)$ is given by

$$I(t) = \sum n_i(x,t) q_i(x,t) \mu_i(x,t) E(x,t), \qquad (1)$$

where n_i, q_i, and μ_i are the density, charge, and mobility of the ith charged species, respectively, and the summation is over all charged species. In general, E, n_i, q_i, and μ_i can depend on position x and time t. Nonuniform distribution of charged species after appliction of a field can result in space-charge-limited conditions characterized by a time-dependent, nonuniform field. Other processes which affect the electrical current include diffusion of charged and neutral species, dissociation of neutral molecules, recombination of ionized species and fluid motion. At the electrodes, charge neutralization and injection can occur. The complexity of electrical signals mandates use of a complementary technique, such as optical transients,[3] which is sensitive to scatterers, such as the ferrofluid particles, but not to ionic species. When the spatial distribution of scattering particles changes, scattered or transmitted intensity also varies which allows for the determination of particle velocities and mobilities. In addition to electrical and optical transients, quasi-elastic light scattering was employed to determine the diffusion coefficient and size of the scatterers.

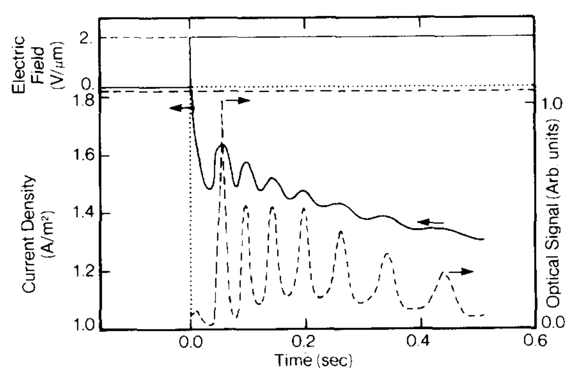

FIG. 1. Typical electrical current density and the low angle scattering signal from ferrofluids obtained with a sudden application of electric field. Data were obtained with 50 V applied across 25-μm-thick cell. The ferrofluid was diluted 1:1 with heptane and contained 5.0 mg AOT/ml of diluted colloid.

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