Reactive sputtering also allows a wide variation of film index through adjustment of the reactive gas flowrates, making possible the fabrication of wide-bandwidth multi-layer or graded-index AR coatings. Multi-layer high-reflectivity coatings of 98% reflectivity for both surface-emitting and in-plane lasers have also been demonstrated. Sensitive control of film thicknesses is accomplished through in situ monitoring of the coating reflectivity.

Alternative techniques for achieving AR coatings of the appropriate index have involved either decreasing the index of silicon nitride (≈2.0) by introducing excess nitrogen, or increasing the index of silicon dioxide (≈1.45) by decreasing the amount of oxygen present. Such approaches generally produced less than satisfactory films, or suffered from process variability. For example, silicon nitride targets can be RF sputtered in argon to produce nitride films; the addition of excess nitrogen into the chamber will increase the nitrogen content of the film and decrease the index. In practice however, non-uniformities of the silicon nitride target causes reproducibility problems with this technique. We have deposited nitrogen-rich silicon nitride by DC sputtering a silicon target in argon with excess nitrogen, but poor film quality results from this method because the excess nitrogen causes nitride to form on the target itself, causing plasma arcing and particle generation into the film. Silicon dioxide can be deposited by sputtering silicon with argon and oxygen; reducing the oxygen discharge results in silicon-rich (oxygen deficient) coatings of higher index. We have found however that the resulting index is too sensitive to small variations in oxygen flow and background gases to be reproducible. This is due to the large index variation between silicon dioxide and silicon (≈3.5). Our present technique uses flowrates similar to those employed to obtain stoichiometric silicon nitride, but with oxygen introduced to lower the index to the optimum value. This technique overcomes the problem of sensitivity to oxygen flowrate fluctuation because in this case the full variation of index is only between 2.0 (silicon nitride) and 1.45 (silicon dioxide).

The film thickness is controlled through the use of *in situ* monitoring of the coating reflectivity. The beam from a single-wavelength distributed-feedback (DFB) laser is directed onto the coating through a chamber window. The reflected beam exits through the window onto a photodiode which monitors the intensity during deposition. The DFB laser emission is the same wavelength as that of the AR coating so that the coating is at the correct thickness when the reflected beam intensity reaches a null. For coating laser facets, a second *in situ* monitoring technique is used. In this case, the laser being coated is biased inside the chamber and its power output is monitored during the deposition to detemmine the point of optimal facet coating thickness.

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9:20 AM, G4

Electrical Properties of Bismuth Titanate Dielectric Thin Films: *L. A. Wills* and B. W. Wessels, Dept. of Materials Science and Engineering and Materials Research Center, Northwestern University, Evanston, IL 60208.

Bismuth titanate is a dielectric material that is a member of the family of ferroelectric bismuth oxide structures that exhibit high dielectric constants and strengths. These materials potentially have numerous applications in electronic and electro-optic devices. Since the material is ferroelectric, it may be suitable for use as the dielectric in non-volatile, thin film semiconductor memories. In the present study, $Bi_4Ti_30_{12}$ thin films were deposited by organometallic chemical vapor deposition in a modified, low pressure reactor. Triphenyl bismuth, titanium isopropoxide, oxygen an or water were used as reactants. The bismuth titanate was deposited on single crystal, (100) oriented silicon at temperatures of 600° - 800°C. Growth rates ranged from 0.2 - 5μm/hr resulting in film thicknesses of 0.5 - 2.0 μm. The films were polycrystalline with a (0k0) preferred orientation.

The electrical properties of the bismuth titanate films were measured on MIS structures prepared on the p-type silicon substrates. The resistivity of the thin films was of the order of 10^6 - 10^8 ohm-cm. The dielectric constant of the films ranged from 30 - 160. It was found that the dielectric properties were sensitive to deposition conditions. Capacitance-voltage measurements at 1 MHz on the MIS structures exhibited a large hysteresis. The magnitude of the hysteresis depended on film deposition conditions with structures fabricated using films deposited at higher deposition temperatures exhibiting larger hysteresis. The origin of the hysteresis and the role of polarization of the ferroelectric as well as trapping states are under active investigation.

9:40 AM, G5 †

Electrical Properties of $SrTiO_3$ Thin Dielectric Films: *W. A. Feil***, B. W. Wessels*, L. M. Tonge** and T. J. Marks**, *Dept. of Materials Science and Engineering, **Dept. of Chemistry, Northwestern University, Evanston, IL 60208.

There is considerable interest in the dielectric material $(Ba,Sr)TiO_3$ for numerous electronic and electro-optic devices because of its large dielectric constant. This material is a ferroelectric, making it potentially suitable for use as the dielectric in non-volatile, thin film semiconductor memories. In the present study, we have prepared $SrTiO_3$ thin films by low pressure, organometallic chemical vapor deposition. Titanium isopropoxide, strontium dipivaloylmethanate, oxygen and or water were used as reactants. Films were deposited on either (0001) sapphire or (100) silicon substrates at growth temperatures of 650° - 850°C. Growth rates ranged from 0.3 - 4.5 μm/hr resulting in film thicknesses of 0.5 - 12 μm.

The electrical properties of the polycrystalline films were measured using MIS structures prepared on p-type silicon substrates. $SrTiO_3$ films deposited using water as the reactant gas were semiconducting with resistivities of the order of one ohm-cm. However, by adding oxygen to the growth ambient, the films became insulating with resistivities increasing to 10^9 ohm-cm. The dielectric constant of the insulating films ranged from 25 - 100. Capacitance-voltage measurements on the MIS structures exhibited hysteresis. To test the origin of the hysteresis, trapping states in the films were measured using transient photocapacitance spectroscopy. Several deep level states were observed having energy levels at 1.5, 2.7 and 3.0 eV. The effect of post-deposition annealing on the formation of defect states was examined.

10:00 AM, Break

10:20 AM, G6 †

Reduction of Oxygen Incorporation and Lifetime Measurements in Epitaxial $Si_{1-x}Ge_x$ Films Grown by Low Temperature Rapid Thermal CVD: *P. V. Schwartz*, J.C.Sturm, Dept. of Electrical Engineering, Princeton University, Princeton, NJ 08544, and C.Magee, Evans East, Inc., Plainsboro, NJ 08536.

We have investigated the incorporation of oxygen in epitaxial silicon and silicon-germanium films grown by CVD in a susceptor free - lamp heated system. In previous work, background concentrations of oxygen in films of silicon and silicon-germanium, grown at temperatures of 700 and 625°C respectively, have reached levels of 10^{20} cm^{-3}. These samples exhibited surprisingly negligible degradation of structural and electrical properties. In this work, we have identified the source of this oxygen and suceeded in reducing oxygen levels to under 10^{18} cm^{-3}.

Initial work was done in a quartz chamber that was vented to atmospheric pressure to load each sample. Multilayer structures of silicon and silicon-germanium, which were grown at different temperatures on the same substrate, have been analyzed by Secondary Ion Mass Spectroscopy (SIMS). The oxygen concentrations in the films increased with the decrease of the growth temperature as expected due to the known increased stability of oxygen on the surface of silicon at low temperatures. We also have found that the oxygen concentrations are consistantly greater in the silicon-germanium layers than in the silicon layers grown at the same temperature.

By adding a loadlock to the growth chamber to prevent venting during sample loading, we have reduced the oxygen concentra-

tions below the detection limit of SIMS (approximately 10^{18} cm^{-3}). This leads us to believe that the oxygen contamination was due to the adsorption of water molecules to the chamber walls (quartz) during an atmospheric pressure loading of the sample. This water subsequently desorbed from the walls during growth. The fact that the oxygen incorporated more readily in the silicon-germanium layers is surprising considering published results stating that germanium can be used for the low temperature oxide removal from a silicon surface (GeO desorption). Therefore, for higher oxygen concentrations in silicon-germanium films, we conclude that the GeH_4 must enhance the desorption of water vapor from the wall of the growth chamber. This provides a much larger partial pressure of water vapor during the growth of silicon-germanium compared to that of silicon.

Minority carrier generation lifetime measurements were then made in films of low concentrations of oxygen (< 10^{18} cm-3) using MOS structures. The silicon-germanium layers were capped with a silicon layer to provide for a high quality Si-SiO_2 interface. Because the growth of a high temperature thermal oxide might relax the strain of the silicon-germanium layer, a low temperature deposited oxide was used as ther insulating layer. Typical lifetimes are 10 ns although control wafers indicate that the quality of the deposited oxide is the limiting factor in the lifetime measurements, not the silicon-germanium films themselves.

10:40 AM, G7

Deposition Of Silicon Carbide In A Limited Reaction Processor: *F.H. Ruddell,* D.W. McNeill, B.M. Armstrong and H.S. Gamble, Department of Electrical and Electronic Engineering, The Queen's University of Belfast, Ashby Building, Stranmillis Road, Belfast BT9 5AH, N.Ireland.

There is considerable interest in the production of heterojunction bipolar transistors on silicon substrates. One method of manufacturing such devices is to use a wide bandgap emitter grown epitaxially on the silicon substrate. Silicon carbide (SiC) is a suitable material for this application as it has a bandgap of 2.2eV and its lattice mismatch with silicon is only 20%. However the growth of expitaxial silicon carbide requires temperatures greater than 1000°C. If standard chemical vapour deposition (CVD) techniques are used the process thermal budget is large enough to cause significant redistribution of dopant impurities in the device structure. The fast temperature ramp rates obtained using rapid thermal processing (RTP) may be combined with CVD to minimise process thermal budget and ensure optimum device performance. This technique is known as limited reaction processing (LRP).

This paper will describe the deposition of silicon carbide layers in an LRP reactor using silane/propane gas chemistry. Silicon carbide layers with 50% carbon content distributed uniformly through them have been deposited at 970°C.

11:00 AM, G8

The Study of Interdiffusion and Defect Generation in $Si_{1-x}Ge_x$ Strained Superlattices: *S.M. Prokes,* M. Twigg, and M. F. Fatemi, U.S. Naval Research Laboratory, Washington, DC 20375, and K.L. Wang, Department of Electrical Engineering, UCLA, Los Angeles, CA 90024.

Interdiffusion measurements in initially asymmetrically strained $Si_{1-x}Ge_x$/Si superlattices grown by molecular beam epitaxy at 500°C are reported. Thermal degradation of the superlattice has been monitored using powder diffraction, cross-sectional TEM, and plan-view TEM. In the powder diffractometer method, both "small-angle" and "high angle" superlattice peaks were monitored, allowing comparisons of the thermal mixing in the near-surface layers versus mixing in the complete superlattice. Results indicate initially enhanced diffusion, especially near the top half of the superlattice, which is attributed to the initial presence of non-equilibrium defects. It was found to be a transient effect, and thus bulk interdiffusion measurements were carried out once isoconfigurational conditions were attained. The temperature dependent interdiffusion coefficient obtained from x-ray diffraction can be described by D=679 exp(-4.4eV/kT)cm^2/s in the temperature range 698°C to 876°C for superlattice having an average Ge concentration of .09. In the diffusion analysis which is applied here, gradient energy effects and coherency strain effects have been estimated, and their contribution to the bulk interdiffusion will be discussed.

Defect generation as a function of annealing is also examined using rocking curve analysis and transmission electron diffraction. TEM results indicate that no significant dislocation density is apparent in the top third of the superlattices, even at the highest annealing temperature. Dislocations spaced roughly 2μm apart are apparent in the lower part of the superlattice, in the regions at least 200nm away from the superlattice/buffer interface. Rocking curve analysis also suggests the presence of an additional structure at the superlattice/buffer interface, which becomes apparent after certain heat treatments. TEM analysis of this phenomenon will also be discussed.

11:20 AM, G9

Fabrication of Lattice-Mismatch-Compensated Single Crystal SiGe/Si Heterostructure by Ge and B Ions Implantation: *Ken Ohta,* Junichi Sakano and Seijiro Furukawa, Graduate School of Science and Engineering, Tokyo Institute of Technology, 4259 Nagatsuda, Midoriku, Yokohama 227, Japan.

Recently, $Si_{1-x}Ge_x$/Si heteroepitaxial growth has been intensively studied to realize new Si devices such as HBT. The high dose Ge ion implantation technique for fabricating the heterostructure without ultra-high-vaccum (U.H.V.) system could be easily employed in conventional Si IC's process. In this case, solid phase epitaxial (SPE) regrowth to recover the crystalinity is necessary after such high dose ion implantation process. We have observed, however, that because of crystallographic limitation for the atoms to move from random sites to tetrahedral sites, the critical thickness for the commensurated growth of $Si_{1-x}Ge_x$ film on Si by SPE method is much smaller than that by MBE and the other deposition method. Indeed, there are many dislocations around the boundary of the $Si_{1-x}Ge_x$/Si system fabricated by SPE. In this paper, we will report that heavy doping of boron (B), which has a smaller atomic diameter than those of Si and Ge, into the $Si_{1-x}Ge_x$ layer can drastically improve the crystalline quality, as the result of compensation of the lattice mismatch between SiGe and Si by introducing B.

In experiment, we implanted Ge and B ions into Si(100) substrates, taking the acceleration voltages for each ion to be proper one at which the projected ranges of the ions should be almost the same. And then, the samples were annealed in N_2 atmosphere.

RBS measurment shows the drasic decreasing of the channeling yields of the $Si_{1-x}Ge_x$ layer by introducing of B into the layer. The dependence of scattering center density on amount of B dose has also been calculated by the multiple scattering model from the spectrum of Si substrate. From this analysis, we could find the existance of optimum dose of B. RBS spectra of the film fabricated by Ge and B ions implantation under the optimum condition shows that the minimum channeling yield of Ge spectrum decreases as low as about 4%.

The dependence of sheet resistance and carrier concentration has been measured by van der Pauw method. For this experiment, the dose of Ge was changed at constant energy of 80keV with constant implantation condition of B (5.5X$10^{15}$$cm^{-2}$, 15keV). We could find the existance of the optimum atomic ratio of N (Ge)/N (B) for making the sheet resistance the minimum, which was 75Ω /□.

These results suggest that the lattice mismatch can be compensated by mixing the three type of atoms. Theoretically, the optimum atomic concentration ratio of Ge to B (X/Y) to be 5.6 to match the average lattice constant of $Si_{1-X-Y}Ge_XB_Y$ to that of Si at small X and Y, taking account of atomic diameter of the each atom. The optimum ratio Ge/B observed is slightly smaller than theoretical one.

The depth profile of Ge and B after regrowth annealing at 700°C for 1h followed by an annealing at 1060°C for 30min indicates that B atoms can scarcely diffuse even after such high temperature annealing. This suggests that co-exist of Ge and B in at the optimum ratio provides thermal stability of the alloy. At the presentation, the performance of HBT fabricated by such method will be showed.